Vadose Zone Monitoring of Fields Irrigated with Recycled Processing and Municipal Wastewaters.

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Abstract

Irrigation of fields with recycled municipal wastewater and effluent from wineries allows for the beneficial reuse of nutrients and water, while utilizing the soil profile to treat the process water and prevent degradation of groundwater. However, some constituents may pass through the soil profile and detrimentally impact groundwater. In our current research, we are using soil solution samplers, often referred to as suction lysimeters, installed at various depths within the vadose zone to monitor subsurface water quality at sites receiving the recycled wastewaters. Analysis of soil solution samples collected from fields irrigated with winery stillage indicated that there is a high degree of spatial and temporal variability in the amount of total dissolved salts, total suspended solids, and inorganic nitrogen levels which is closely related to the hydraulic loadings and application cycles of the wastewater. Soil solution samples collected below 4 feet in the area treated with tertiary level municipal wastewater had relatively lower nitrate and concentrations than the water collected with the 0-4 feet depth, which may be indicative of the soil's potential denitrification capability.

Introduction

Land application of process winery stillage has been practiced for several decades at the Fresno/Clovis Regional Wastewater Reclamation Facility (RWRF). This disposal technique allows for the beneficial reuse of nutrients, organic matter, and water, while utilizing the soil profile to treat the process water. However, application of winery stillage can lead to subsurface and ground water degradation, because these waters typically contain elevated levels of organic carbon, total suspended solids, nutrients, and minerals. Groundwater quality at disposal sites has primarily been assessed through groundwater monitoring well studies. However, little information is available on the quality of subsurface water as it migrates through from the soil through the soil profile commonly referred to as the unsaturated or vadose zone.

In order to prevent any additional degradation of groundwater, the California Regional Water Quality Control Board (CRWQCB) has been decreasing limits on hydraulic, nitrogen, and Biological Oxygen Demand (BOD) loading during permit renewals. The CRWQCB has set limits of 300 lb/acre instantaneous BOD loading and

100 lb/acre average loading. The new permit limit reduces the ability to surface irrigate, because application depths in range of three to six inches exceed the instantaneous BOD loading for common BOD concentrations in food process wastewater.

In Phase 1 of our research, the Center for Irrigation Technology (CIT) and the California water Institute (CWI) assisted the City of Fresno's Public Utilities in monitoring subsurface water quality at a winery stillage disposal site. Vadose zone monitoring at the site was required for compliance with the CRWQCB Monitoring and Reporting Program, as stipulated in the RWRF's Waste Discharge Requirements. The objective of the work with the City was to collect soil water (vadose zone) samples at 2 and 4 ft depth in stillage disposal areas and evaluate the concentrations of chemical constituents in those samples. The 2nd phase of the research which is currently in progress, involves the monitoring of soil and solution samples within the top four feet of fields planted with two forages- Sudan grass and Elephant grass. The major objectives in this phase of the project are: (1) to examine the effectiveness of the two forages to act as scavenging crops for the organic and nitrogen loading from the winery stillage application; and, (2) to assess the ability of these crops to alleviate any soil salinity build up associated with the application of the winery stillage (Cassel S., 2005). In a related study, we are conducting a soil water quality monitoring under ponding basins containing tertiary treated municipal wastewater. The primary objective of this study is to estimate potential denitrification losses during percolation.

In this paper, we present an overview of the installation and sampling plan used for monitoring the soil solution within the vadose zone, data depicting the trends in the spatial and temporal variability for the constituents in samples collected at the winery stillage site, and some preliminary soil solution data from the site treated with the municipal wastewater. The presentation concludes with an outline of proposed future work aimed at assessing how well solution samples obtained from lysimeters represent the actual field conditions.

Materials and Methods

A. Stillage site

The Stillage Disposal Site is located at the Fresno/Clovis Regional Treatment Facility, CA. The site was used for disposal of winery stillage waste since 1974. It was originally 95 acres, but was later expanded to about 145 acres and the area received between 500,000 and 1,000,000 gallons of waste per day. Stillage wastes were disposed at the site until the end of 2003, then the practice ceased. The disposal site was comprised of 6 sections, categorized as A through F (Figure 1).

Before winery stillage application, the beds were plowed to 6-8 inch depth, and then leveled to a 0.1 percent slope. Then long and narrow checks/curbs were prepared around each bed. At the time of application, stillage was distributed / spread with the use of splash plates to prevent the formation of holes at the bed inlet. During 2003, Sudan grass was planted in section A and irrigated with secondary effluent because well water was not available at the time of application.

Soil water quality in the vadose zone was monitored using suction lysimeters in all six sections. Since the maximum rooting depth of Sudangrass is around three feet, lysimeters were installed at 2 and 4 feet. Vadose zone monitoring at those two depths was valuable to assess solute movement through the soil profile and determine the role of Sudangrass in reducing water contamination below the root zone.

Nine pairs of lysimeters were installed in sections A through E following the manufacturer's procedure (Soilmoisture Equipment Corp. 1999). A pair consisted of one lysimeter installed at 2 ft depth and another lysimeter placed at 4 ft with a nearby soil moisture access tube. Figure 2 shows the relative positions of the monitoring devices installed at a given location. To ensure adequate sample volume for laboratory analyses, a Diviner 2000 soil moisture probe (Sentek Environmental Technologies, 1999) was used to determine the position of the wetting front following stillage application. Vadose zone samples were collected when the wetting front reached the depth of the lysimeter porous cup. Soil moisture readings were taken every 1-2 days after stillage application depending on loading of the beds and measurements continued until the vadose zone sample was collected.

Sampling in the E-W direction allowed us to examine the impact of stillage application at the eastern, middle and western parts of each section. Each row consisted of three pairs of lysimeters, spaced evenly across the north-south (N-S) direction. The suggested placement of the lysimeters is presented in Figure 1. The N-S sampling provided additional data in an effort to account for any spatial variability in soil hydraulic properties. Additionally, the primary purpose of the Vadose Zone Monitoring Program is not to compare the loadings between sections but to evaluate the loadings in each section. One pair of lysimeters was also installed at 2 and 4 ft at a location that never received stillage for background reference.

B. Municipal Wastewater

The municipal waste water site is located in the city of Madera, CA. The City owns and operates the wastewater treatment plant (WWTP). The WWTP effluent discharge and ultimate sludge disposal are regulated under WDR Order No. 95-046. This order currently limits the plant to a maximum permitted flow of 7 MGD. Final disposal of the treated effluent takes place on City-owned lands located adjacent to the WWTP. The City owns fourteen 20-acre plots. Some of these plots are leased to farmers for growing fodder crop while the rest of the plots are used by the city as ponding basins either for effluent and sludge disposal or for sludge drying purposes. Sometimes, these holding ponds are drained and farmed every one to two years with wheat followed by corn for fodder.

In one of the ponding basins, suction lysimeters were installed at two locations at depths of 2, 4 10 and 15 feet below the soil surface. Vadose zone monitoring at these depths was important in order to assess the movement of the solute through the soil profile and at depths generally greater than the root zones of any crops traditionally grown on these fields.

Results and Discussion

A. Stillage site

The stillage constituent loadings were calculated based on the stillage quality data and the records for hydraulic loadings. In all beds, total biological oxygen demand (BOD) loadings exceeded 1000 lb ac^{-1} and reached very high values (>10,000 lb ac^{-1}) in sections C, D, and F during the second applications. These very high loadings were mostly explained by the elevated BOD concentrations of the stillage as well as the large volume of stillage applied. The lowest BOD loadings were found in sections A and E. During the first applications, BOD loadings were less variable among beds. Average BOD loadings ranged from 34 to 320 lb ac-d^{-1} during the first applications and from 17 to 280 lb ac-d^{-1} for the second applications. Although BOD loadings were very high in sections C and F for the second applications, the corresponding average BOD loadings did not exceed 100 lb ac-d^{-1} due to the long drying cycles between stillage applications. This indicated that drying time was a very important factor to reduce average BOD loadings. The total dissolved (TDS) and suspended (TSS) solids, nitrate-N (NO_3-N) and ammonium-N (NH_4-N) loadings were also very high and variable among beds.

The pH of the solution samples was relatively neutral and ranged from 5.3 to 8.7. For most beds, the pH of the solutions collected at 4 ft was slightly greater than that of samples taken at 2 ft, with sections C and D showing the highest pH values (Table 1).

The EC of the lysimeter solutions were high and varied from 1,936 to 10,437 µmho cm^{-1} (Table 1). Section A, planted with Sudan grass, had the lowest EC among all beds. Low EC values were also observed in section F during the first sampling events. In most beds, the EC of the solutions collected at 4ft was lower than that of samples obtained at 2 ft. Sections B, D, and E were characterized by the highest EC levels in the lysimeter samples.

The TSS concentrations were lower than TDS concentrations in the collected solutions (Table 2). During the first samplings, the TDS of the solutions were higher than that of the influent stillage, except in beds B21 and F90. An opposite trend was observed for TSS. The TDS of the 4-ft depth samples were lower than that of the 2-ft solutions in most sections. For beds E68 and E71, the TDS of the 4-ft solutions were very high in spite of a relatively low level in the influent stillage. The elevated TDS in section A could negatively affect Sudan grass growth.

The NH_4-N concentrations were relatively low in most samples (Table 3). The NO_3-N levels were less than 1 mg L_{-1} in many beds (Table 3). The NH_4-N concentrations were greater than the NO_3-N levels in sections A through E during the first samplings. The higher NO_3-N concentrations observed in solutions collected in section F suggested that nitrification might have started at the time of sampling, i.e, 3-4 days after stillage application, and that some of the NH_4-N had been oxidized to NO_3-N. Basic summary statistics conducted on the lysimeter solution data, indicated that among all constituents analyzed, NO_3-N displayed the greatest spatial variability on a per section basis. For example, in section A, coefficient of variability (CV) values of 230% and 249% were obtained for NO_3-N at 2-ft and 4-ft depths during the first sampling, respectively.

B. Municipal Wastewater

Most of the data collected at the Madera waste water site is currently being analyzed. Examples of the spatial and temporal variability in chloride (Cl), nitrate (NO_3) and ammonia (NH_3-N) concentrations in the lysimeter samples are shown in Figures 3, 4, and 5 respectively. Generally, the Cl concentrations at the four depths were similar to that measured in the pond's surface water throughout the entire monitoring period. This is most likely due to the fact that the chloride ion is acting as a non-rective tracer as it moves through the soil profile with the percolating water. However, in the case of the NO_3 (Figure 4) and NH_3-N (Figure 5) ions, there were differences between the levels in the pond and those samples collected within the profile. More importantly, no inorganic nitrogen (NO_3-N and NH_3-N) levels were detected at the 15feet depth during the monitoring period. These results may be representative of the nitrogen dynamics, such as the degree of nitrification and denitrification, occurring within the soil profile.

Conclusions and Future Research

Analysis of soil solution samples collected from fields irrigated with winery stillage indicated that there is a high degree of spatial and temporal variability in the amount of total dissolved salts, total suspended solids, and inorganic nitrogen levels which is closely related to the hydraulic loadings and application cycles of the wastewater. Soil solution samples collected below 4 feet in the area treated with tertiary level municipal wastewater had relatively lower nitrate concentrations than the water collected within the 0-4 feet depth, which may be indicative of the soil's potential denitrification capability.

In the sampling plan currently in use for the vadose zone monitoring at the stillage site, soil water quality in the vadose zone is monitored using suction lysimeters in all six sections. In our, future work, we intend to examine the spatial correlation between soil solution samples installed along a transect to find out how representative of the field are the solution sample obtained by the various lysimeters. This statistical characterization of the spatial distribution of the organic and nitrogen loading will be useful: in designing and implementing future monitoring sampling networks; modeling the overall flow and transport rates of the various stillage constituents; and, providing important information on how different stillage discharge regimes affect the loading rates at various locations in the field. In the case of the municipal wastewater site, it is suggested that soil cores from the area be tested under ideal laboratory conditions to determine the potential denitrification rates of these soils.

References

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Sentek Environmental Technologies. 1999. *Diviner 2000 User Guide Version 1.0.* Sentek Pty Ltd. South Australia. Internet: http/www.Sentek.com.au

Soilmoisture Equipment Corp. 1999. 1900 Soil water sampler – operating instructions. Santa Barbara, CA. 16 pp.

Table 1. Average pH and EC in lysimeter samples

pH

Bed	First sampling		Second sampling	
	2 feet	4 feet	2 feet	4 feet
A4s	6.0	6.2	6.2	6.6
A8s	6.0	6.6	6.8	8.1
A12s	5.7	6.3	7.2	-
Average A	*5.9*	*6.3*	*6.8*	*7.3*
B21n	8.0	8.1	6.2	7.8
B25n	6.7	6.7	6.1	6.7
B29n	7.0	7.3	6.4	6.9
Average B	*7.3*	*7.4*	*6.2*	*7.1*
C38n	5.3	5.3	7.8	7.4
C42n	7.4	6.5	8.2	7.9
C46n	5.5	7.2	5.2	6.1
Average C	*5.8*	*6.5*	*6.9*	*7.1*
D54n	7.9	7.9	8.1	7.8
D57s	8.2	7.4	7.7	7.6
D61n	8.7	8.3	8.0	8.0
Average D	*8.1*	*7.9*	*7.9*	*7.8*
E68n	7.8	7.6	7.1	7.8
E71s	8.3	7.5	7.2	7.4
E75n	8.2	8.1	8.1	7.9
Average E	*8.1*	*7.7*	*7.5*	*7.7*
F84	6.7	7.0	6.7	6.9
F90	6.6	6.9	5.5	6.7
F96	6.9	7.3	5.7	6.3
Average F	*6.7*	*7.1*	*5.8*	*6.6*
Average of all beds	7.0	7.1	6.7	7.2
Average of all beds except F	7.0	7.2	7.1	7.4

EC (µmho cm^{-1})

Bed	First sampling		Second sampling	
	2 feet	4 feet	2 feet	4 feet
A4s	4413	2463	4647	1936
A8s	3755	3877	3490	3000
A12s	3917	3990	3383	-
Average A	*4063*	*3389*	*3884*	*2468*
B21n	8120	5340	8515	8527
B25n	7280	6790	7090	7063
B29n	5847	4850	7103	7800
Average B	*7058*	*5519*	*7451*	*7797*
C38n	3780	3381	6480	5990
C42n	15290	9563	7615	7737
C46n	3970	4343	5743	6650
Average C	*6158*	*6060*	*6490*	*7021*
D54n	6730	4915	6573	4800
D57s	6663	6987	5793	6303
D61n	8730	10193	9653	8793
Average D	*6987*	*7671*	*7340*	*6861*
E68n	8060	8183	7430	6570
E71s	10127	10437	8247	8030
E75n	7250	6910	6877	5830
Average E	*8714*	*8710*	*7518*	*6933*
F84	4703	4240	8025	5692
F90	3264	3560	6407	6295
F96	3830	3381	6473	6213
Average F	*3938*	*3727*	*6757*	*6146*
Average of all beds	5608	5394	6631	6498
Average of all beds except F	6562	6270	6584	6653

Table 2. Average TDS and TSS in lysimeter samples

TDS ($mg\ L^{-1}$)

Bed	First sampling		Second sampling	
	2 feet	4 feet	2 feet	4 feet
A4s	4536	3952	3110	1560
A8s	3157	3947	2929	2325
A12s	4320	2456	1860	-
Average A	*4080*	*3451*	*2788*	*1943*
B21n	7761	4956	-	8916
B25n	-	7247	9643	8003
B29n	-	4529	8857	8374
Average B	*7761*	*5577*	*9250*	*8431*
C38n	4381	2844	-	4652
C42n	15844	11151	7104	6429
C46n	4251	4073	5763	-
Average C	*6621*	*6420*	*6210*	*5985*
D54n	6140	4281	-	4095
D57s	8100	4328	5229	6003
D61n	-	5724	8914	7984
Average D	*6793*	*4654*	*7072*	*6269*
E68n	6916	10446	8001	4652
E71s	-	11433	9103	7341
E75n	6387	5811	6805	5931
Average E	*6652*	*9395*	*8302*	*6423*
F84	4481	3740	11009	7036
F90	2899	3468	8711	6769
F96	3324	2632	9467	8550
Average F	*3616*	*3246*	*9472*	*7852*
Average of all beds	4726	4942	7751	6991
Average of all beds except F	5836	6017	6986	6634

TSS ($mg\ L^{-1}$)

Bed	First sampling		Second sampling	
	2 feet	4 feet	2 feet	4 feet
A4s	47	4	12.0	2
A8s	420	32	2	-
A12s	7	205	7	-
Average A	*142*	*80*	*7*	*2*
B21n	78	52	-	229
B25n	-	200	542	282
B29n	-	20	134	221
Average B	*78*	*90*	*338*	*244*
C38n	6	55	-	28
C42n	1030	54	350	199
C46n	328	132	156	-
Average C	*340*	*84*	*220*	*157*
D54n	481	38	-	17
D57s	366	45	110	124
D61n	-	67	181	148
Average D	*443*	*47*	*146*	*106*
E68n	251	482	307	226
E71s	-	344	138	307
E75n	453	265	494	407
Average E	*352*	*341*	*261*	*327*
F84	47	47	212	44
F90	43	17	68	154
F96	6	25	153	47
Average F	*32*	*30*	*134*	*73*
Average of all beds	147	92	180	163
Average of all beds except F	257	131	201	201

Table 3. Average NH_4-N and NO_3-N in lysimeter samples

NH_4-N (mg L^{-1})

Bed	First sampling		Second sampling	
	2 feet	4 feet	2 feet	4 feet
A4s	43	24	19	10
A8s	-	25	33	0
A12s	12	36	23	-
Average A	*22*	*30*	*25*	*6*
B21n	22	79	78	84
B25n	54	102	177	110
B29n	18	123	53	142
Average B	*32*	*101*	*83*	*108*
C38n	5	34	-	165
C42n	21	78	36	54
C46n	21	53	71	-
Average C	*14*	*58*	*54*	*82*
D54n	11	21	8	22
D57s	8	25	4	17
D61n	26	7	2	16
Average D	*16*	*18*	*4*	*18*
E68n	16	68	11	79
E71s	-	26	11	8
E75n	5	147	4	91
Average E	*12*	*73*	*10*	*48*
F84	3	4	20	6
F90	3	2	31	15
F96	4	4	36	15
Average F	*3.2*	*3.4*	*32*	*13*
Average of all beds	12	36	30	43
Average of all beds except F	20	57	29	57

NO_3-N (mg L^{-1})

Bed	First sampling		Second sampling	
	2 feet	4 feet	2 feet	4 feet
A4s	0.33	12	3.7	0.30
A8s	0.25	0.11	0.9	-
A12s	4.5	1.3	0.1	-
Average A	*1.9*	*5.2*	*1.6*	*0.30*
B21n	0.17	0.20	0.01	0.01
B25n	0.16	0.16	0.34	0.01
B29n	0.27	0.20	0.11	0.30
Average B	*0.20*	*0.19*	*0.19*	*0.08*
C38n	1.71	3.91	-	0.01
C42n	0.01	0.21	0.01	0.20
C46n	0.30	0.07	0.25	2.1
Average C	*0.80*	*1.1*	*0.13*	*1.0*
D54n	0.30	0.20	0.07	0.11
D57s	0.20	0.01	0.2	0.5
D61n	-	0.20	0.01	0.07
Average D	*0.28*	*0.14*	*0.10*	*0.24*
E68n	0.11	0.37	0.07	0.11
E71s	0.37	0.33	0.07	0.01
E75n	0.25	0.25	0.01	0.01
Average E	*0.26*	*0.33*	*0.06*	*0.04*
F84	28	0.30	0.16	0.11
F90	17	22	0.71	0.17
F96	78	24	0.97	0.35
Average F	*39*	*16*	*0.70*	*0.20*
Average of all beds	16	6.5	0.54	0.29
Average of all beds except F	0.73	1.4	0.45	0.33

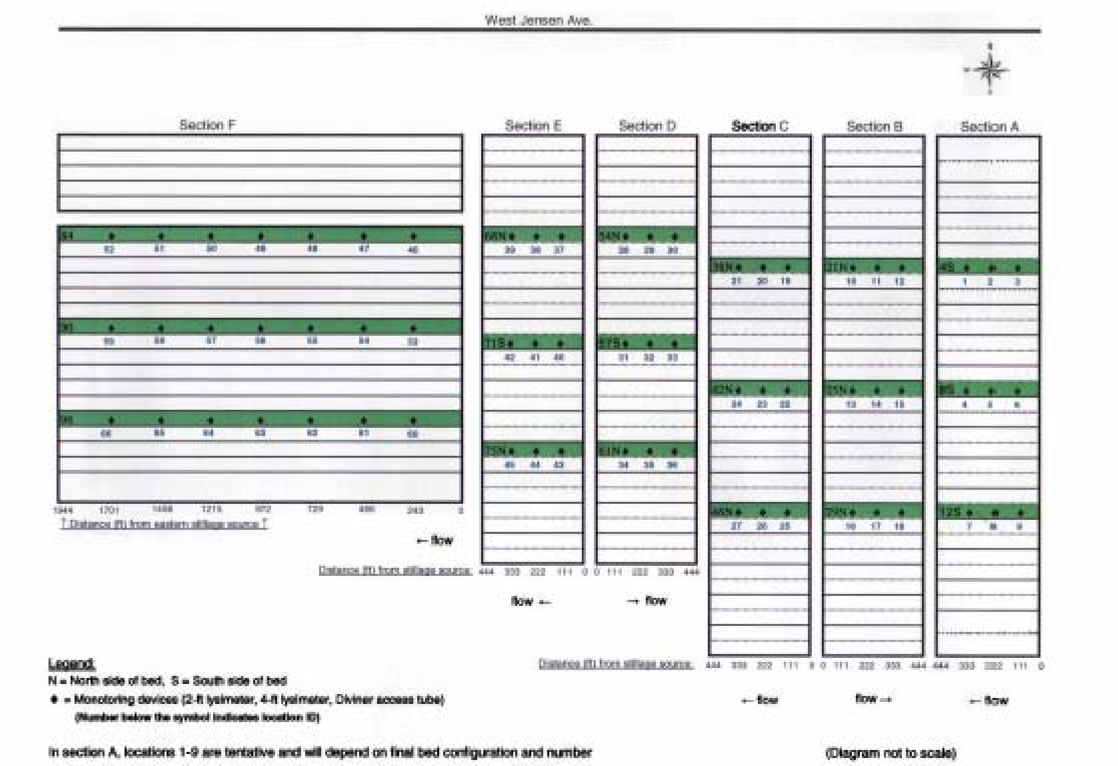

Figure 1: Layout of experimental plots at Stillage site showing location of lysimeters.

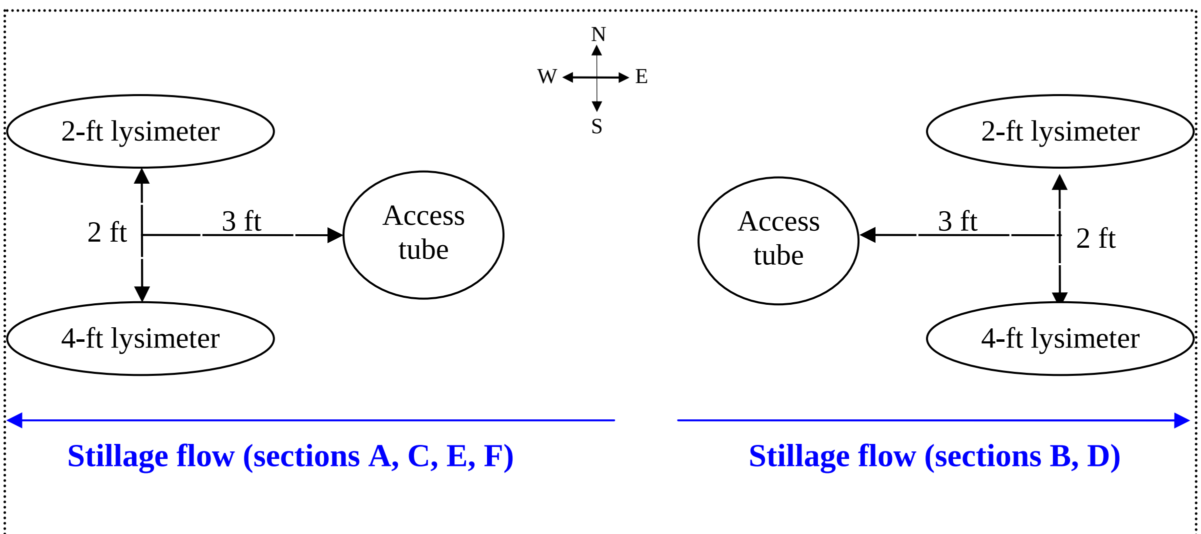

Figure 2: Relative position of the monitoring devices at each location

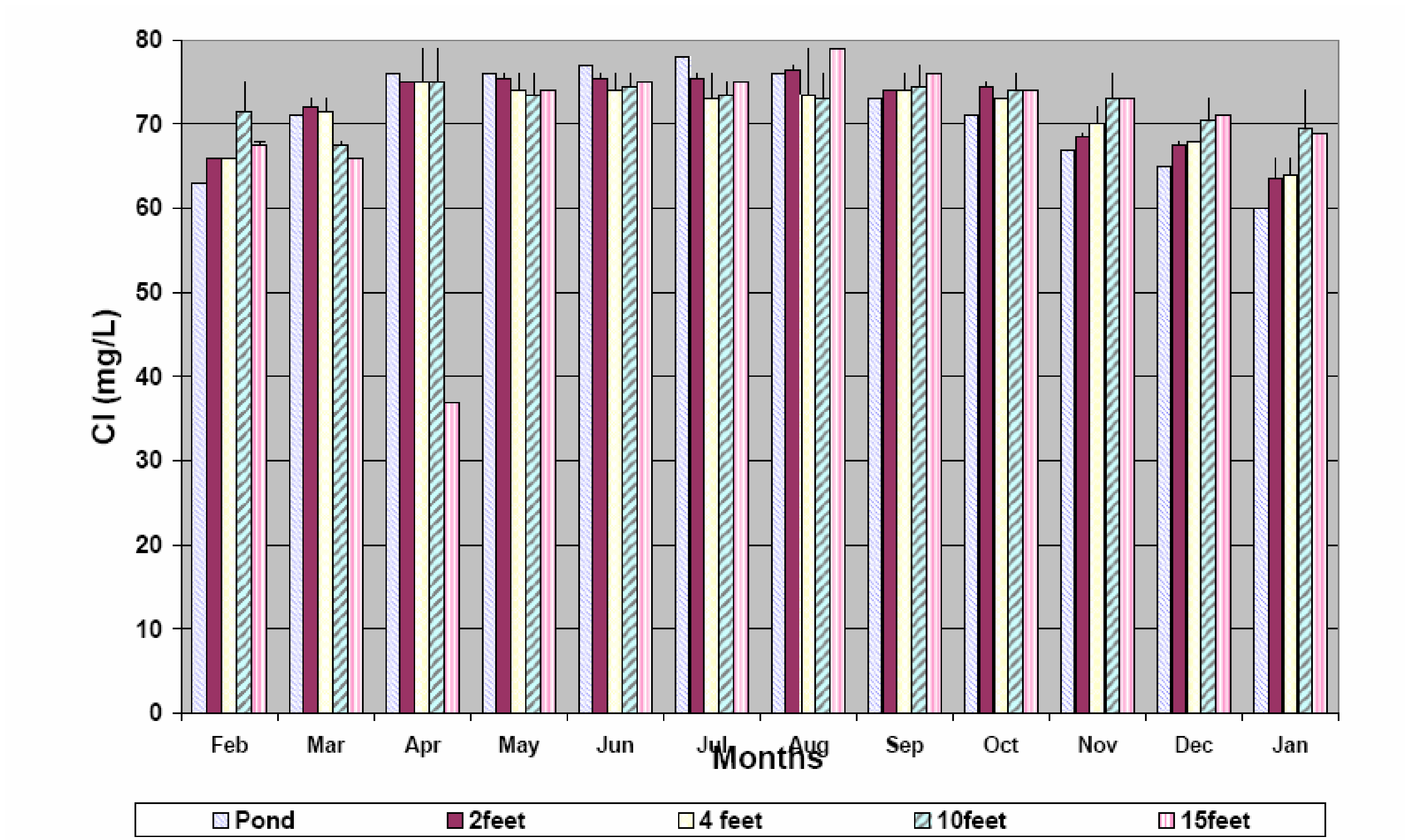

Figure 3: Average chloride concentrations detected at the municipal wastewater site.

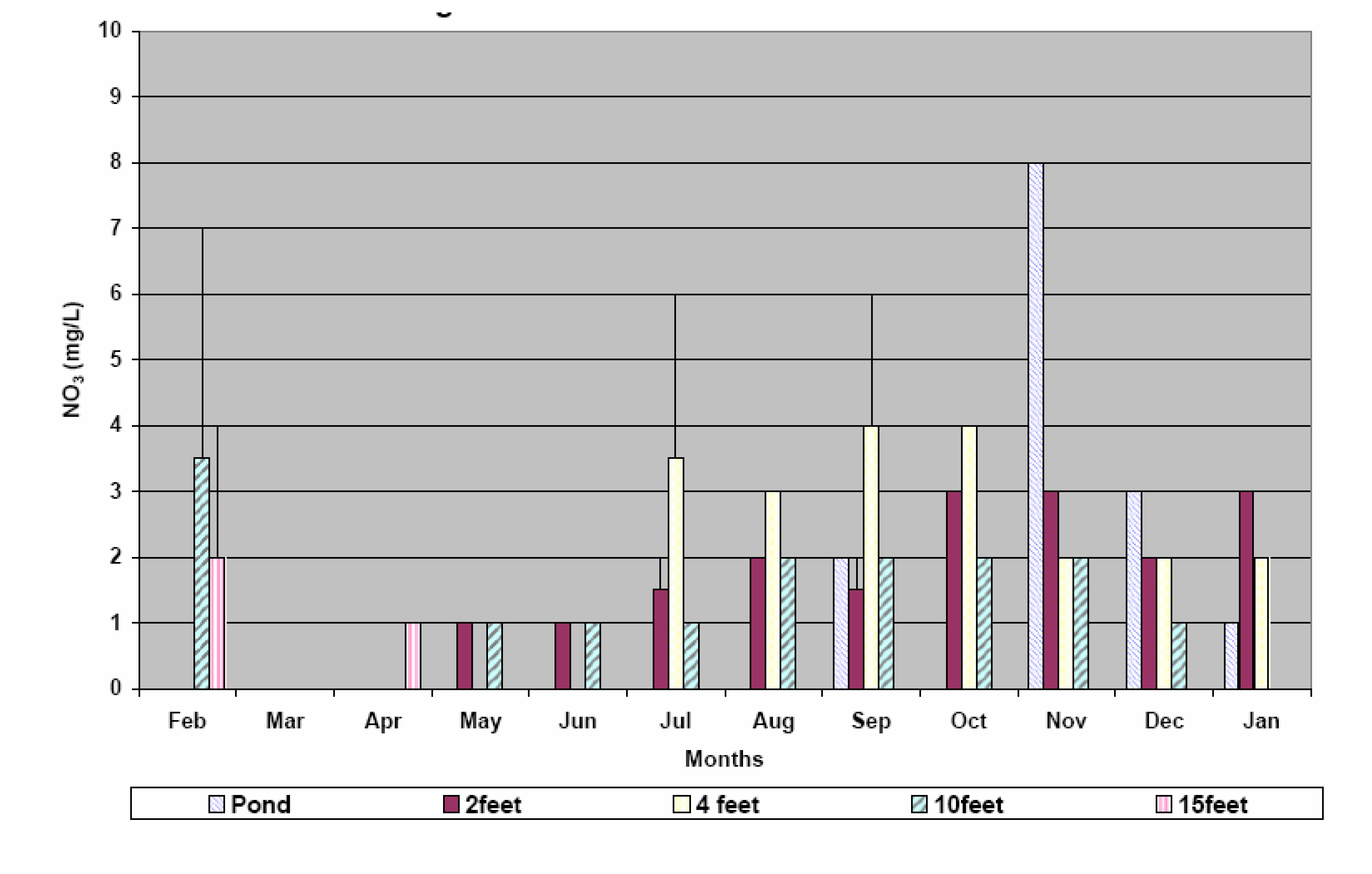

Figure 4: Average nitrate concentrations detected at the municipal wastewater site.

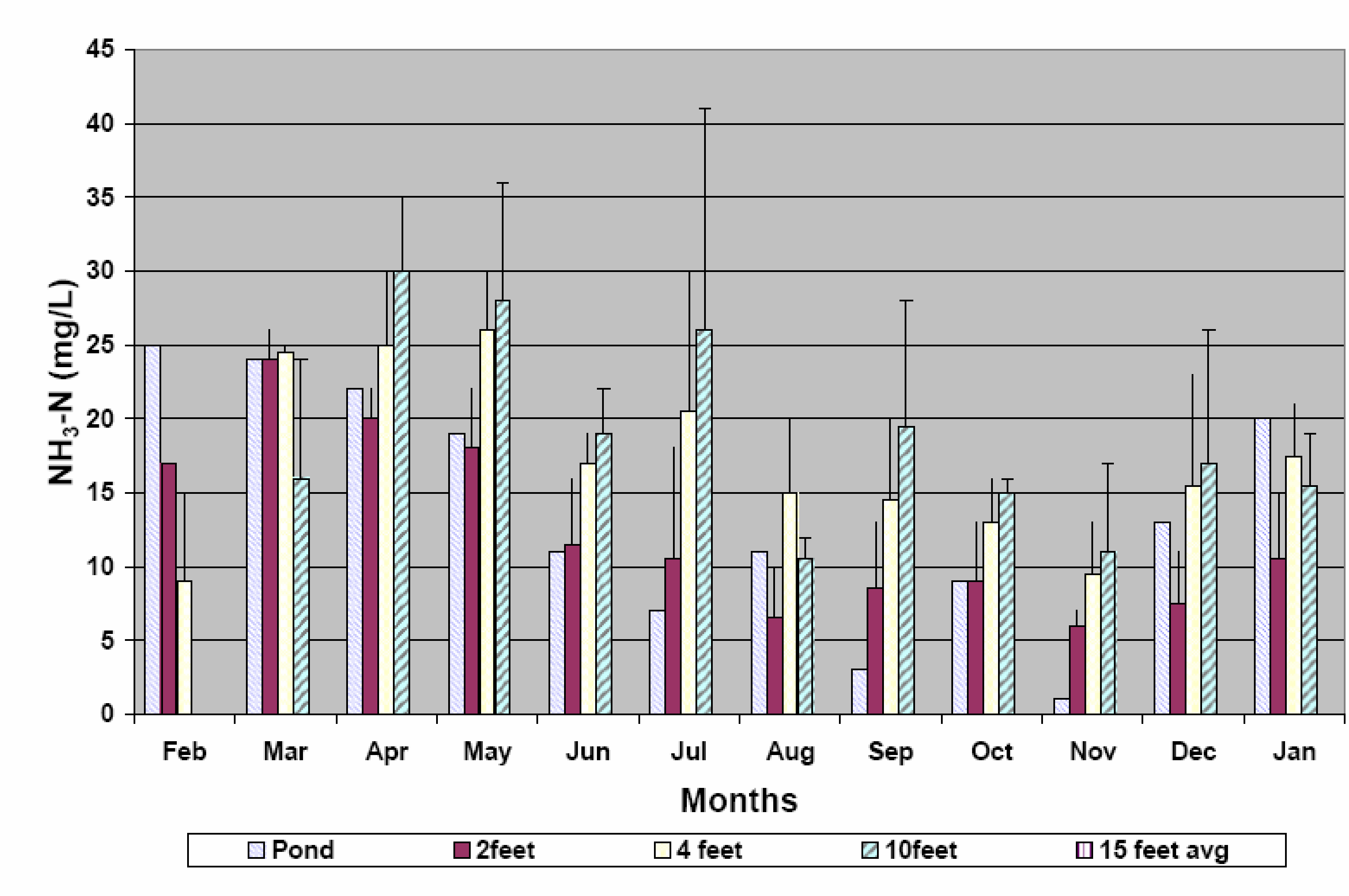

Figure 5: Average ammonia-N concentrations detected at the municipal wastewater site.