

USE OF SUCTION LYSIMETERS TO MONITOR VADOSE ZONE GROUNDWATER QUALITY AT A WASTEWATER LAND APPLICATION FACILITY

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ABSTRACT

Land application of wastewater can be a cost-effective and environmentally responsible wastewater disposal method. To evaluate the impact of wastewater land application on groundwater resources, groundwater samples must be collected and analyzed. Suction lysimeters are a low-cost alternative to monitoring wells for measuring groundwater quality. Lysimeters can be used to collect groundwater from the unsaturated vadose zone, before the application area percolate mixes with groundwater from the upper aquifer.

Land application is used to dispose of wastewater generated at a truckwash facility in northern California, where tanker trucks hauling food-grade products (e.g., wine, molasses, vegetable oil) are rinsed and sanitized. Three lysimeters (two in walnut orchards and one in pasture) are used to monitor groundwater conditions at the truckwash land application facility. Lysimeter data collected from 1999 to 2001 were used to evaluate the impact of wastewater land application on groundwater quality, and to determine the effectiveness of the lysimeters in monitoring vadose zone groundwater quality.

Based on daily flow records and local meteorological data, a water balance was conducted to estimate the monthly volume of percolate leaching from each field. Using water quality data for the applied wastewater and supplementary irrigation well water, the monthly total nitrogen (TN) load for each field was calculated. Crop nitrogen uptake values were then used to estimate percolate TN concentrations for each field (annual averages of 0.0 to 3.0 mg/L). Lysimeter samples were collected and analyzed quarterly for TN (annual averages of 0.1 to 8.2 mg/L). The annual average lysimeter TN values compared well to the estimated TN values. Based on the results of the study, suction lysimeters may be relied upon to provide representative vadose zone groundwater quality data.

KEYWORDS. land application, suction lysimeter, groundwater quality, vadose zone.

INTRODUCTION

Food-processing wastewater contains organic matter and nitrogen that can cause environmental damage when discharged to surface waters. However, wastewater constituents can be used beneficially when wastewater is land applied to irrigate crops. Applied organic matter is broken down by soil bacteria, and nitrogen is used for plant growth. To avoid nuisance conditions and protect groundwater quality, wastewater irrigation must occur at loading rates that do not exceed the land application system's ability to assimilate organic matter and nutrients (Reed, 1995).

A truckwash located in the California Central Valley uses a land application system to dispose of wastewater generated from washing tanker trucks. Products transported include vegetable oil,

molasses, fruit juices, and wine. When a tanker truck enters a wash bay, food product remaining in the tank is drained into a collection tank. The accumulated food product is pumped periodically from the collection tank and hauled away for use in animal feed production. After the tanker truck is emptied, the wash cycle is performed. All washwater drains from the wash area to a wastewater collection sump. Sump flows are pumped to an onsite treatment and temporary storage facility. Onsite treatment includes sedimentation, pH neutralization, polymer addition, and dissolved air flotation for removal of organic solids. Settled solids and solids removed by dissolved air flotation are hauled away for use in animal feed production.

In November 1998, the truckwash received a waste discharge permit to apply truckwash wastewater to a designated land application site located nearby. Wastewater is hauled to the land application area in 4,500 gallon tanker trucks. An average of four to five truckloads are hauled per day. The hauled wastewater is pumped into two 11,000 gallon storage tanks for temporary storage. The wastewater detention time in the storage tanks is limited to 24 hours to control odors. A third tank is used to store pumped irrigation water from an onsite irrigation well. Truckwash wastewater is blended with the stored irrigation water, and the blended water (consisting of 25 to 50 percent truckwash wastewater) is pumped to the spray irrigation system. The land application site includes two walnut orchards (Field 1 and Field 2, occupying 12.0 acres and 9.0 acres, respectively) and a pasture area (Field 3, occupying 9.3 acres).

The volume of blended water applied to the fields is recorded daily, and samples of the blended water are collected periodically for laboratory analysis, in accordance with the permit monitoring schedule. References to applied wastewater volumes and quality in this paper signify truckwash wastewater blended with irrigation well water.

Monitoring requirements also include quarterly collection and analysis of vadose (unsaturated) zone groundwater samples from the land application area. The samples are analyzed for organics [Biochemical Oxygen Demand (BOD)] and nutrients [total Kjeldahl nitrogen (TKN), nitrate nitrogen ($\text{NO}_3\text{-N}$), and total nitrogen (TN)]. To collect vadose zone samples, three 72-inch suction lysimeters were installed at the land application site in 1998 (one in each walnut orchard, and one in the pasture area). Suction lysimeters consist of a section of plastic pipe with a rubber cap with hose fittings at the top, and a partially porous ceramic cap at the bottom. They are installed vertically in the soil with the top exposed at the ground surface. Vadose zone groundwater samples are collected by using a vacuum pump to create a vacuum within the lysimeter that draws moisture into the lysimeter through the ceramic cap.

From 1999 to 2001, truckwash wastewater blended with irrigation water from the onsite well was applied to the walnut orchard and pasture areas. Monthly wastewater samples were collected and analyzed to verify that annual design loading rates were not exceeded. During summer months, when additional water was required, supplementary irrigation water from the onsite well was applied directly to the fields. Based on the applied depth of blended wastewater and supplementary irrigation water, a water balance was prepared for each year to estimate the annual volume of percolate for each field. Results of laboratory analyses of wastewater and well water samples were used to estimate percolate nitrate concentrations. The estimated percolate nitrate concentrations were then compared to measured nitrate concentrations from vadose zone groundwater samples collected using the suction lysimeters.

WATER BALANCE FOR LAND APPLICATION SYSTEM

The components of a water balance for a land application system typically include precipitation, evapotranspiration, wastewater and supplementary irrigation water application, and percolation. The water inputs and outputs to the system can be summarized by observing that, for a given

time period, precipitation + applied wastewater + applied well water = evapotranspiration + percolation.

In Table 1, local precipitation and evapotranspiration data for the study period are presented. The meteorological data were collected at two California Irrigation Management Information System (CIMIS) weather stations located within 15 miles of the truckwash. It can be seen in Table 1 that precipitation for the truckwash area varied from 10.6 to 16.1 in/yr, with most of the rainfall occurring during the winter months. Evapotranspiration for the truckwash area varied from 48.5 to 50.8 in/yr.

Daily applied wastewater volumes were totaled for each month and divided by the field areas to determine the monthly applied depths for each field. It can be seen that the majority of the wastewater (48 to 62 in/yr) was applied to Field 3 (pasture), with smaller amounts (0 to 25 in/yr) applied to Fields 1 and 2 (walnut orchards). More wastewater was applied to the pasture area because it was expected that pasture would be more tolerant of wastewater salinity. Applications of unblended supplementary irrigation water were also measured, and the recorded volumes were used to calculate the monthly depths of applied well water. As seen in Table 1, unblended well water was not applied to Field 3. The annual depth of supplementary well water applied to Fields 1 and 2 ranged from 36 to 53 in/yr.

For each field, monthly percolation depths were estimated assuming that percolation = precipitation + applied wastewater + applied well water - evapotranspiration (zero when negative). As seen in Table 1, estimated percolation depths range from 16 to 35 in/yr.

ORGANIC AND NUTRIENT LOADING FOR LAND APPLICATION SYSTEM

As discussed above, the wastewater discharge permit for the truckwash land application system includes water quality monitoring requirements for organics (BOD) and nutrients (TKN, NO₃-N, and TN). In Table 2, the results of laboratory analyses of wastewater samples collected during the study period are presented. It can be seen that BOD values range from 370 to 5490 mg/L, with annual averages ranging from 1100 to 2913 mg/L. It should be noted that wastewater constituent concentrations measured during the end of 1999 and the first half of 2000 were artificially high, as the truckwash wastewater was not completely mixed with the blended well water at the sample collection point. To obtain more representative samples, well-mixed wastewater samples were collected at a downstream distribution point beginning in July 2000. To estimate water quality for the first half of the year 2000, average water quality values from the second half of the year 2000 were used. BOD was not detected in the unblended supplementary well water.

Concentrations for wastewater nitrogen in the forms of TKN, NO₃-N, and TN are also presented in Table 2. Annual average TN values range from 4.5 to 8.9 mg/L, with most of the nitrogen in the form of TKN (primarily organic nitrogen). NO₃-N concentrations for the onsite well are also provided, ranging from 7.0 to 9.7 mg/L. It can be observed that the TN concentrations in the blended wastewater are generally lower than the NO₃-N values in the supplementary well water.

In Table 3, monthly wastewater BOD concentrations are used with the applied wastewater depths to calculate BOD loading rates for the land application system. It can be seen in Table 3 that with the exception of the latter half of 1999 (when it is believed that wastewater BOD results were artificially high due to poor mixing), BOD loading rates for the pasture area were consistently less than 100 lb/ac-d. Typically, BOD loading rates below 100 lb/ac-d are considered desirable for avoiding nuisance conditions such as odors (Reed, 1995). BOD loading in the walnut orchards did not exceed 60 lb/ac-d during the study period.

TN loading rates for the land application system were calculated using the application depths and concentrations for the applied wastewater and supplementary irrigation water. As shown in Table 3, annual TN loading rates ranged from 50 to 116 lb/ac-yr. Typical design TN loading rates for land application systems may range as high as 300 lb/ac-yr, depending on the type of crop grown. As shown in Table 4, crop nitrogen uptake values typically range from 200 to 400 lb/ac-d for forage crops, and from 150 to 200 lb/ac-d for nut orchards (California Fertilizer Association, 1995). In Table 4, the pasture nitrogen uptake is estimated to be one fourth the average value for forage crops because the pasture was not harvested aggressively (i.e., $300/4 = 75$ lb/ac-d).

ESTIMATED PERCOLATE QUALITY AND LYSIMETER SAMPLE GROUNDWATER QUALITY FOR LAND APPLICATION SYSTEM

In Table 4, the applied wastewater and well water TN load is added to the fertilizer nitrogen load (220 lb/ac applied to the walnut fields in June as dry urea, equivalent to 100 lb/ac as N) to determine the total TN load. To estimate the amount of TN that may appear in percolating leachate, it is assumed that 15 percent of the applied TN is removed by soil nitrogen reduction processes, such as ammonia volatilization and denitrification. Nitrate denitrification by soil microbes is favored by the high BOD:TN ratio of the applied wastewater (over 100). Crop uptake is also considered, resulting in annual leached TN values ranging from 0 to 24 lb/ac [Leached TN = $0.85(\text{Applied water TN} + \text{Fertilizer TN}) - \text{TN uptake}$]. When the leached TN values are divided by percolate depth, the percolate TN concentration (assumed to be primarily in the form of $\text{NO}_3\text{-N}$) can be estimated. As seen in Table 4, estimated percolate $\text{NO}_3\text{-N}$ concentrations range from 0.0 to 3.0 mg/L. The estimated values are all less than measured values of $\text{NO}_3\text{-N}$ observed at the onsite well.

To verify that groundwater at the land application system is protected, vadose zone groundwater samples are collected using suction lysimeters. As shown in Table 5, average lysimeter BOD values range from 1 to 12 mg/L, with the lowest results observed during the most recent year of operation. These results confirm that organic loading does not exceed the assimilative capacity of the land application system. It can be seen in Table 5 that lysimeter BOD concentrations tend to be lower during the summer, when higher BOD loading rates generally occur (see Table 3). The lower BOD values may be due to increased metabolic activity of soil bacteria responsible for BOD decomposition due to warmer temperatures occurring during summer months.

Lysimeter $\text{NO}_3\text{-N}$ values are also presented in Table 5. With the exception of Field 2, which received the least amount of truckwash wastewater (none in 2001), average vadose zone groundwater $\text{NO}_3\text{-N}$ concentrations ranged from 0.1 to 2.6 mg/L during the study period. Average $\text{NO}_3\text{-N}$ concentrations in the lysimeter samples from Field 2 approached the $\text{NO}_3\text{-N}$ concentration observed in groundwater samples collected from the onsite well (7.0 to 9.7 mg/L).

CONCLUSION

Truckwash wastewater was blended with onsite irrigation well water and used for irrigation of walnut orchards and pasture from 1999 to 2001. Organic (BOD) loading rates for the land application system were determined to be less than 100 lb/ac-d, which is appropriate for avoiding malodorous conditions. The average TN loading rate to the pasture area was 87 lb/ac-yr, while the average TN loading rate to the walnut areas was 200 lb/ac-yr, of which 100 lb/ac-yr was from applied fertilizer. Based on soil nitrogen removal processes and crop uptake, estimated percolate $\text{NO}_3\text{-N}$ concentrations ranged from 0.0 to 3.0 mg/L for all three fields.

Analysis of vadose zone groundwater collected in suction lysimeters at the land application site generally shows agreement with the predicted percolate NO₃-N concentrations. During the first year of the study, estimated percolate NO₃-N concentrations ranged from 0.8 to 2.1 mg/L, while average lysimeter results ranged from 1.3 to 2.4 mg/L. With the exception of Field 2, which was watered primarily with unblended well water, lysimeter sample average NO₃-N concentrations during the remaining two years of the study ranged from 0.1 to 2.6 mg/L, which was within the predicted range of 0.0 to 3.0 mg/L. While soil hydrological conditions are complex and it cannot be expected that lysimeter results will always match with predicted concentrations, it was observed that lysimeter results at the truckwash land generally agreed with predicted NO₃-N values during the period of study.

REFERENCES

1. California Fertilizer Association, *Western Fertilizer Handbook*, Eighth Edition, Interstate Publishers, Inc., 1995.
2. Reed, Sherwood C., Ronald W. Crites, and E. Joe Middlebrooks, *Natural Systems for Waste Management and Treatment*, McGraw-Hill, Inc., New York, NY, 1995.

TABLE 1
WATER BALANCE FOR LAND APPLICATION SYSTEM

Month	Precip., in	ET, in	Applied wastewater, in			Applied well water, in			Percolation, in		
			Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
Jan-99	3.2	0.5	0.0	0.0	2.9	0.0	0.0	0.0	2.7	2.7	5.5
Feb-99	3.4	1.3	0.0	0.0	3.1	0.0	0.0	0.0	2.1	2.1	5.3
Mar-99	1.0	3.0	2.4	1.1	1.7	0.0	0.0	0.0	0.5	0.0	0.0
Apr-99	0.9	5.2	2.0	1.3	2.2	0.0	0.0	0.0	0.0	0.0	0.0
May-99	0.2	6.9	0.0	0.0	6.0	9.4	10.6	0.0	2.7	3.9	0.0
Jun-99	0.0	7.4	0.0	0.0	4.9	9.4	10.6	0.0	2.0	3.2	0.0
Jul-99	0.0	7.7	0.0	0.0	6.2	9.4	10.6	0.0	1.7	2.9	0.0
Aug-99	0.0	6.4	0.0	0.0	8.3	9.4	10.6	0.0	3.0	4.2	2.0
Sep-99	0.0	5.1	0.0	0.0	8.0	9.4	10.6	0.0	4.3	5.6	2.9
Oct-99	0.2	3.4	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	4.4
Nov-99	1.4	1.4	0.0	0.0	6.2	0.0	0.0	0.0	0.1	0.1	6.2
Dec-99	0.2	1.3	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	3.9
Total	10.6	49.6	4.5	2.4	62.1	46.8	53.0	0.0	18.9	24.7	30.2
Jan-00	4.2	0.8	0.0	0.0	4.1	0.0	0.0	0.0	3.4	3.4	7.5
Feb-00	5.8	1.2	0.0	0.0	4.3	0.0	0.0	0.0	4.6	4.6	8.8
Mar-00	0.8	3.8	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	1.6
Apr-00	1.2	5.2	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.8
May-00	0.8	6.2	0.0	0.0	5.6	8.0	9.4	0.0	2.5	4.0	0.1
Jun-00	0.1	7.7	2.3	1.3	2.1	8.0	9.4	0.0	2.6	3.0	0.0
Jul-00	0.0	7.6	2.9	0.0	5.6	8.0	9.4	0.0	3.2	1.8	0.0
Aug-00	0.0	6.6	2.0	3.1	4.5	9.9	11.8	0.0	5.4	8.3	0.0
Sep-00	0.1	4.7	1.8	0.0	7.3	4.0	4.7	0.0	1.2	0.1	2.7
Oct-00	2.5	2.8	3.1	0.0	4.8	2.0	2.4	0.0	4.8	2.1	4.6
Nov-00	0.2	1.2	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	3.7
Dec-00	0.3	0.7	0.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	4.8
Total	16.1	48.5	12.1	4.4	57.4	39.8	47.1	0.0	27.7	27.3	34.6
Jan-01	2.9	0.9	0.0	0.0	5.2	0.0	0.0	0.0	2.0	2.0	7.2
Feb-01	2.1	1.6	0.0	0.0	4.4	0.0	0.0	0.0	0.5	0.5	4.9
Mar-01	1.6	3.4	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	3.0
Apr-01	1.4	4.6	2.3	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0
May-01	0.0	7.8	2.5	0.0	4.8	6.0	9.4	0.0	0.7	1.6	0.0
Jun-01	0.1	7.7	2.3	0.0	5.6	8.0	9.4	0.0	2.6	1.8	0.0
Jul-01	0.0	7.4	3.5	0.0	3.4	8.0	9.4	0.0	4.0	2.0	0.0
Aug-01	0.0	6.9	3.0	0.0	4.8	8.0	11.8	0.0	4.1	4.9	0.0
Sep-01	0.3	5.0	2.2	0.0	4.8	4.0	4.7	0.0	1.5	0.0	0.1
Oct-01	0.3	3.3	2.8	0.0	4.5	2.0	2.4	0.0	1.8	0.0	1.6
Nov-01	1.8	1.3	3.2	0.0	2.5	0.0	0.0	0.0	3.7	0.5	3.0
Dec-01	3.7	0.8	3.3	0.0	0.0	0.0	0.0	0.0	6.2	2.9	2.9
Total	14.2	50.8	25.0	0.0	47.7	35.8	47.1	0.0	27.0	16.3	22.8

TABLE 2
APPLIED WATER QUALITY FOR LAND APPLICATION SYSTEM

Month	Applied wastewater				Well water
	BOD, mg/L	TKN, mg/L	NO ₃ -N, mg/L	TN, mg/L	NO ₃ -N, mg/L
Jan-99	1,041	2.8	1.1	3.9	7.0
Feb-99	2,301	8.4	0.7	9.1	-
Mar-99	2,660	19.6	0.1	19.7	-
Apr-99	2,107	3.0	1.4	4.4	-
May-99	1,920	18.1	0.9	19.0	-
Jun-99	2,130	5.0	0.1	5.1	-
Jul-99	3,091	0.5	0.1	0.6	-
Aug-99	5,352	18.0	1.1	19.1	-
Sep-99	2,640	0.5	1.1	1.6	-
Oct-99	1,900	0.5	0.9	1.4	-
Nov-99	5,490	0.5	0.1	0.6	-
Dec-99	4,326	0.5	0.1	0.6	-
Avg.	2,913	6.5	0.6	7.1	7.0
Jan-00	1,100	6.1	2.8	8.9	9.7
Feb-00	1,100	6.1	2.8	8.9	-
Mar-00	1,100	6.1	2.8	8.9	-
Apr-00	1,100	6.1	2.8	8.9	-
May-00	1,100	6.1	2.8	8.9	-
Jun-00	1,100	6.1	2.8	8.9	-
Jul-00	1,600	3.6	5.9	9.5	-
Aug-00	370	3.0	5.0	7.9	-
Sep-00	1,420	8.0	1.9	9.9	-
Oct-00	826	2.0	1.1	3.1	-
Nov-00	726	13.0	1.6	14.6	-
Dec-00	1,660	6.9	1.4	8.3	9.3
Avg.	1,100	6.1	2.8	8.9	9.5
Jan-01	1,175	0.5	0.1	0.6	9.5
Feb-01	2,320	8.7	0.1	8.8	-
Mar-01	1,280	0.5	0.3	0.8	-
Apr-01	1,720	1.3	0.1	1.4	-
May-01	1,830	5.0	0.1	5.1	-
Jun-01	2,230	0.5	3.4	3.9	-
Jul-01	2,092	6.1	0.4	6.5	-
Aug-01	520	5.2	0.6	5.8	-
Sep-01	1,520	7.3	0.0	7.3	-
Oct-01	1,650	6.8	0.1	6.9	-
Nov-01	2,352	2.3	0.9	3.2	-
Dec-01	800	1.5	2.6	4.1	-
Avg.	1,624	3.8	0.7	4.5	9.5

TABLE 3
ORGANIC AND NUTRIENT LOADING FOR LAND APPLICATION SYSTEM

Month	BOD load, lb/ac-d			TN load, lb/ac		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
Jan-99	0	0	22	0	0	3
Feb-99	0	0	59	0	0	6
Mar-99	47	22	33	11	5	8
Apr-99	33	20	35	2	1	2
May-99	0	0	84	15	17	26
Jun-99	0	0	79	15	17	6
Jul-99	0	0	139	15	17	1
Aug-99	0	0	326	15	17	36
Sep-99	0	0	159	15	17	3
Oct-99	0	0	106	0	0	2
Nov-99	0	0	256	0	0	1
Dec-99	0	0	158	0	0	1
Total	-	-	-	87	90	94
Jan-00	0	0	33	0	0	8
Feb-00	0	0	38	0	0	9
Mar-00	0	0	37	0	0	9
Apr-00	0	0	39	0	0	9
May-00	0	0	45	17	20	11
Jun-00	19	11	17	22	23	4
Jul-00	34	0	65	23	20	12
Aug-00	6	8	12	25	31	8
Sep-00	20	0	78	13	10	16
Oct-00	18	0	29	6	5	3
Nov-00	0	0	26	0	0	15
Dec-00	0	0	63	0	0	10
Total	-	-	-	106	110	116
Jan-01	0	0	45	0	0	1
Feb-01	0	0	83	0	0	9
Mar-01	0	0	45	0	0	1
Apr-01	30	0	35	1	0	1
May-01	34	0	65	16	20	6
Jun-01	38	0	94	19	20	5
Jul-01	53	0	53	22	20	5
Aug-01	11	0	18	21	25	6
Sep-01	26	0	56	12	10	8
Oct-01	33	0	55	9	5	7
Nov-01	56	0	45	2	0	2
Dec-01	19	0	0	3	0	0
Total	-	-	-	105	101	50

Note: BOD values represent average daily loads for each month (see units), and are not totaled.

TABLE 4
ESTIMATED PERCOLATE QUALITY FOR LAND APPLICATION SYSTEM

Parameter	1999			2000			2001		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
Applied water TN load, lb/ac	87	90	94	106	110	116	105	101	50
Fertilizer TN load, lb/ac	100	100	0	100	100	0	100	100	0
Total TN load, lb/ac	187	190	94	206	210	116	205	201	50
TN uptake, lb/ac	150	150	75	160	160	75	160	160	75
Leached TN, lb/ac	9.0	11.9	5.1	15.4	18.2	23.5	14.2	11.0	0.0
Percolate depth, in	18.9	24.7	30.2	27.7	27.3	34.6	27.0	16.3	22.8
Estim. perc. NO ₃ -N, mg/L	2.1	2.1	0.8	2.4	2.9	3.0	2.3	3.0	0.0

TABLE 5
COMPARISON OF LYSIMETER GROUNDWATER SAMPLE RESULTS AND
ESTIMATED PERCOLATE QUALITY FOR LAND APPLICATION SYSTEM

Test	Test period	1999			2000			2001		
		Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
Lysimeter BOD, mg/L	1st quarter	14	2	17	6	5	5	1	1	1
	2nd quarter	1	2	4	6	4	18	-	-	-
	3rd quarter	2	-	2	3	3	4	1	1	3
	4th quarter	2	5	2	3	3	22	1	1	2
	Average	5	3	6	4	4	12	1	1	2
Lysimeter NO ₃ -N, mg/L	1st quarter	1.6	2.7	3.4	1.4	1.6	0.5	0.1	2.1	0.1
	2nd quarter	1.1	0.1	0.1	6.8	8.4	0.1	0.3	8.0	0.2
	3rd quarter	0.4	-	1.1	0.9	9.0	0.6	0.0	9.0	1.0
	4th quarter	6.3	4.1	0.5	1.3	13.7	0.1	0.0	7.0	0.0
	Average	2.4	2.3	1.3	2.6	8.2	0.3	0.1	6.5	0.3
Estim. perc. NO ₃ -N, mg/L		2.1	2.1	0.8	2.4	2.9	3.0	2.3	3.0	0.0