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MOVEMENT OF POLLUTANTS FROM SEPTIC SYSTEMS AND PERFORMANCE OF RIPARIAN BUFFERS IN SUBURBAN SETTINGS

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ABSTRACT

Nonpoint source (NPS) pollution has been recognized as the leading source of water quality problems in the United States. On-site wastewater management systems are among the nonpoint sources that may cause water quality degradation. Approximately 25% of the United States population and 50% of people living in North Carolina rely on on-site systems for managing their household sewage. The most common type of on-site wastewater management is a conventional septic system composed of a septic tank and a drainfiled. In a septic system wastewater containing dissolved and suspended solids is dispersed into a series of trenches dug into the natural soil. In a properly functioning septic system, wastewater infiltrating the soil receives treatment in the unsaturated zone before reaching a saturated zone (i.e., ground water) or a slowly permeable layer where a saturated zone or perched water table may form. In the saturated zone, water generally moves in horizontal direction until reaching a natural (or man-made) drainage or a well where water is extracted from the ground. The overall objective of the research presented here was to assess movement of water and selected constituents of domestic wastewater through the soil in the buffer areas between septic system drainfields and natural streams.

Three septic systems serving single-family homes located in northern part of Wake County, NC, were selected for the study. The drainfields of two of the systems were near a small running creek, and the third system was more than 150 m from a major creek. The soil at each site was described in the field and soil samples were collected for laboratory analysis. Saturated hydraulic conductivity of three depth intervals in the unsaturated zone and the surface infiltration rates at different locations in the drainfield areas of Systems 1 and 2 were measured in situ. Three wells and three to six banks of piezometers (two different depths in each bank) were installed at different locations inside and outside the drainfield of each system for collecting ground water samples and monitoring the water level. In addition, time domain reflectometry (TDR) rods and tensiometers were installed near the observation/sampling wells and piezometers for determining soil water content and soil water pressure head (i.e., matric potential) of the unsaturated zone, respectively. Each system was visited biweekly. During each visit soil water content and pressure head of the unsaturated zone, and depth to water table and submergence potential at two depths were measured. Once a month, water samples from the wells and piezometers were collected for chemical analysis. In addition to ground water, soil solution samples were collected using tension samplers, and water samples from different locations along the neighboring stream or creek were collected for analysis.

On average, the amount of wastewater applied to the drainfields of each of the systems was less than 40% of the daily design flow for that system. None of the three systems showed any sign of hydraulic failure during monitoring period. Overall, there was good agreement between the water table data obtained from the wells and the pressure heads measured with piezometers at two depths below the water table. The water table was generally higher during late fall and winter and was lowest during the summer months when evapotranspiration (ET) was high. Similarly, soil water content was higher and soil water pressure head was closer to zero during the fall and winter. Although soil water content under the drainfield of these systems was relatively high during part of the year, the soil remained unsaturated allowing the systems to hydraulically function properly. With few exceptions, the concentrations of both nitrate-nitrogen

(NO_3-N) and ammonium-nitrogen (NH_4-N) in the creek water were less than 0.5 mg/L. Ammonium-N concentrations as high as 5 mg/L were occasionally measured in samples of well water and soil solution collected from the drainfield areas of the systems. Nitrate-N concentrations greater than 5 mg/L, however, were observed frequently in ground water and soil solution samples. Based on these results, it appears that denitrification and dilution are the primary mechanisms for low concentration of nitrogen compounds in the creek water at these sites.

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SUMMARY AND CONCLUSIONS

Nonpoint source (NPS) pollution has been identified as a leading cause of water quality degradation in the United States. On-site wastewater management systems are among the nonpoint sources contributing to the water quality problems. Approximately 25% of the households in the United States and 50% of North Carolina population use on-site systems for wastewater management. The most common type of on-site wastewater management system is a conventional septic system composed of a septic tank and a drainfield. In a conventional septic system, sewage from the dwelling served by the system enters the septic tank where most of the solids settle and undergo anaerobic digestion. Wastewater containing dissolved and suspended solids is then dispersed in the drainfield area through a series of trenches dug into the natural soil. Based on the North Carolina population using septic systems, and assuming an average daily water use of 260 L per individual, the volume of wastewater applied daily to North Carolina soils through septic systems exceeds 1.1 billion L (2.96×10^8 gallons). A decline in ground water quality can be attributed to the use of on-site wastewater disposal systems in high density areas, as well as to the improper installation of septic systems in unsuitable soils.

While a great deal of attention has been devoted to nonpoint sources resulting from agricultural operations, only a limited number of studies have addressed the impact of septic systems on the quality of surface and ground water at watershed scales. Although the total amount of nitrogen present in wastewater generated by a household may be limited, its application rate over the drainfield area far exceeds the rate that fertilizers are applied to agricultural fields. A limited number of studies have shown that septic systems can contribute to the degradation of ground water quality. A few studies have also concluded that although nitrate concentrations may be high under the drainfield of septic systems, the concentrations of contaminants in ground water away from the drainfield decrease due to dilution.

Population increase in unsewered areas results in a higher use of on-site wastewater management systems. At the same time, the increased awareness regarding water quality, particularly in sensitive watersheds such as the Neuse River Basin, demands more knowledge about the efficacy of soils to treat septic tank effluent. The overall goal of this study was to assess the movement of water and selected constituents of domestic wastewater through soils in the buffer areas between the drainfield of a number of septic systems and natural streams.

Three individual septic systems in northern Wake County (within the Neuse River Basin) were selected for the study. The first system, referred to as System 1, served a 3-bedroom home with a design loading rate of 1,360 L/d (360 gal/d). The second and third systems (Systems 2 and 3) served 4-bedroom homes with a design loading rate of 1,815 L/d (480 gal/d). Systems 1 and 2 were near each other on neighboring properties and were relatively close to a running creek. System 3 was installed at a distance of more than 150 m from a major creek that was located on the border of the property. Septic tank effluent from System 1 was dispersed within two subdrainfields by a low-pressure pipe (LPP) distribution system. For System 2 wastewater was applied to the drainfield through a pressure manifold and for System 3 wastewater entered the drainfield by gravity. All three systems were installed in grassy areas surrounded by mature trees.

The soil in the drainfield area of each system was described in the field and a series of soil samples were collected from the soil surface to a depth of 200 cm or deeper for particle size analysis. Saturated hydraulic conductivity (K_{sat}) of three depth intervals in the unsaturated zone was measured in situ at six locations within the drainfield areas of Systems 1 and 2. The infiltration rate of the undisturbed surface of the two drainfield areas was measured by the double-cylinder infiltrometer technique at 21 locations.

A series of time domain reflectometry (TDR) rods, and banks of tensiometers at different depths were installed at various locations inside and outside the drainfield area of each of the three systems for measuring soil water content and pressure head of the unsaturated zone (i.e., matric potential), respectively. To collect soil solution from near the trenches, tension samplers at two different depths were also installed at two locations near a trench in each drainfield. To monitor water table elevation and collect ground water samples three observation/sampling wells were installed within the drainfield area of each system. In addition, three to six banks of piezometers, each containing two piezometer tubes extended to different depths, were installed inside and outside of the drainfield of the systems for determining submergence potential and collecting ground water samples from different depths.

All three sites were visited biweekly for recharging the tensiometers if needed. One day after this visit, each site was revisited and the water meter for the house was read and soil water content at different depth intervals was measured by TDR. In addition, soil water pressure head at various depths and locations in the unsaturated zone was determined by measuring the tension (vacuum) inside each tensiometer, and the level of water in each piezometer and observation well was measured using a battery operated probe.

Once a month, during the first day visit of each site the water in each well and piezometer was bailed out and fresh ground water was allowed to flow in for sampling. Using a hand vacuum pump, tension was applied to each tension sampler for collecting soil solution from the unsaturated zone. During the next day visit, a water sample was collected from each of the wells and piezometers installed at the site. In addition, the content of each tension sampler was collected and a water sample was collected from each of the sampling locations along the creek. The samples were transported to the laboratory and analyzed for pH, electrical conductivity (EC), NH_4-N, NO_3-N, total Kjeldahl nitrogen (TKN), PO_4-P, total P (TP), and total organic carbon (TOC).

The soil in the drainfield area of System 1 appeared to be uniform. With a few exceptions, the samples that were collected from the soil surface to 150 cm depth had a sandy loam texture. Between the 150 and 200 cm depths, the average soil texture was sand to loamy sand. Although the soil texture did not change significantly with depth in the upper 150 cm, the K_{sat} values were in general higher in the upper 40 to 60 cm than deeper depths. The lowest measured K_{sat} (1.6 cm/d) was for the 90 to 105 cm depth interval and was four times higher than the area loading rate for the system. Based on the lowest K_{sat} value at this site, we expected all the applied wastewater to the drainfield to infiltrate the trenches and move vertically into the ground water. The infiltration rate in the upper part of the drainfield was lower than areas near the creek. Due to relatively high infiltration rate over the drainfield area, we expect most of the rainfall to infiltrate and move vertically into the shallow ground water at this site.

The soil in the drainfield area of System 2 also appeared to be uniform. For this system, the soils in the upper 40 to 45 cm depths had a sandy loam texture, between 45 and 80 cm the soil texture was loamy sand, and below 80 cm the soil texture was sand to loamy sand with very little clay. The lowest measured K_{sat} at this site was 3.5 cm/d at the 60 cm depth. The saprolite at approximately the 105 to 120 cm depth interval had much higher hydraulic conductivity. In general, K_{sat} of soil at this site was high enough not to cause hydraulic failure. The infiltration rate for the area between the drainfield and the creek was relatively high. Over the drainfield, the infiltration rate ranged between 0.9 and 9.7 cm/h. Except for very high intensity rainfall, we do not expect any potential runoff from the drainfield to flow directly into the creek.

The soil in the drainfield area of System 3 was relatively thick. At this site the clay content increased with depth and reached a maximum of approximately 35% at 90 to 110 cm depth interval. Below the Bt horizon, the clay content of saprolite decreased and reached an average value of 5% at 210 cm depth.

Based on readings of the water meters, the average values for the volume of wastewater applied daily to the drainfields were 530 L for System 1, 640 L for System 2, and 608 L for System 3. These volumes represent approximately 40, 35, and 33% of the design flow for Systems 1, 2, and 3, respectively. Overall, considering the relatively low volume of wastewater applied daily to each system, the saturated hydraulic conductivity of the soils were high enough not cause hydraulic failure of these systems.

In general, the water table elevations at all three sites fluctuated with the seasons. At System 1, the water table in the middle of one subfield was mostly above the bottom of the creek. Near the creek and at the edge of the other subfield, on the other hand, the water table was below the bottom of the creek for a few months during dry periods. Higher water level in the middle of the drainfield could be the result of mounding due to wastewater application to the drainfield. Based on a three-point water table analysis, during the wet periods, ground water flowed from the drainfield toward the creek, while at other times, ground water flowed mostly parallel to the creek. Overall, there was a good agreement between the ground water table elevation measured in the wells and pressure heads measured at two depths in the piezometers. There was virtually no difference between the pressure heads at two different depths at two locations near the subfields. The highest difference in the pressure head in vertical direction was observed at a location above the drainfield. Based on our observation of ground wetness at the south-west corner of the drainfield area, it appears that this area was a ground water discharge area from up slope of the property. When the water table is low, we do not believe significant amount of pollutants from this drainfield moves laterally toward the creek on the property.

For system 2, the water table elevation at a location near the creek was generally lower than the water table at locations near the drainfield. Only for a short time during the August of 2002 did the water level elevation near the creek fall below the bottom of the creek. In general, the ground water flow at this site was from the drainfield area toward the creek. The direction of ground water flow based on measured water table elevations was in north-east direction (perpendicular to the general contour of the land). Except for the summer of 2002, the water level elevations in the piezometer installed at 240 cm depth between the drainfield and the ditch on the north side of the drainfield were slightly higher than the water level elevations in the peizometers installed at deeper depth. At the other locations, there was little difference between the water level elevations in the piezometers installed at different depths. Overall, the piezometers results agree with the water table elevations obtained by measuring the water levels in wells. The piezometer data indicate that for most of the times, water from the drainfield area moved toward the creek.

All three observation/sampling wells at System 3 were below the drainfield. The differences in the water level in these wells indicated that ground water moved from north-west toward south-east direction (for position of drainfield see Fig. 8). It appears that ground water from this system does not move directly toward the creek on the south side. The patterns for the water level elevation in the three piezometers were similar to the patterns for the water table elevation measured in the wells. From March through June, 2003, there was little difference between the water table elevations in corresponding wells and piezometers at all locations. Overall, the results for water level in the piezometer tubes corresponded fairly well with the water table elevations measured in the wells at three locations.

The soil water content measured in situ at System 1 showed moderate variability with depth and time for each of the locations. At the location above the drainfield, the wettest zone was the 90 to 120 cm depth interval, and the soil water content at each depth interval was relatively low during the summer months and relatively high during the winter when evapotranspiration is low. In the middle of the drainfield, water contents in the upper 45 cm showed more variation than water contents at the 60 to 90 cm depth interval. The trenches of this system were approximately 45 cm deep, and the water table was relatively shallow under the drainfield. As a result, the water content at the 60 to 90 cm depth interval was the highest and remained relatively constant. The average water content at 45 to 60 cm depth interval was 0.34 m^3/m^3.

At a location above the drainfield, the soil water pressure head in System 1 was close to zero or slightly negative from December 2001 through April 2002, and from November 2002 through early March 2003. At other times the soil water pressure head was mainly negative. Inside the drainfield, the soil water pressure head was mostly negative, indicating unsaturated conditions. Although there was not a substantial difference between the summer and winter months, the soil water pressure head was generally lower in the summer months as compared to winter months. Also, in general, soil water pressure heads increased with depth, indicating higher soil water contents at deeper depths. At locations between the drainfield and the creek, the pattern of soil water pressure head distribution with time was relatively similar to the patterns for the two locations inside the drainfield. In general, there was a good agreement between the trends of the soil water pressure head and the soil water content measured by TDR.

At locations above and below the drainfield of System 2, higher soil water contents were measured during winter months compared to summer. Inside the drainfield, however, there was not a substantial difference in water contents between the summer and winter months, which is due to the fact that wastewater is applied to this drainfield throughout the year. The soil water pressure head measured at three depths above, in the middle, and below the drainfield near the beginning of the trenches corresponded fairly well with the corresponding soil water content measured by TDR. There were significant differences between the soil water pressure heads measured during winter and summer months for each depth above and below the drainfield.

Inside the drainfield, the variation in soil water pressure head was much less from winter to summer. Except for a few short periods, the soil in the drainfield area of this system remained unsaturated during the monitoring period. As indicated earlier, this system received approximately one-third of the daily design flow of 480 gallons/day. Also, the drainfield was located on a side slope and ground water within the drainfield was relatively deep. Hydraulically, this system functioned properly by maintaining an unsaturated zone below its trenches.

The level of ponding at seven locations inside the trenches of System 3 was measured from November 2002 through July 2003. The depth of wastewater ponding was relatively low near the beginning of the two trenches, and the highest level of ponding was measured at a location in the middle of the upper trench. This location is near the driveway and may receive runoff from paved areas. There was little to no ponding at the end of the two trenches. Although ponding was observed continuously in part of each trench, this system appeared to function properly.

Except for the upper 15 cm, the soil water content above the drainlines did not change substantially during the monitoring period. Relatively high soil water contents above the drainlines were perhaps due to runoff that came from a rather large driveway sloping toward the drainfield area. Inside the drainfield, the water contents at 60 to 90 and 90 to 120 cm depth intervals remained relatively high at all times. The soil water contents in the upper 60 cm showed little difference between summer and winter months. The driest location was below the drainfield.

At locations above and below the first trench near the driveway the soil water pressure head remained fairly uniform and did not decrease below -60 cm at any depth/location, indicating wet conditions. The tensiometer results were consistent with the soil water content values obtained by TDR, and the level of wastewater ponding in the upper trench near these locations. Because the trenches were 60 to 90 cm deep and contained water at all times, it is very possible to have zones of saturation around this area. In some instances, the soil water pressure head measured with a tensiometer was positive indicating that the tensiometer cup was either in the middle of a saturated zone (submerged below a perched water table) or intercepted by a macropore full of water. At a location between the two trenches on the east side of the drainfield the soil water pressure head was also fairly constant after June, 2002. Below the lower drainline the soil water pressure head had a similar trend to a location between the two trenches. Overall, the tensiometer results corresponded fairly well with the soil water content variation with time and space as well as to the wastewater ponding levels in the trenches.

The pH of the water samples collected from the creek near the drainfields of Systems 1 and 2 varied between 5.7 and 6.8. For both systems, the ground water and soil solution samples had a lower pH than the surface water in the creek. In general, the pH values for the water samples collected from wells fluctuated more than the ones for the piezometers. For System 3, the pH of the water in the creek varied between 6 and 7.2 for the monitoring period. The results are consistent with the pH for the surface water in the creek at the other two sites a few miles away. The pH of the soil solution samples collected by the tension samplers varied between 6 and 7.3, while the ground water pH was substantially lower and remained below 6.5.

The electrical conductivity (EC) of the water samples collected from seven locations in the creek adjacent to Systems 1 and 2 remained relatively low and did not vary substantially for the duration of monitoring. The EC of the water samples collected from wells and piezometers, as well as the soil solution, was in general higher than the EC of the creek samples. Overall, the EC of water samples collected from wells, piezometers, and soil solution for System 1 was higher than the corresponding values for System 2. In general, electrical conductivity represents the amount of total dissolved solutes in a solution. The results indicate that dilution is perhaps the main reason for the reduction in the solute concentration in ground water moving from the drainfield toward the creek. For System 3, the electrical conductivity of water samples collected from the main creek on the south side of the property was slightly higher than the water samples from the side creek. In general, the EC of the ground water samples collected at this site was relatively low. Occasionally, the measured EC of ground water samples was above 100 µS/cm. The EC values for the samples of the soil solution collected from the unsaturated zone near the trenches at two locations were more than 100 µS/cm for most samples.

Except for two sampling periods, the ammonium-N (NH_4-N) concentrations in the water samples collected from the seven locations in the creek near Systems 1 and 2 remained relatively small. In the unsaturated zone of both systems, NH_4-N concentrations remained less than 1 mg/L for most of the monitoring period. Low levels of NH_4 in the soil solution collected near the trenches indicate that the environment around the trenches remained aerobic during our study. In the ground water, relatively high levels of NH_4 were only observed in the well that was installed in the middle of one of the subfields of System 1. Overall, the levels of NH_4 in the water samples collected from two different depths using the piezometers remained relatively low for both systems. For System 3, the NH_4-N concentrations in the water samples collected in the creeks were relatively low and with one exception did not exceed 0.5 mg/L. The NH_4-N concentrations in the well samples generally remained below 0.4 mg/L. A similar trend was observed in the samples collected from the piezometers. Ammonium-N concentrations in the soil solution samples collected by the tension samplers were less than 0.5 mg/L, but increased to more than 5 mg/L only once in two of the tension samplers.

The nitrate-N (NO_3-N) levels in the ground water samples collected from the wells and the tension samplers for System 1 were substantially higher than their corresponding NH_4-N levels. Higher concentrations of nitrate were observed during the winter and spring months than during summer and fall. In the creek, however, the NO_3-N levels remained below 0.5 mg/L for the duration of monitoring. In general, lower nitrate levels were observed during the summer months. This could be due to higher nutrient uptake by plants, or higher microorganism activities, although the possibility of higher leaching and a greater dilution due to summer rains cannot be ignored.

For System 2, the levels of nitrate in the water in the creek were relatively low and showed the same trend as the locations along the creek adjacent to the drainfield of System 1. The levels of nitrate in the soil solution collected from near the trenches by the tension samplers, on the other hand, were substantially higher, but did not show any specific trend. The NO_3-N concentrations in the ground water samples collected from the wells were generally low and reached 25 mg/L in two of the wells only once during the summer of 2002. Overall, the concentrations of nitrate in the soil solution and in ground water under this system were lower than the corresponding values for System 1.

For System 3, the concentration of NO_3-N in the creeks was very low and did not exceed 0.4 mg/L during the monitoring period. In the soil solutions collected from the tension samplers, on the other hand, NO_3-N concentration reached as high as 18.5 mg/L. Overall, the soil solution had higher nitrate concentration than the ground water. Nitrate-N concentrations in the samples collected from the wells and piezometers remained below 7 mg/L, but showed relative increases during late spring 2003. Overall, based on the ammonium and nitrate in the samples from near the trenches it appears that this septic system is functioning properly by maintaining an unsaturated zone below the trenches and converting the ammonium in the septic tank effluent to nitrate. Lower nitrate concentration in the ground water compared to soil solution samples perhaps indicates reduction in nitrate concentration by dilution or denitrification.

The levels of phosphate-P (PO_4-P) in the ground water or soil solution samples for System 1 rarely exceeded 1 mg/L. The total P concentrations in the water samples from the wells or tension samplers were also less than 1 mg/L for most of the times. Only for the piezometer samples the total P levels exceeded 1 mg/L a few times. For the samples collected from the creek near this system the concentrations of PO_4-P and total P were less than 0.1 and 0.16 mg/L, respectively, for the entire monitoring period. Similarly, the PO_4-P concentrations in the creek samples for System 2 were generally below the detectable limit and never reached 0.08 mg/L. With one exception, the PO_4 levels for the soil solution and ground water samples were very low during the monitoring period. With one exception, the total P concentrations in the water samples from the creeks near System 3 were less than 0.1 mg/L. For this system, the total P concentration in the soil solution samples matched the phosphate concentration for individual sampling, indicating that most of the P in the soil solution was in the form of phosphate. For well and piezometers samples, however, higher levels of total P than phosphate-P were observed in the water samples.

The concentrations of total organic carbon (TOC) for all the samples collected from the creeks, tension samplers, wells, and piezometers at all three sites showed an interesting trend. In all cases, a substantially higher TOC concentration was detected in the samples that were collected in late 2001 and again from late September through December 2002. Since we have limited data, we cannot draw a firm conclusion for such an increase. Although we cannot rule out the possibility of invalid data, we suspect that the increase in TOC content of all the samples could be natural trends occurring during the fall season (when leaves fall), and a more comprehensive evaluation is needed to determine if the trend is real.

RECOMMENDATIONS

1. The current setback of 50 ft from streams, as required by North Carolina regulations, appears to be adequate and should be maintained.

2. The location of septic system drainfields on the landscape should consider the potential subsurface flow from upslope areas.

3. Runoff from paved or other impermeable areas around the dwelling served by a septic system should be diverted away from the drainfield area of the system.

4. Care should be taken to properly design, install, and manage septic systems installed in the vicinity of streams and other surface water bodies.

5. Additional studies should be conducted to assess the impact of major rainfall events on transport of nutrients and other pollutants from septic systems into natural and man-made drainage systems.

6. Additional studies should be conducted to assess the potential impact of septic systems on seasonal variations of organic carbon in ground water as well as streams and other surface waters around septic system drainfields.

INTRODUCTION

Nonpoint source (NPS) pollution has been identified as the Nation's largest source of water quality problems (USEPA, http://epa.gov/owow/nps/facts/point1.htm). According to USEPA, NPS pollution is widespread due to activities that disturb the land or water. Among the nonpoint sources contributing to the degradation of our water resources are septic systems (Bicki and Brown, 1991; Hantzsche and Finnemore, 1992; Tinker, 1991; Wernick et al., 1998). Approximately 25 million households or 24% of the housing units in the United States use on-site septic systems (Burea of Census, 1993a). In North Carolina, almost one-half of the population relies on septic systems for domestic wastewater management (Burea of Census, 1993b). Based on the North Carolina population of 8,407,248 for 2003 (Bureau of Census, 2004) and the average number of people living in a household (2.5), we estimate the number of on-site wastewater treatment/disposal systems in the state to exceed 1.66 million. Assuming an average daily water use of 260 L per individual (EPA, 2002), and estimated number of people currently using septic systems (4.3 million), the volume of wastewater applied daily to North Carolina soils through septic systems exceeds 1.1 billion L (2.96×10^8 gallons). A decline in ground water quality can be attributed to the use of on-site wastewater disposal systems in high density areas, as well as to the improper siting of septic systems in unsuitable soils. Hampton and Jones (1985) estimated that 70% of the soils in the United States have characteristics that limit their use for on-site treatment/disposal of domestic wastewater.

Septic System Design

In North Carolina, a conventional or modified conventional septic system is composed of a septic tank and a drainfield (Fig. 1A). Wastewater from the dwelling served by the septic system enters the septic tank by gravity. After most solids settle out, wastewater containing dissolved and suspended solids moves by gravity into a series of 90-cm (3-ft) wide trenches dug into the soil in the drainfield. In general, these trenches are 60 to 90 cm (2 to 3 ft) deep and are partially filled with gravel. A 4-in corrugated pipe installed in the gravel envelope carries the applied effluent into the trench. A distribution box or another non-mechanical distribution system divides the volume of effluent coming from the septic tank and distributes the wastewater among the trenches. For areas where the drainfield sits above the septic tank outlet, or when a more uniform distribution of wastewater among trenches is required, a pressure manifold (Berkowitz, 1985; EPA, 2002) is used in place of the distribution box for applying wastewater to the trenches (Fig. 1B).

Not all the soils are suitable for a conventional or modified conventional system. Also, for large systems (e.g., systems serving schools, apartments, office buildings), as well as some of the small systems serving single-family homes, a more uniform distribution of wastewater over the entire drainfield is desired. Low-pressure pipe (LPP) distribution is commonly employed for this purpose. For LLP distribution systems, wastewater from the septic tank enters by gravity into a storage or retention tank (commonly referred to as pump tank). From the pump tank, wastewater is pumped through a series of perforated pipes installed in relatively narrow and shallow trenches. In general, the trenches of the LPP systems are at least 20 cm (8 in) wide and 30 to 45 cm (12 to 18 in) deep. The perforated pipe is placed in a gravel envelop inside the trench. Figure 1C presents a schematic diagram of the plan view of a LPP septic system.

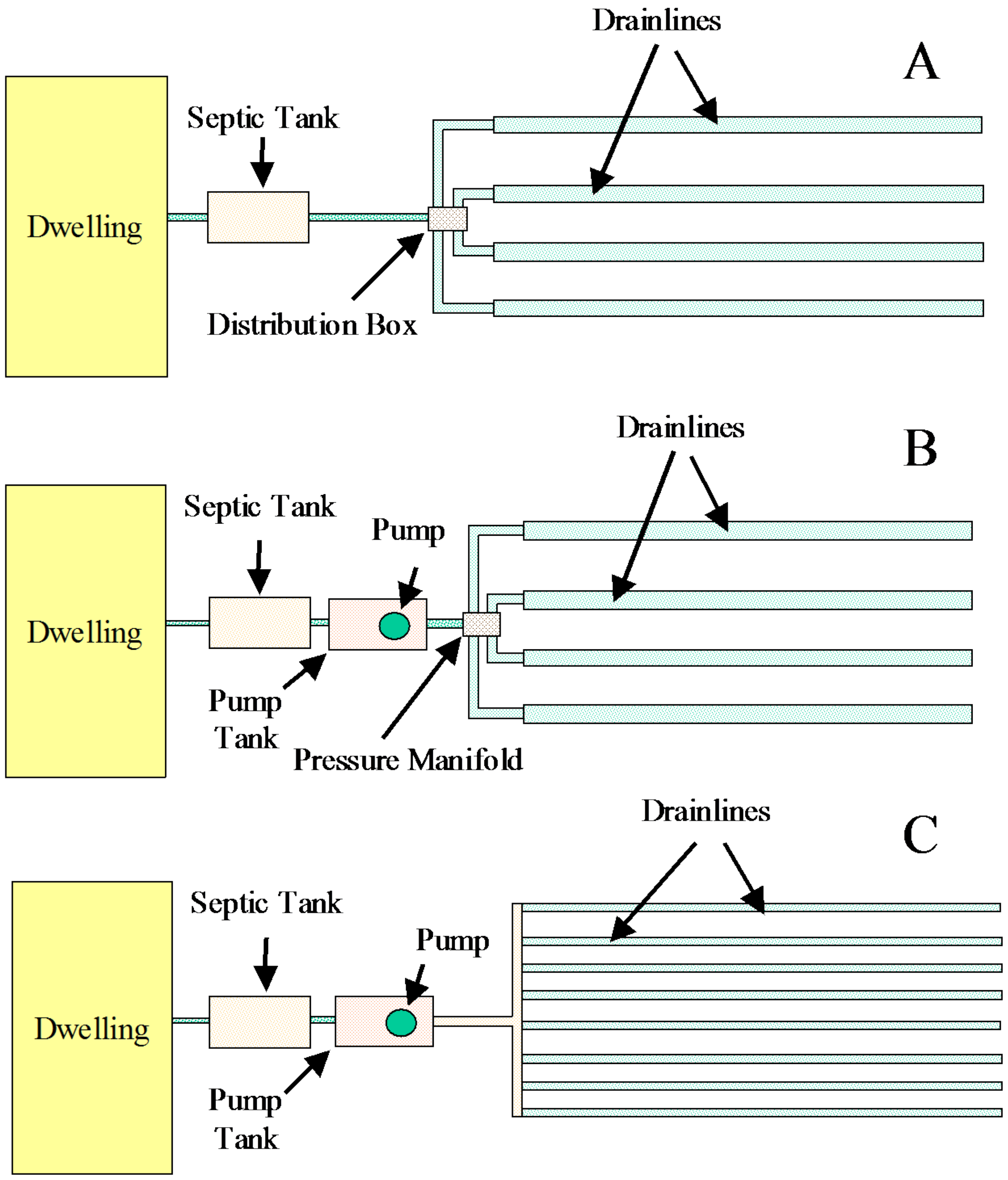

Figure 1. A Schematic diagram of the plan view of a conventional septic system with a distribution box (A), a conventional septic system with a pressure manifold (B), and a septic system with low-pressure pipe distribution system (C).

In order for a septic system to function properly, all the wastewater applied to the trenches daily must infiltrate the soil within each 24 hours. After wastewater infiltrates the soil from the trenches, it must move vertically down into a deep water table or move laterally to allow a zone of unsaturated soil under the trenches at all times. Figure 2 presents a schematic diagram showing the contribution of a septic system in a hydrologic cycle.

Septic Systems as a Nonpoint Source of Pollution

While a great deal of attention has been devoted to nonpoint sources resulting from agricultural operations (Bjorneberg et al., 1996; Eghball and Gilley, 1999; Howell et al., 1995; Johnston et al., 1998; Jokela, 1992; Mostaghimi et al., 1992; Ramanarayanan et al., 1998; Schreiber and Cullum, 1998; Sharpley et al., 1991; Steinheimer et al., 1998), only a limited number of studies have addressed the impact of septic systems on the quality of surface and ground water at watershed scales. Wernick et al. (1998) studied the impact of septic systems and agricultural activities related to animal husbandry on the level of nitrate-N in Salmon River near Vancouver, British Columbia in Canada. They determined that both residential development using septic systems and agriculture operations contributed to the elevated levels of nitrate-N in the main

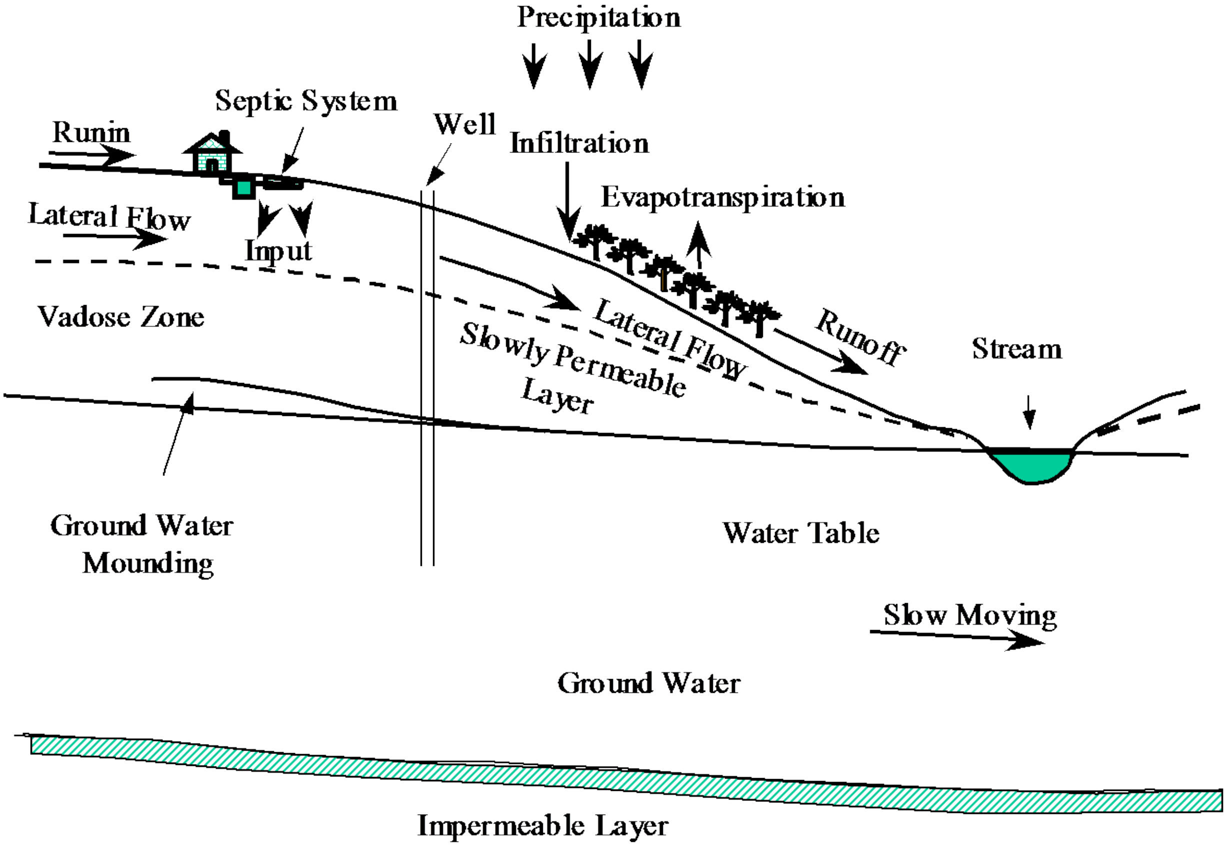

Figure 2. A schematic diagram of a hydrologic cycle showing the contribution of a septic system to the soil and ground water.

Salmon River. They also associated high nitrate levels in one of the tributary of this river with septic system density. Katz et al. (1980) evaluated the nitrogen concentrations in ground water samples collected between 1972 and 1976 from sewered and unsewered areas in Nassau County, New York. Based on their ammonium and nitrate data, they concluded that the ground water under sewered areas had a higher quality than ground water under unsewered areas. They identified septic systems and cesspools, as well as fertilizer applied to nonagricultural lands, as the main sources of nitrogen in ground water. Tinker (1991) reported on the nitrate-N level in ground water under five different subdivisions in Wisconsin, and concluded that septic systems and lawn fertilization were the main cause of high nitrate levels in ground water under and down gradient from these subdivisions.

Reneau et al. (1989) presented a review of the fate and transport of inorganic and biological contaminants in soils under septic systems. They concluded that leaching of nitrate and perhaps transport of ammonium pose the greatest pollution potential from septic systems. Robertson et al. (1991) found significant movement of a nitrate plum under a 14-year old and a relatively young (< 3 years old) septic systems serving single-family homes in Ontario, Canada. Chen and Harkin (1998) applied ^{15}N-NH$_4$Cl and bromide as tracer to the drainfields of three septic systems in Wisconsin. They reported that although dissipation of N occurred due to dilution, nitrate-N from sources other than septic systems was continuously mixed with ^{15}N in ground water. They concluded that septic systems are not a dominant source of nitrate in ground water down gradient from septic systems. Based on results of a previous study of a septic system in a soil with a shallow water table near a canal in Florida reported by McNeillie et al. (1994), Anderson (1998) concluded that septic system impacted the ground water near the system, but concentrations of contaminants 15 m down gradient from the system were at or near the background levels.

In North Carolina, Cogger et al. (1988) showed that one-ft (30 cm) of separation distance (unsaturated soil) between the bottom of the trenches and water table in sandy soils of the Lower Coastal Plain Region is not adequate for treating septic tank effluent. Morey and Amoozegar (2004) reported relatively high levels of nitrate (up to 18 mg/L) in water samples they collected from the top of the shallow ground water under the (mound) drainfield area of a small septic system installed at a distance of approximately 15 m from the Neuse River in Craven County. Surbrugg (1992) evaluated the concentrations of selected inorganic constituents of wastewater in the soil below a subfield of a large septic system located in Wake County in the Piedmont region. He reported that concentrations of nitrate and common cations in the soil under the septic tank effluent dispersal area were not significantly different than the corresponding background levels. Also, he concluded that leaching of nitrate was the reason for low nitrate level in the soil samples from under the drainfield of the system.

The amount of N applied to soils through septic systems in residential subdivisions not connected to sewer may pose major problems for both surface and ground waters. In agricultural operations, fertilizers are applied seasonally. In residential subdivisions, on the other hand, septic tank effluent containing nitrogen and other potential pollutants is applied to the soils below the land surface throughout the year. Although some of the nitrogen applied to the drainfield area may be taken up by plants (lawn, shrubs, trees), in most cases most of the nitrogen taken up by these plants is returned to the soil through grass clippings or leaves falling. As a result, most of the nitrogen present in septic tank effluent eventually enters ground or surface waters. This amount could be significant in residential areas served by septic systems. For example, consider 100 homes on a 100-acre (45-ha) subdivision in a subwatershed. Assuming an average of four individuals per household with an annual total nitrogen production of 8.8 to 24.8 kg per family (based on nitrogen output of 6 to 17 g per person per day, as reported by EPA, 2002), the total amount of N applied to the ground in the subwatershed is approximately 860 to 2,480 kg/year. Furthermore, since septic tank effluent containing nitrogen and other pollutants is applied to a relatively small area (i.e., drainfield) on a lot, the application rate of nitrogen over the drainfield far exceeds the rate commonly applied to agricultural fields. For example, the average long-term acceptance rate (LTAR) permitted by the North Carolina Laws and Rules (15A NCAC 18A.1900) for low-pressure pipe septic system is 0.125 gal/(ft^2d) [equivalent to 0.5 cm/d or 5 L/(m^2d)] for clayey soils, and 0.5 gal/(ft^2d) [equivalent to 2 cm/d or 20 L/(m^2d)] for sandy or loamy soils (NCDENR, 2007). Based on the range of nitrogen concentration in septic tank effluent (26 to 75 mg/L), the amount of nitrogen that can potentially be applied to the drainfield area calculated per hectare basis is between 475 to 1,370 kg/ha (422 to 1,220 lbs/acre, respectively) for the clayey soils and 1,900 to 5,475 kg/ha (1,690 to 4,875 lbs/acre, respectively) for sandy soils. [NOTE: For a family of 4 living in a 4-bedroom dwelling divide the numbers by 2, and for a family of 2 living in a 4-bedroom house divide the numbers by 4.]

Considering the desire of people living in suburban areas with no access to public sewer systems, and economic benefits of using septic systems for managing household sewage on site, the number of septic systems installed in the state will continue to increase. At the same time, an increased awareness regarding water quality, particularly in sensitive watersheds such as the Neuse River Basin, demands more knowledge about the efficacy of soils to treat septic tank effluent.

Objective

The main objective of this study was to assess the movement of water and selected constituents of domestic wastewater through soils in the buffer areas between the drainfield of a number of septic systems and natural streams.

MATERIALS AND METHODS

Three septic systems serving single-family homes in Wake County (within the Neuse River Basin) were selected for the study. Systems 1 and 2 were serving two neighboring residences in a small subdivision near the Falls Lake. A small creek was located near the drainfields of these systems. The third system was located on a relatively large lot bordering a major creek in the northern part of Wake County. Each system will be described in detail.

System 1

Septic system number one (hereafter referred to as System or Site 1) served a 3-bedroom home with a design loading rate of 1,360 L/d (360 gal/d). The drainfield of the system was located in a relatively low area between the road in front of the property and a small creek that was on the property. Wastewater from a pump tank located near the dwelling was dispersed within the drainfield by a low-pressure pipe (LPP) system composed of twelve 45-cm (18-in) wide, 38-cm (15-in) deep, and 18.3-m (60-ft) long trenches that were installed within two subfields. The area loading rate (LTAR) for the system was 4 L/(m^2d) or 0.4 cm/d [0.1 gal/(ft^2d)]. The drainfield area was covered with grass and had a 2 to 3% slope from the top of the drainfield to the creek side. The buffer area between the drainfield and the creek was covered by a number of relatively large trees and a few shrubs. The depth to saturated zone (water table) within the drainfield area ranged from < 60 cm (2 ft) to > 240 cm (8 ft) measured from the land surface directly next to the observation well. Figure 3 presents a schematic diagram of the plan view of the system showing the relative locations of the drainlines with respect to the creek on the property.

Soil/Site Characterization

The soil at this site appeared to be uniform. Soil samples were collected from the soil surface to 200 cm depth for particle size analysis. The distribution of sand, silt and clay of these samples were determined in the laboratory by the pipette method (Gee and Bauder, 1986). With a few exceptions, the samples from the soil surface to 150 cm depth had a sandy loam texture. Between 150 and 200 cm depth, the average soil texture was sand to loamy sand. Table 1 presents the average percent of sand and clay for samples collected from the surface to 200 cm depth.

Saturated hydraulic conductivity (K_{sat}) of the unsaturated zone at three depths was measured at four locations within the drainfield area by the constant-head well permeameter method (Amoozegar and Wilson, 1999). Two of the locations were close together. The relative locations where measurements were conducted are shown in Fig. 3. Briefly, for each measurement, a 6 cm diameter (2r) hole was dug to the desired depth. A planer auger was used to flatten the bottom of the hole (to form a cylindrical hole), and a nylon brush was used to scrape off the side-walls of the hole to remove smearing. Using a Compact Constant Head Permeameter (Amoozegar, 1992), a constant depth of water (referred to as the constant head, H) was maintained at the bottom of each hole and water was allowed to infiltrate the soil until a steady-state flow rate (Q) was achieved. The steady-state rate of water flow (Q) from the hole (radius r) under the constant head (H) were used to calculate the K_{sat} by the Glover equation

$$K_{sat} = \{[\sinh^{-1}(H/r) - (1 + r^2/H^2)^{1/2} + r/H]/(2\pi H^2)\}Q \qquad [1]$$

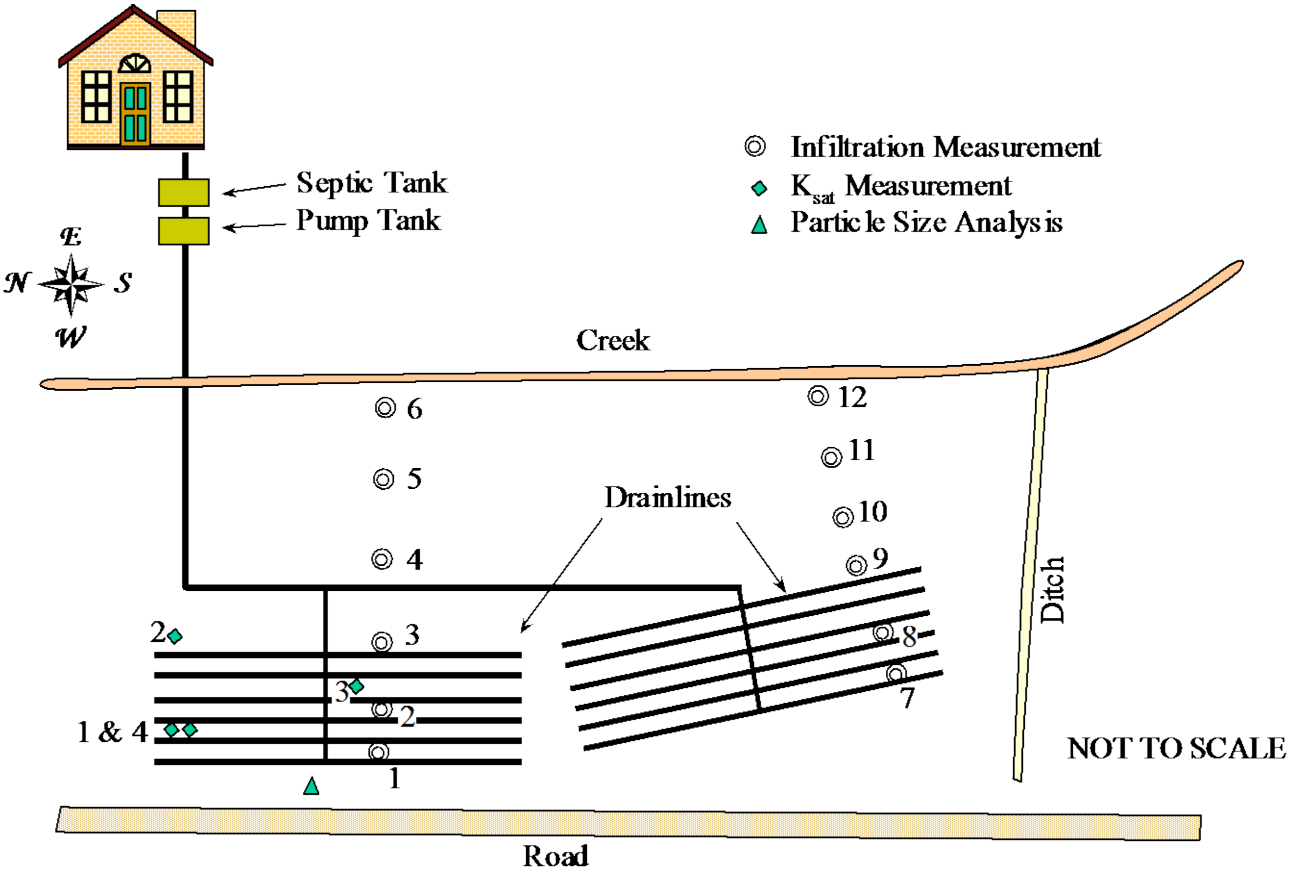

Figure 3. Schematic diagram of the plan view of the septic system at Site 1 showing relative locations of the drainlines, sampling location for particle size analysis and locations where saturated hydraulic conductivity (K_{sat}) and infiltration rates were measured

Table 1. Average particle size distribution for samples collected from the soil surface to 200 cm depth from the drainfield area of System 1.

DEPTH	SAND	CLAY	TEXTURAL CLASS
cm	%	%	
0-25	69	13	sandy loam
25-50	75	12	sandy loam
50-70	72	12	sandy loam
70-90	75	11	sandy loam
90-132	71	10	sandy loam
132-155	56	18	sandy loam
155-178	79	4	loamy sand
178-200	91	2	sand

In addition, the infiltration rate at the soil surface was measured by the double-cylinder infiltrometer (Amoozegar and Wilson, 1999) at 12 locations along two transects perpendicular to the drainlines. The locations where infiltration rates were measured are shown in Fig. 3.

Monitoring

Soil water content and soil water pressure head (tension) at various depths were measured by time domain reflectometry (TDR) and tensiometry techniques, respectively (Ferré and Topp, 2002;Young and Sisson, 2002). Figure 4 presents a plan view of the relative locations of the monitoring devices in the drainfield area of this system. Three 5-segmented rods for Moisture Point TDR System (Environmental Sensors, British Columbia, Canada) were installed at the center and at the upper and lower edges of one of the subfields. These TDR rods allowed measurement of volumetric soil water content at 0 to 15, 15 to 30, 30 to 60, 60 to 90 and 90 to 150 cm depth intervals outside of the drainfield and at 0 to 15, 15 to 30, 30 to 45, 45 to 60 and 60 to 90 cm depth intervals in the middle of the drainfield. To measure soil water tension, six banks of tensiometers, each containing three tensiometers at 30, 60, and 90 cm depths were installed along a transect perpendicular to the drainlines. One bank of tensiometers was installed above the drainfield, two inside the drainfield and three down gradient (toward the creek) from the drainfield. Three banks of piezometers, each containing two piezometers at two different depths, were installed along a transect going through the middle of each subfield. The depths of the piezometers (varying between 1.07 to 1.88 m for the shallower and between 1.80 to 3.35 m for the deeper ones) were dependent on the depth to water table and our ability to bore a hole below the water table. In addition to the piezometers, three sampling wells were installed below the relatively shallow ground water at three locations. The water table level (static water table level) was measured in these three wells to determine the direction of ground water flow with respect to the position of the creek. Two tension samplers, one at the trench bottom level and the 2nd at 20 cm below the trench bottom were installed at two locations inside one of the subfields. In addition to monitoring/sampling devices, four stations along the creek were selected for collecting surface water for analysis.

Every two weeks, the site was visited and the tensiometers were recharged if needed. One day after this visit, the site was revisited for measurements. During this visit the water meter for the house was read and soil water contents at the depth intervals mentioned above were measured by TDR at each of the three locations. In addition, soil water pressure heads at various depths and locations (at the depth where each tensiometer cup was located) were determined by measuring the tension (vacuum) inside each tensiometer by a Tensimeter (soil Measurement Systems, Tucson, AZ). The level of water in each piezometer and observation well also was measured using a battery operated probe.

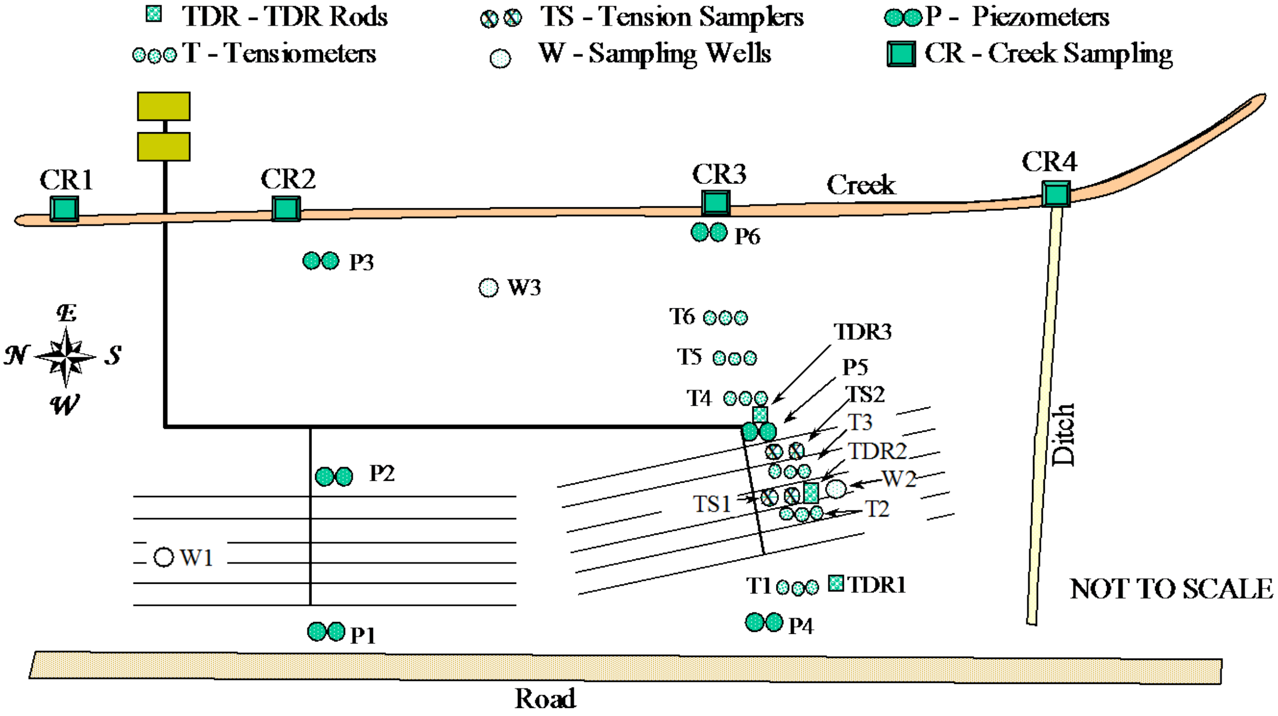

Figure 4. Schematic diagram of the plan view of the septic system at Site 1 showing the relative locations of the drainlines and various monitoring devices.

Once a month, during the initial visit the water in each well and piezometer was bailed out and fresh ground water was allowed to flow in for sampling. In addition, after making sure that no water was present in the tension samplers, using a hand vacuum pump, tension was applied to each tension sampler for collecting soil solution from the unsaturated zone. During the next day visit, a water sample was collected from each of the three wells and 12 piezometers installed at the site. In addition, the content of each tension sampler was collected and a water sample was collected from each of the four locations along the creek (see Fig. 4). These samples were transported to the laboratory. In the laboratory, a subsample was used to measure the pH and electrical conductivity (EC) of each sample using a pH electrode and a conductivity meter, respectively. All the samples were then placed in a refrigerator prior to other chemical analysis. All samples collected from the creek, wells, piezometers, and tension samplers were analyzed for ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), phosphate-phosphorus (PO_4-P), total phosphorus (TP), and total organic carbon (TOC). Ammonium-N was analyzed by the automated phenate method (using salicylate instead of phenate), NO_3-N was analyzed by the automated cadmium reduction method, TKN was analyzed by the Kjeldahl method, and PO_4-P was analyzed by the automated ascorbic acid reduction method following the procedures described in Standard Methods for the Examination of Water and Wastewater (Greenberg et al., 1992). The TOC was analyzed by a TOC analyzer using combustion, and total P was analyzed after digesting the samples.

System 2

The second septic system (hereafter referred to as System 2 or Site 2) served a 4-bedroom single-family home with a design flow rate of 1,815 L/d (480 gal/d). The system had five 90-cm (3-ft) wide conventional trenches and wastewater from the septic tank was applied to the trenches through a pressure manifold (Berkowitz, 1985). The design loading rate for this system was 13 L/(m^2d) or 1.3 cm/d [equivalent to 0.32 gal/(ft^2d)] calculated based on the trench bottom area. The spacing from center to center of neighboring trenches was approximately 2.7 m (9 ft). The vegetative cover for the drainfield area was grass and the buffer area between the drainfield of the system and the creek running adjacent to the drainfield was approximately 15 m wide. Overall, the slope of the land in the drainfield area was approximately 10%.

Soil/Site Characterization

The soils in the drainfield area appeared to be uniform. A series of soil samples was collected for textural analysis. Particle size distributions of these samples were determined by the pipette method, and the results are presented in Table 2. In the drainfield area of this system, the soils in the upper 40 to 45 cm had a sandy loam texture, between 45 and 80 cm the soil texture was loamy sand and below 80 cm the soil texture was sand to loamy sand with very little clay.

Table 2. Average particle size distribution for samples collected from the soil surface to 250 cm depth from the drainfield area of System 2.

DEPTH	SAND	CLAY	TEXTURAL CLASS
cm	%	%	
0-10	65	19	sandy loam
10-40	75	15	sandy loam
40-55	78	9	sandy loam
55-76	78	8	loamy sand
76-110	84	1	loamy sand
110-125	86	< 1	sand
125-135	87	<1	sand
135-172	90	<1	sand
172-191	84	<1	loamy sand
191-216	86	<1	sand
216-232	88	<1	sand
232-250	89	<1	sand

Saturated hydraulic conductivity of three different depth intervals in the unsaturated zone was measured in situ by the constant-head well permeameter technique at two locations in the drainfield area of the system. Double-cylinder infiltrometer technique was used to measure the infiltration rate at 9 locations along two transects. Figure 5 shows the relative locations of these measurements. The drainfield of this system was on a side slope. Within the drainfield relatively flat small areas were selected for infiltration measurements. Outside the drainfield, the land was relatively flat. At all locations the infiltrometer cylinders were pushed into the soil and an adequate depth of water was maintained in both inner and outer cylinders to cover the soil surface within both cylinders. It should be mentioned that, because of the slope of the land in the drainfield area, the depth of water at the lower part of the infiltrative surface was slightly higher than the depth of water in the upper part inside the outer cylinder.

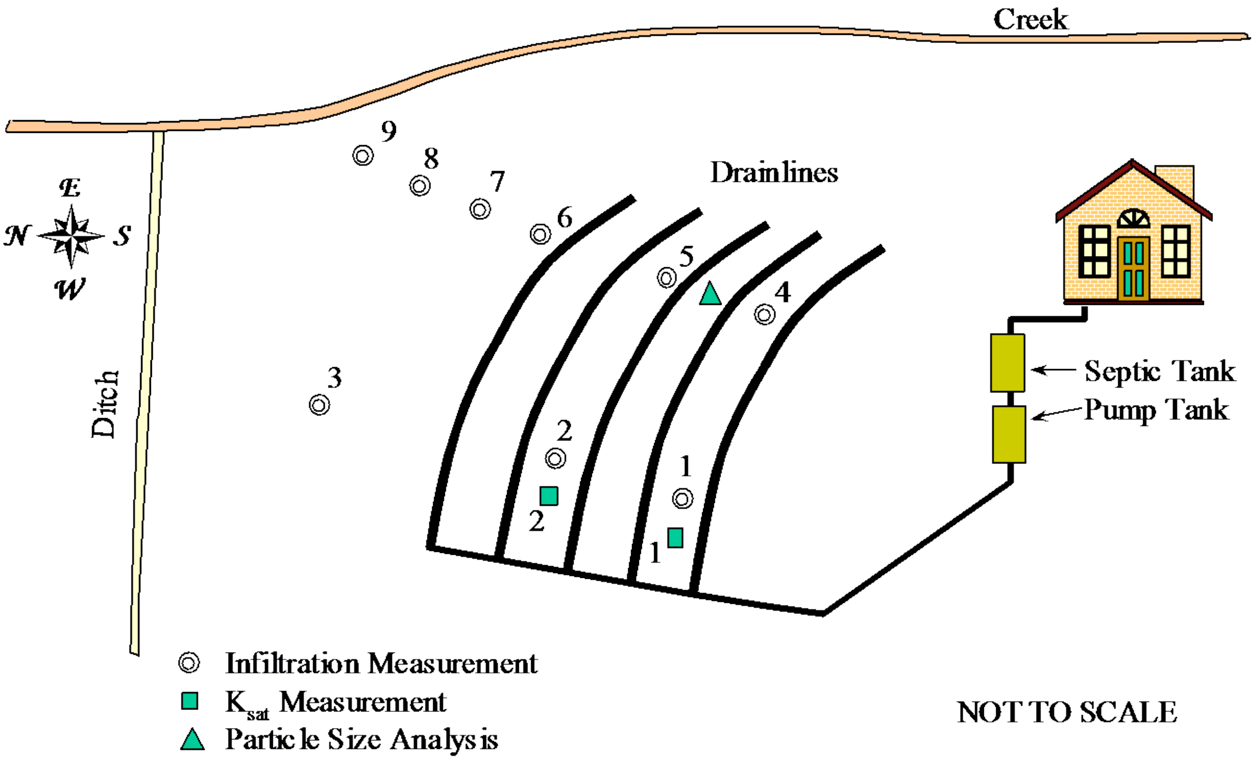

Figure 5. Schematic diagram of the plan view of the septic system at Site 2 showing relative locations of the drainlines, sampling location for particle size analysis and locations where saturated hydraulic conductivity (K_{sat}) and infiltration rates were measured.

Monitoring

Three 5-segmented TDR rods were installed along a transect going from above the first line to below the last line toward the ditch (Fig. 6). The depth intervals for water content measurements inside and outside the drainfield were the same as Site 1. Three banks of tensiometers, each containing tensiometers at 30, 60, and 90 cm depths, were also installed near the TDR rods along the transect. Five tensiometer banks, each with three tensiometers at 30, 60, and 90 cm depths, were also installed along a transect going perpendicular to the drainlines from the top of the drainfield toward the creek (see Fig. 6). In addition, two piezometers at different depths were installed at one location between the drainfield and the ditch and two piezometers at different depths were installed at each of three locations along a transect between the drainfield and the creek. Three observation/sampling wells were installed at the vertices of a triangle in the buffer area between the drainfield and the creek. To sample soil solution from the unsaturated zone under the drainfield two tension samplers, at the trench bottom level and 20 cm below the trench bottom, were installed at two locations in the middle of the drainfield near the tensiometers.

Similar to System 1, this system was visited biweekly for servicing the tensiometers and applying vacuum to the tension samplers. During the next day visit water meter was read, soil water content and pressure head were determined, and water level in each well and piezometer was measured manually. Once a month, a water sample was collected from each well, piezometer, and tension sampler. A water sample was also collected from each of the two locations along the creek at this site. For locations of wells, piezometers, tension samplers, and sampling points along the creek see Fig. 6. All the water samples were analyzed in the laboratory by the procedures described earlier.

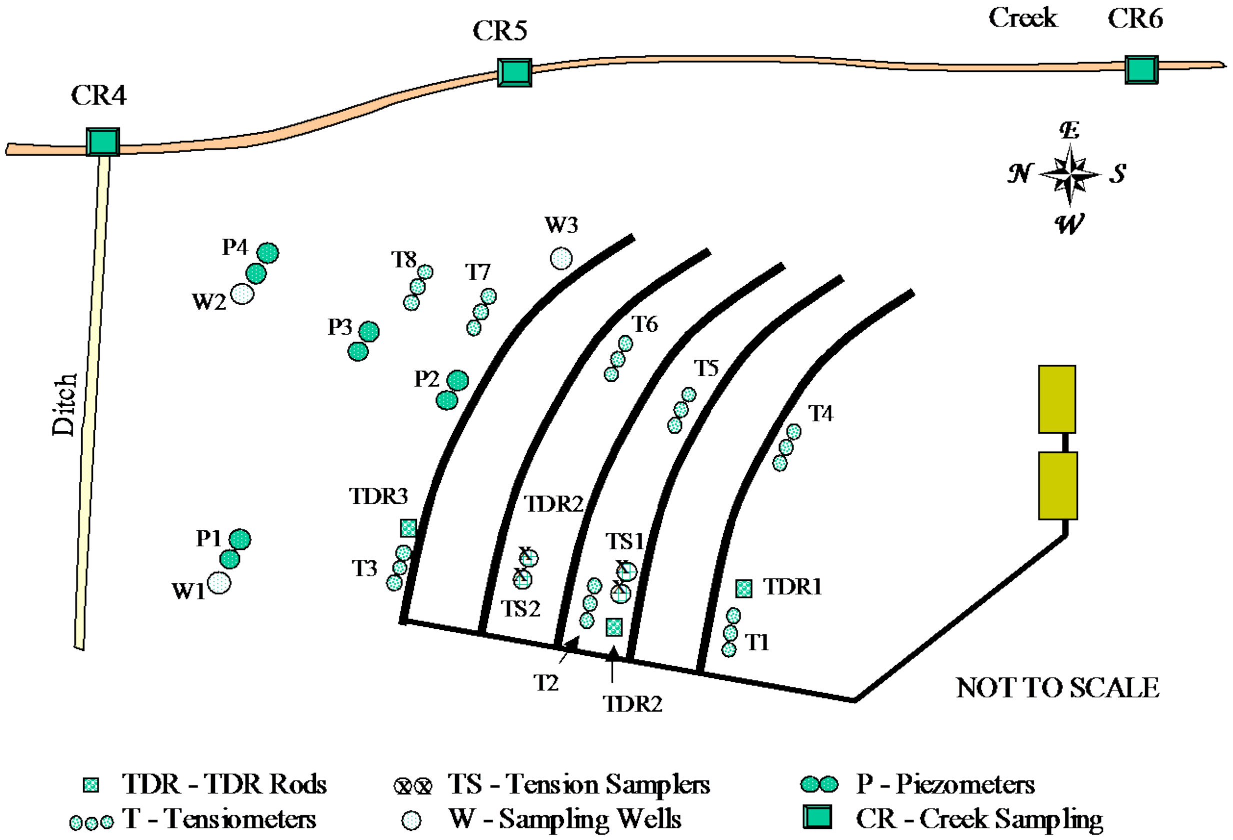

Figure 6. Schematic diagram of the plan view of the septic system at Site 2 showing the relative locations of the drainlines and various monitoring devices.

System 3

The third system was a conventional septic system serving a four-bedroom house located on approximately 5 acres adjacent to a major creek in northern Wake County. The drainfield was composed of two parallel drainlines as shown in Fig. 7. The drainfield area was covered with grass and the surrounding buffer areas on the south and west area of the drainfield were under natural woods. The system was designed for 1,815 L/d (480 gal/d) with a LTAR of 16.25 L/(m^2d) or 1.63 cm/d [equivalent to 0.4 gal/(ft^2d)]. Wastewater from the septic tank moved by gravity into and through the two parallel trenches.

Soil/Site Characterization

The soil in the drainfield area was relatively thick. A series of soil samples was collected from the surface to over 210 cm depth. Particle size distributions of these samples were determined by the pipette method, and the results are presented in Table 3. In the drainfield area the clay content increased with depth and reached a maximum of approximately 35% at 90 to 110 cm depth interval. Blow the Bt, the clay content of saprolite decreased and reached an average value of 5% at 210 cm depth.

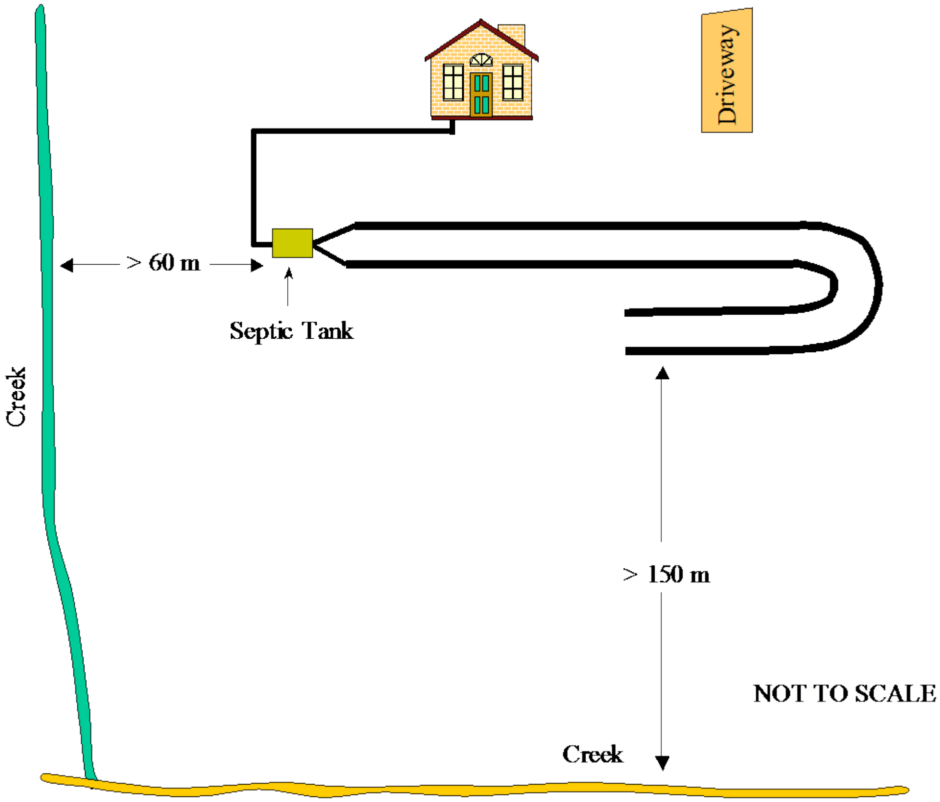

Figure 7. Schematic diagram of the plan view of the septic system at Site 3 showing the relative positions of the trenches with respect to the creeks on two sides.

Table 3. Average particle size distribution for samples collected from the soil surface to more than 210 cm depth from the drainfield area of System 3.

DEPTH	SAND	CLAY	TEXTURAL CLASS
cm	%	%	
0-10	70	10	loamy sand
10-30	63	17	sandy loam
30-50	50	26	sandy clay loam
50-70	45	32	clay loam
70-90	51	32	sandy clay loam
90-110	49	35	sandy clay loam
110-130	64	13	sandy loam
130-150	72	19	sandy loam
150-170	70	16	sandy loam
170-190	73	14	sandy loam
190-210	82	9	loamy sand
210+	85	5	loamy sand

Monitoring

To monitor soil water content in the drainfield four 5-segmented TDR rods were installed to measure soil water content in 0-15, 15-30, 30-60, 60-90, and 90-120 cm depth intervals at four locations above, below and in between the trenches as shown in Fig. 8. Twelve banks of tensiometers, each containing tensiometers at 30, 60, and 90 cm depths were installed along two transects perpendicular to the drainlines. Seven observation wells were installed in the trenches and two sets of tension samplers, each containing a tension sampler at 15 cm (6 in) above the bottom level of the trenches and 20 cm below it, were installed at a distance of 20 cm from the trench side wall. We also installed three observation wells and three piezometers at 3 to 4 m depths. Four stations were selected for collecting water samples from the two creeks at the two sides of the property. For locations of monitoring devices see Fig. 8.

The site was visited biweekly from June, 2002, to July, 2003. During these visits the water meter was read, and soil water content and pressure heads were measured using the TDR and tensiometry. The level of ponding in all seven observations wells inside the trenches and the level of water in each of the monitoring wells and piezometers were also determined manually. Similar to the other sites, once a month, soil solution samples were collected from the tension samplers, wells, piezometers, and at four locations along the creek. All samples were transported to the laboratory and analyzed by the procedures described earlier.

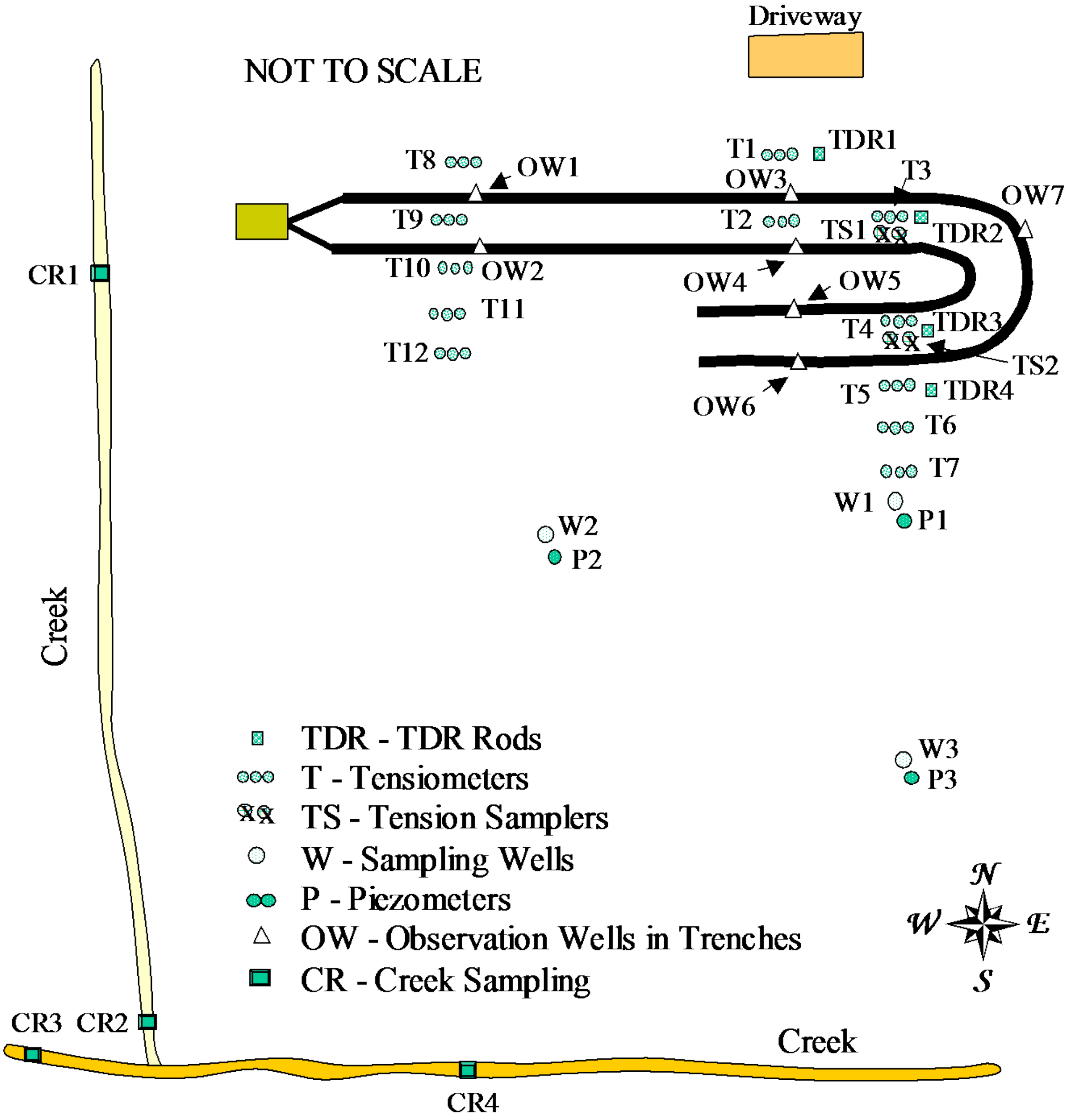

Figure 8. Schematic diagram of the plan view of the septic system at Site 3 showing the relative locations of the drainlines and various monitoring devices.

RESULTS AND DISCUSSION

System 1

Based on the reading of the water meter from August, 2001, through July, 2003, an average of approximately 530 L (140 gallons) of effluent was applied to the drainfield area per day. This amount represents 40% of the design flow for the system. Only once during two years of monitoring this system the average daily water consumption during a two-week period exceeded 1,100 L (300 gallons).

Saturated Hydraulic Conductivity and Infiltration Rate

As mentioned earlier, the drainfield of this system was located in a relatively flat area near a creek. Table 4 presents the K_{sat} values for various depths above the water table at four locations. Although the soil texture at this site did not change significantly with depth in the upper 150 cm, the K_{sat} values were in general higher in the upper 40 to 60 cm than deeper depths. Only at one location the K_{sat} between 70 and 85 cm depth was higher than the K_{sat} of the shallower depths. Overall, the K_{sat} of the upper 60 cm of the soil was high enough that no wastewater ponding was expected to occur within the trenches of the system. The lowest measured K_{sat} (1.6 cm/d) was for the 90 to 105 cm depth interval and was 4 times higher than the area loading rate for the system. Based on these K_{sat} values, we expect all the applied wastewater to the drainfield to infiltrate the trenches and move vertically into the ground water.

Table 4. Saturated hydraulic conductivity (K_{sat}) of different depth intervals at four locations within the drainfield area of System 1. For measurement locations see Fig. 3.

LOCATION	DEPTH	K_{sat}	EQUIVALENT TO K_{sat}
	cm	cm/d	gal/(ft^{2}d)
1	50-66	11.1	2.7
	90-105	1.6	0.4
	142-158	6.2	1.5
2	50-65	28.1	6.9
	67-85	4.2	1.0
3	46-61	28.3	7.0
	70-85	188	46.3
	92-108	1.85	0.5
4	50-65	6.0	1.5
	70-85	2.8	0.7
	90-106	2.1	0.5

The soil surface infiltration rates at 12 locations (see Fig. 3) are presented in Table 5. In general, the infiltration rate in the upper part of the drainfield was lower than areas near the creek. If there is no runoff from other areas (e.g., the road above the drainfield) into the drainfield, we do not expect to have a substantial amount of runoff from the drainfield area into the creek, except during high intensity rainfall events. Due to relatively high infiltration rate over the drainfield area, we expect most of the rainfall to infiltrate and move vertically into the shallow ground water at this site.

Table 5. Infiltration rates at 12 locations within the drainfield area at Site 1

Location	Infiltration Rate
	cm/h
1	8.3
2	0.4
3	1.3
4	21.3
5	15.5
6	30.0
7	0.7
8	2.9
9	0.7
10	1.8
11	2.6
12	100.8

Water Table Elevation

The water levels in the three wells representing the water table surface, with the dashed-line representing the relative elevation of the bottom of the creek at a reference location near CR4 (see Fig. 3) are shown in Fig. 9. In general, the water table elevation fluctuated with season. At location 2, which was in the middle of a subfield, water table was mostly above the bottom of the creek. At location 3 near the creek and at the edge of the other subfield, on the other hand, the water table was below the bottom of the creek for a few months during dry periods. Higher water level at location 2 could be the result of mounding due to wastewater application to the drainfield. Based on a three-point water table analysis, during the wet periods, ground water flow was generally in the west to east direction toward the creek. At other times, ground water flow was mostly from south to north parallel to the creek. Based on the results during the dry periods when water table is low, we do not believe significant amount of pollutants from this drainfield moves laterally toward the creek on the property.

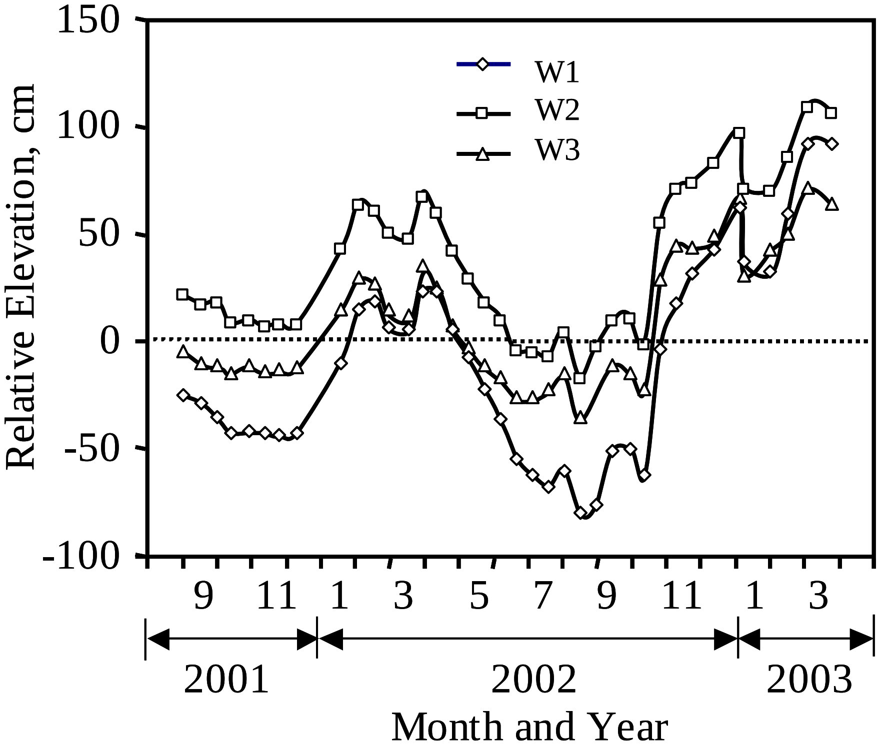

Figure 9. Water table relative elevations at three locations from September 2001 to April 2003 for Site 1. The elevation of the bottom of the creek at location marked CR4 in Fig. 4 was selected as the reference location with zero elevation (shown as dashed-line).

The water levels in the two piezometers, representing the pressure head (submergence potential) at two depths for each of 6 locations along two transects are shown in Figs. 10 and 11. In all the figures, “a” represents the deeper and “b” represents the shallower piezometer at each location. [For the locations of the piezometers see Fig. 4.] Overall, there was a good agreement between the water table elevation in Well #2 and pressure heads measured in Piezometer 5 near the one subfield (for locations see Fig. 4). There was virtually no difference between the pressure heads at two different depths at each of locations 2 and 5 near the subfields. The most difference in the pressure head in vertical direction was observed at location 4 above the drainfield (Fig. 11). Based on our observation of ground wetness at the south-west corner of the drainfield area (near location 4), it appears that this area is a ground water discharge area from up slope of the property.

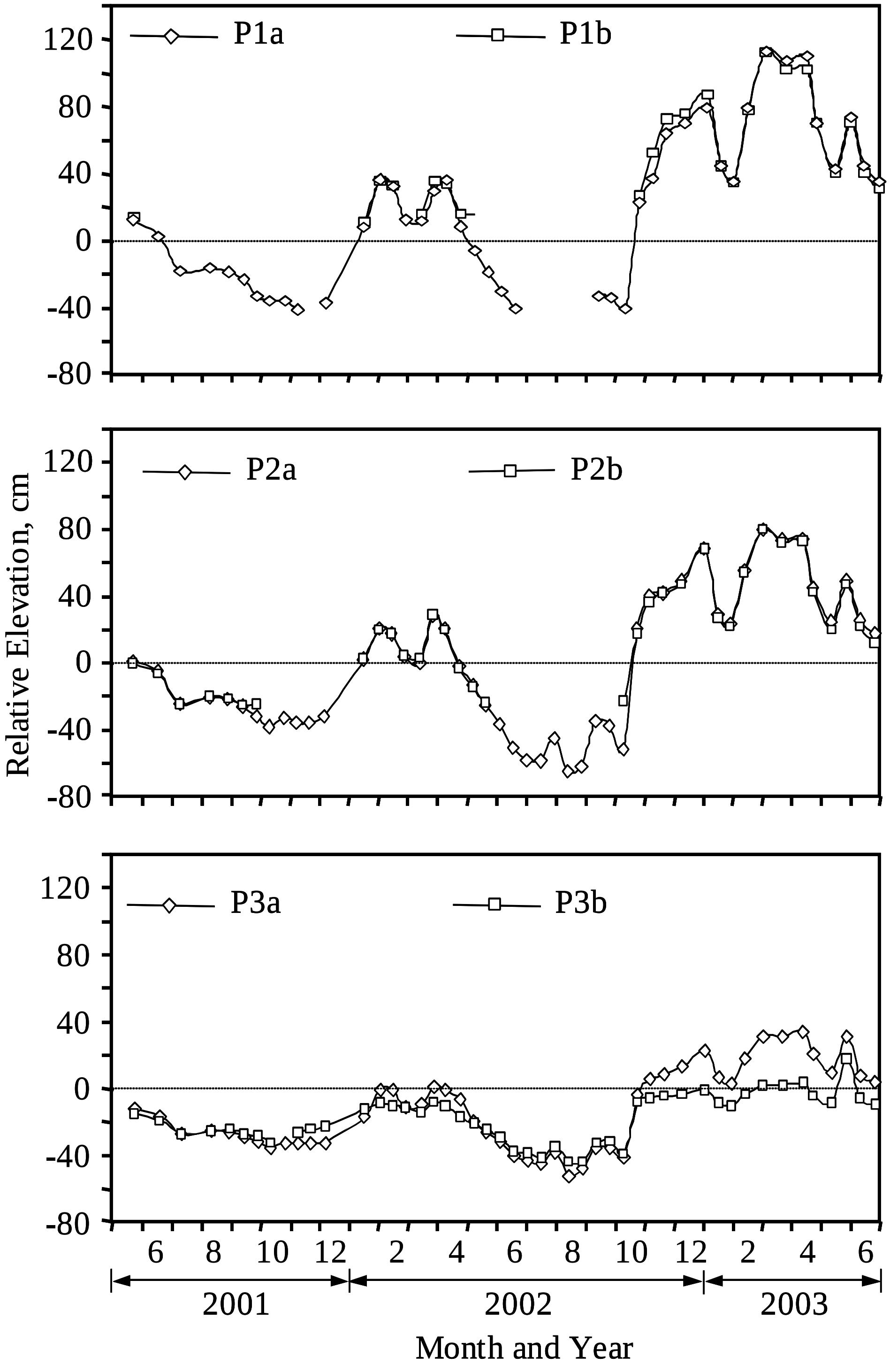

Figure 10. Relative elevations of the water level in the piezometers representing the relative pressure heads for two different depths at three locations along a transect perpendicular to the drainlines in one subfield at Site 1. In this figure, “a” represents the deeper and “b” represents the shallower piezometer at each location. Also, no data point is shown for any date when the piezometer was dry.

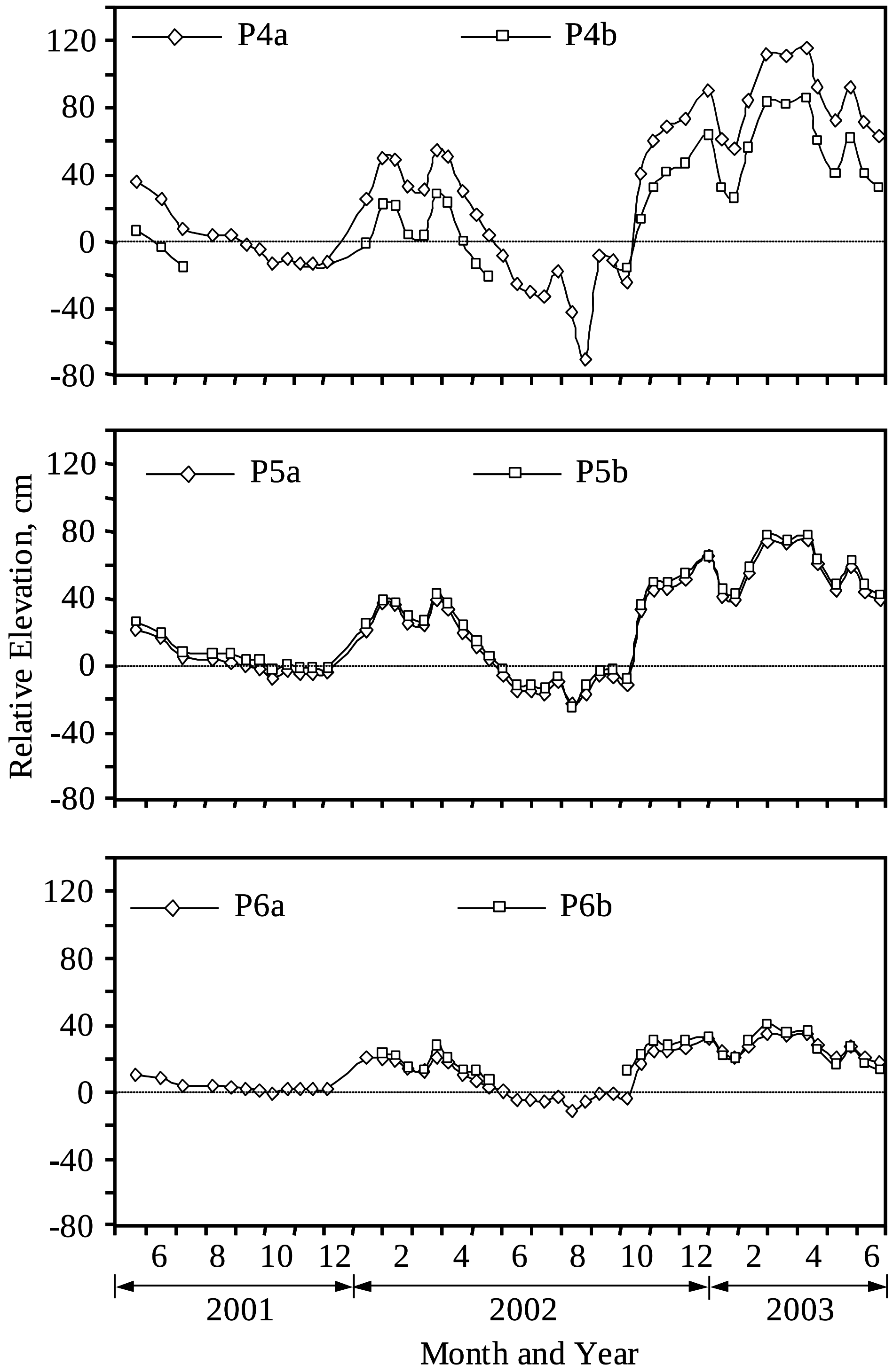

Figure 11. Relative elevations of the water level in the piezometers representing the relative pressure heads for two different depths at three locations along a transect perpendicular to the drainlines in the second subfield at Site 1. In this figure, “a” represents the deeper and “b” represents the shallower piezometer at each location. Also, no data point is shown for any date when the piezometer was dry.

Soil Water Content and Pressure Head

The soil water content measured in situ showed moderate variability with depth and time for each of the locations. Figure 12 presents the soil water contents measured at five depth intervals for each of three locations inside and outside one of the subfields. At the location above the drainfield, the soil water content at all five depth intervals showed similar trends. In general, the wettest zone was the 90 to 120 cm depth interval. Overall, the soil water content at each depth interval was relatively low during the summer months and relatively high during the winter when evapotranspiration is low.

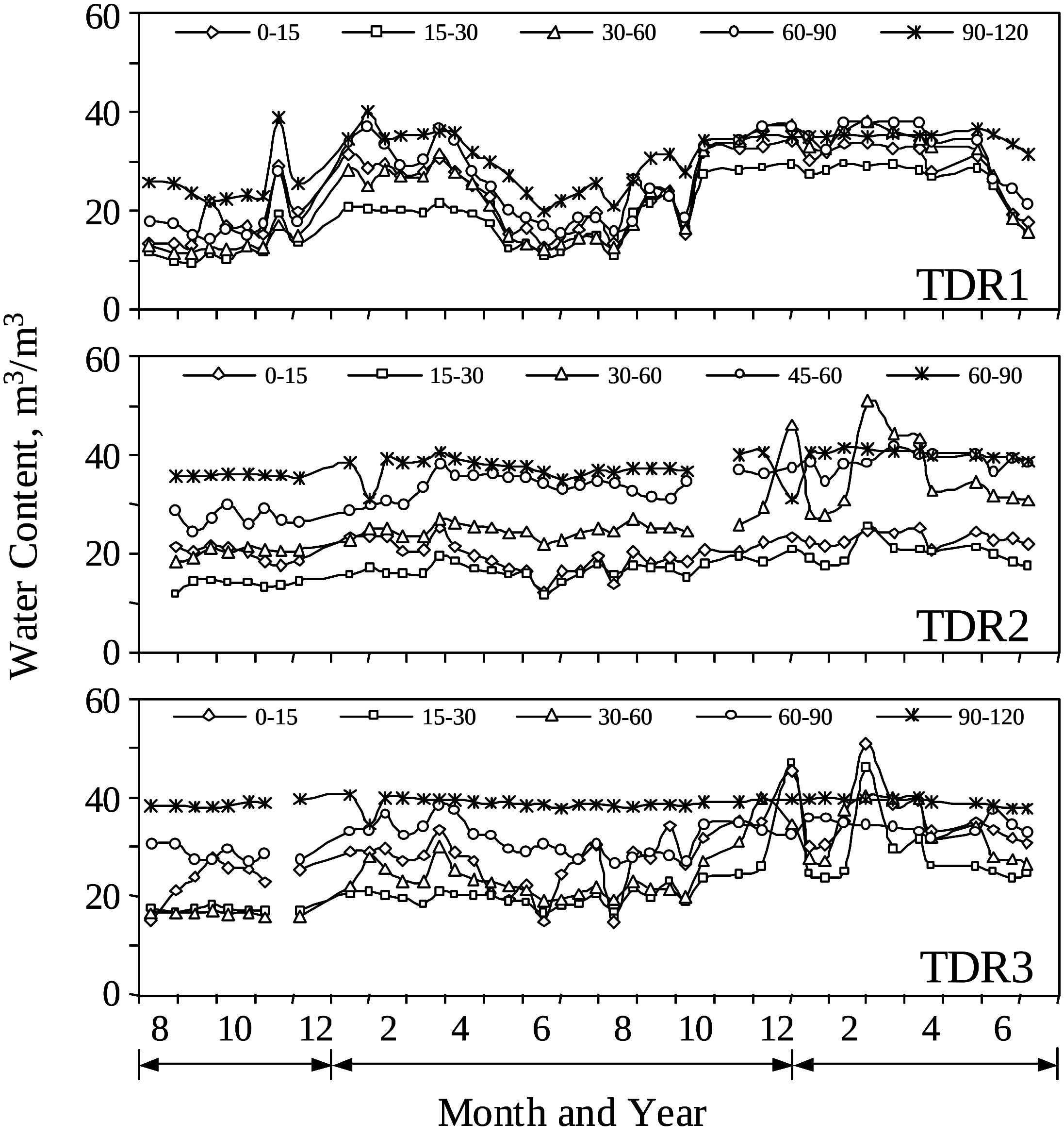

Figure 12. Soil water contents at five depth intervals measured in situ by the TDR technique at three locations at Site 1. For locations of the TDR measurements see Fig. 4.

In the middle of the drainfield, water content in the upper 45 cm showed more variation than water content at 60 to 90 cm depth interval. At the 60-90 cm depth interval water content was the highest (average value of 0.37 m^3/m^3) and remained relatively constant (CV^1 = 6.5%). The trenches of this system were approximately 45 cm deep. The average water content at 45-60 cm depth interval was 0.34 m^3/m^3. Since water table was relatively shallow in the middle of the drainfield, the water content at 60 to 90 cm depth interval remained relatively constant. The same was true for the water content at 90 to 120 cm depth interval below the drainfield. The average water content at this depth interval at location 3 was 0.38 m^3/m^3 with a CV of only 2.5%. Similar to the other locations, the lowest water content was detected in the 15 to 30 cm depth interval (see Fig. 12).

We did not calibrate the TDR system for this site or other sites. As a result, the individual water content values may be different than actual water content. However, for each depth interval and location, the water content values relative to each other present the status of soil water content at that depth interval. For example, the measured water content at 15 to 30 cm depth interval was generally lower than other depths, and the values were as low as less than 10% on volume basis. Ten percent water content on volume basis seems to be rather low for the type of soil at our study site. Despite of this, we believe the values presented in Fig. 12 show the real trend among the individual values for each depth interval.

The soil water pressure heads at three depths for six locations along a transect going through the subfield are shown in Fig. 13. At location 1 above the drainfield, the soil water pressure head was close to zero or slightly negative from December, 2001, through April 2002, and from November 2002, through early March, 2003. At other times the soil water pressure head was mainly negative. As a reference, soil water pressure head of zero or positive indicates saturation, and negative soil water pressure head indicates unsaturated conditions. Also, in general, soil water pressure heads between -100 and -330 cm indicates field capacity. In general, soil water pressure head at this location increased with depth, and there was a good agreement between the trends of the soil water pressure head and the soil water content measured by TDR.

At location 2 within the drainfield (see Fig. 4), the soil water pressure head was mostly negative, indicating unsaturated conditions. Although there was not a substantial difference between the summer and winter months, the soil water pressure head was generally lower in the summer months as compared to winter months. Also, in general, soil water pressure head increased with depth, indicating higher soil water content at deeper depths. Similar results were obtained for location 3 inside the drainfield. These results, consistent with the soil water content results, indicated that although soil water content inside the drainfield was relatively high, unsaturated conditions persisted in the upper 90 cm of the soil, particularly during the summer months.

Locations 4, 5, and 6 were between the drainfield and the creek (see Fig. 4). The pattern of soil water pressure head distribution with time was relatively the same for all locations (Fig. 13). Although slightly more wet, the pattern was similar to the patterns for the two locations inside the drainfield.

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[1] CV = coefficient of variation or coefficient of variability. CV = 100 × standard deviation/mean

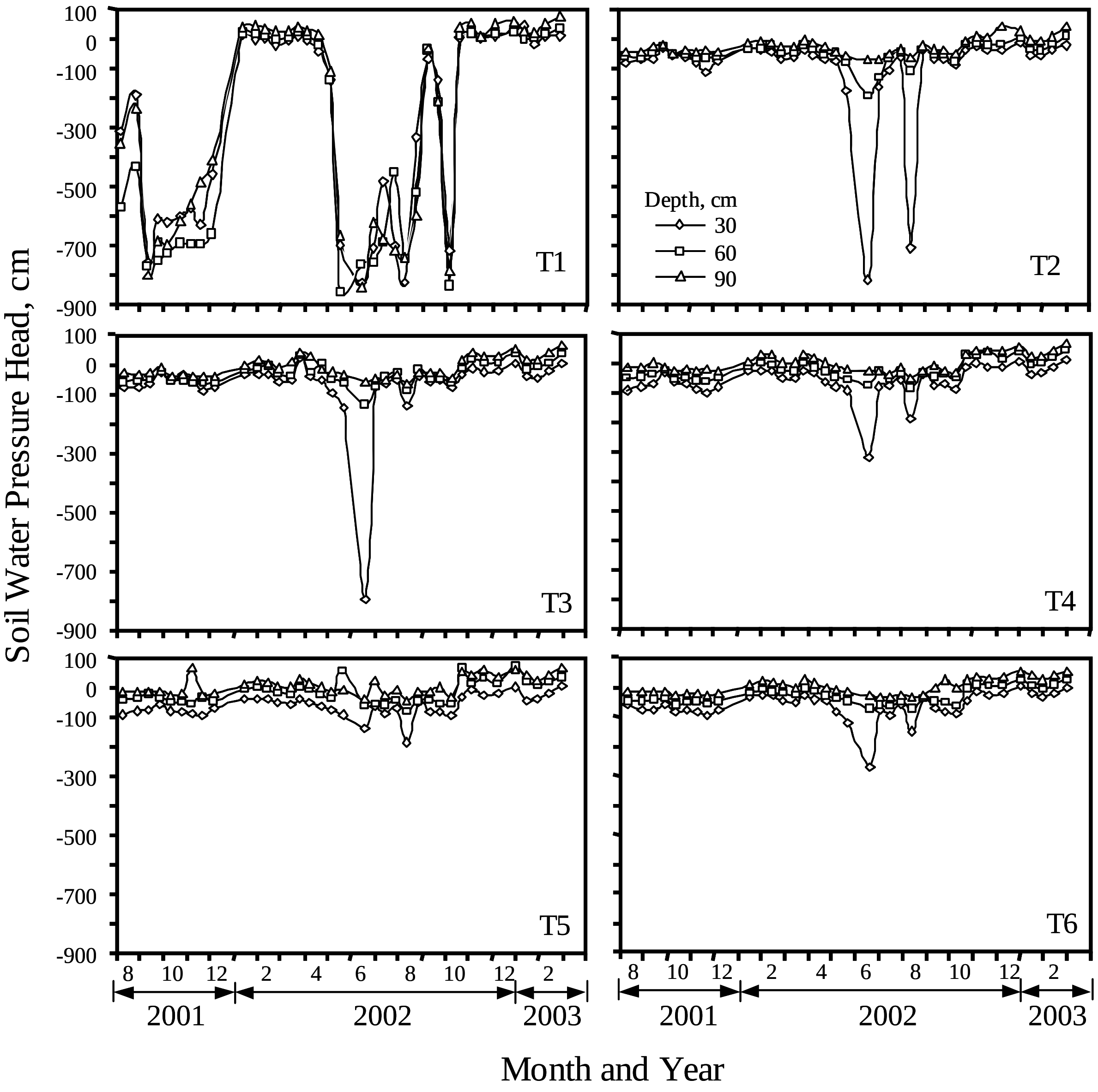

Figure 13. Soil water pressure heads for three depths at six locations along a transect going through one of the subfields at Site 1. The number in each graph represents the location of the tensiometer bank (see Fig. 4).

Distribution of Chemical Constituents

Acidity (pH) and Electrical Conductivity (EC): The pH of the water samples collected from November, 2001, to June, 2003, at four locations in the creek near the drainfield at Site 1 (Fig. 14) varied between 5.7 and 6.8 with an average of 6.4. The ground water and soil solution samples had a lower pH than the surface water in the creek. The average values for the ground water samples collected from the three wells were 4.9, 5.6, and 5.4 for Wells #1, 2, and 3, respectively. The average values for the water samples collected from all 12 piezometers for the duration of monitoring was 5.5, and the average for the four tension samplers was 5.3. In general, the pH values for the water samples collected from wells fluctuated more than the ones for the piezometers. The pH values for all the samples collected from wells, piezometers, and tension samplers are presented in Appendix A.

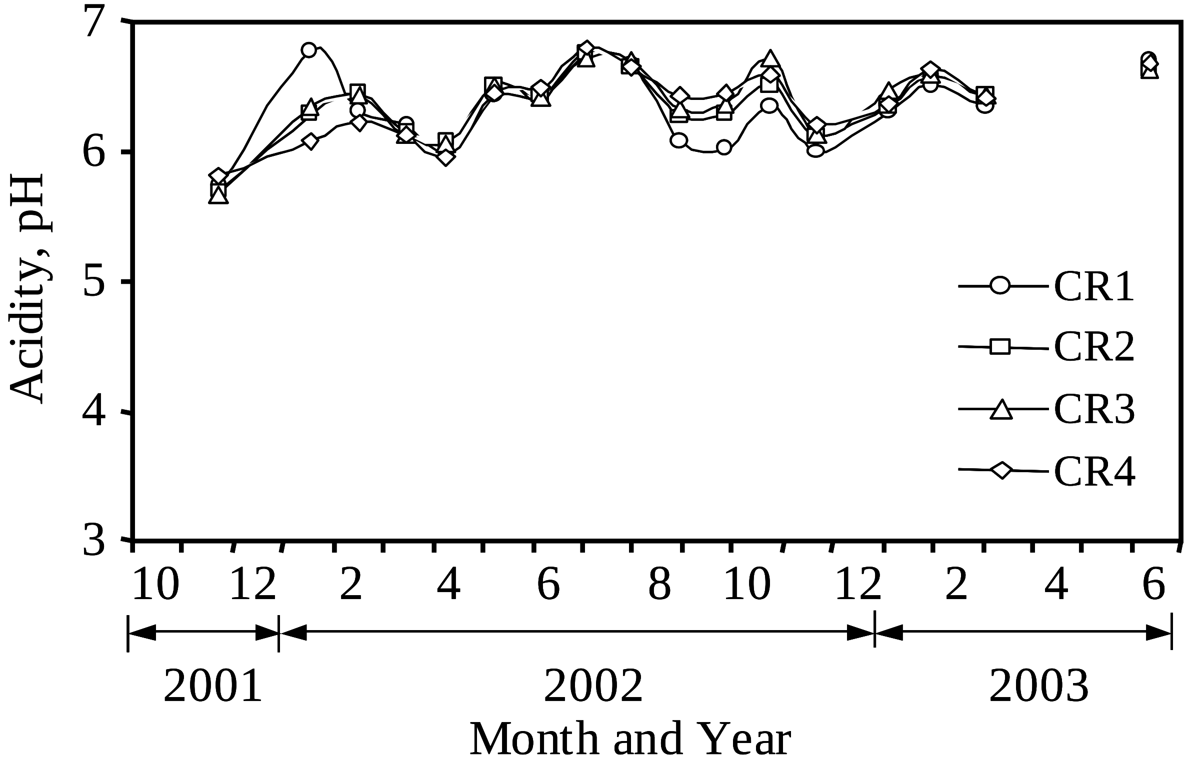

Figure 14. The acidity (pH) of the water at four locations in the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

The electrical conductivity (EC) of the water samples collected from four locations in the creek remained relatively low and did not vary substantially for the duration of monitoring (Fig. 15). The water samples collected from Well #1 installed inside the drainfield, however, had relatively high EC values (average of 835 µS/cm or µmhos/cm) while the water samples collected from Well # 3 near the creek had low EC values (average = 168 µS/cm). Similarly, the water samples collected from the piezometers installed near or in the middle of the subfields had substantially higher EC than the water samples collected from the piezometers installed near the creek. The average EC of soil solution samples collected from the unsaturated zone near the bottom of the trenches at locations 1 and 2 shown in Fig. 4 were 754 and 506 µS/cm, respectively. In contrast, the soil solutions collected from the zone above the bottom of the trenches at locations 1 and 2 (see Fig. 4) had average EC values of 115 and 198 µS/cm, respectively. The EC results for the wells, piezometers and tension samplers are shown in Appendix A.

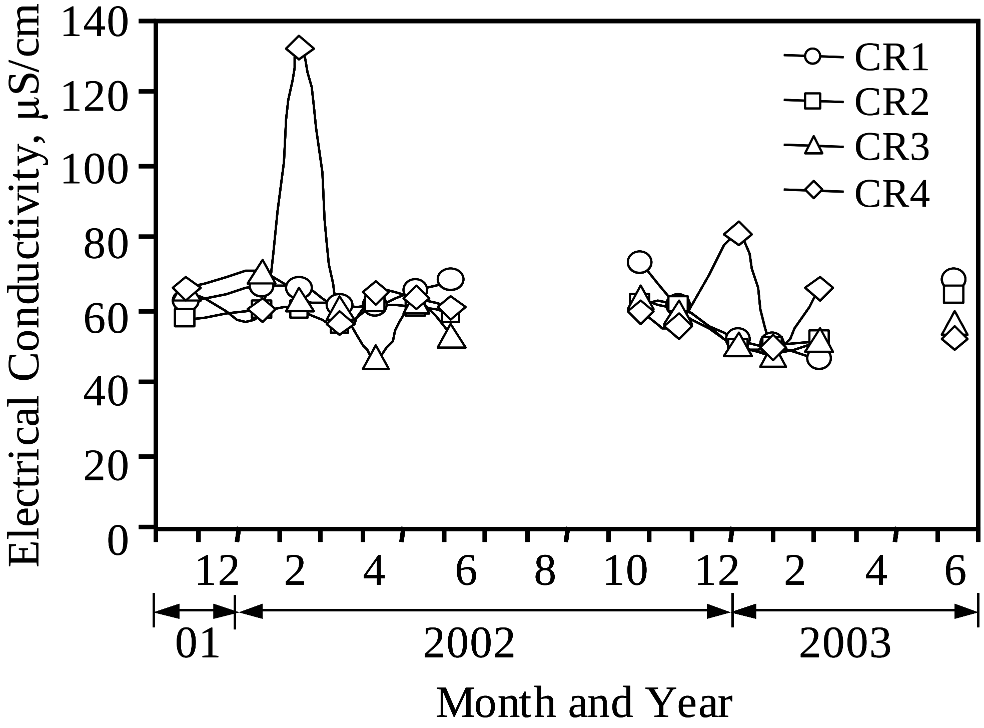

Figure 15. Electrical conductivity of water at four locations in the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

In general, electrical conductivity represents the amount of total dissolved solutes in a solution. The results indicate that dilution is perhaps the main reason for the reduction in the solute concentration in ground water moving from the drainfield toward the creek. The same type of results were obtained for specific inorganic chemicals.

Ammonium (NH_4-N) and Nitrate Nitrogen (NO_3-N): Except for two sampling periods, the concentrations of NH_4-N in the water samples collected from the four locations in the creek remained relatively small with an overall average of 0.2 mg/L for all four locations (Fig. 16). In the unsaturated zone, the level of NH_4-N remained less than 1 mg/L for most of the monitoring period (Fig. 17). In the ground water, on the other hand, relatively high levels of NH_4 were observed in Well #2 in the middle of one of the subfields (Fig. 18). In the water samples collected from Well #3 near the creek (see Fig. 4), the concentration of NH_4-N was generally low, and reached a high value of 3.4 mg/L only once. Except for one sampling date, the level of NH_4-N in the water samples collected from two different depths at six locations (using the piezometers) remained less than 1.2 mg/L (Appendix A). In Figs. 16-18 all values shown as 0.05 mg/L were below detection limit of the analysis.

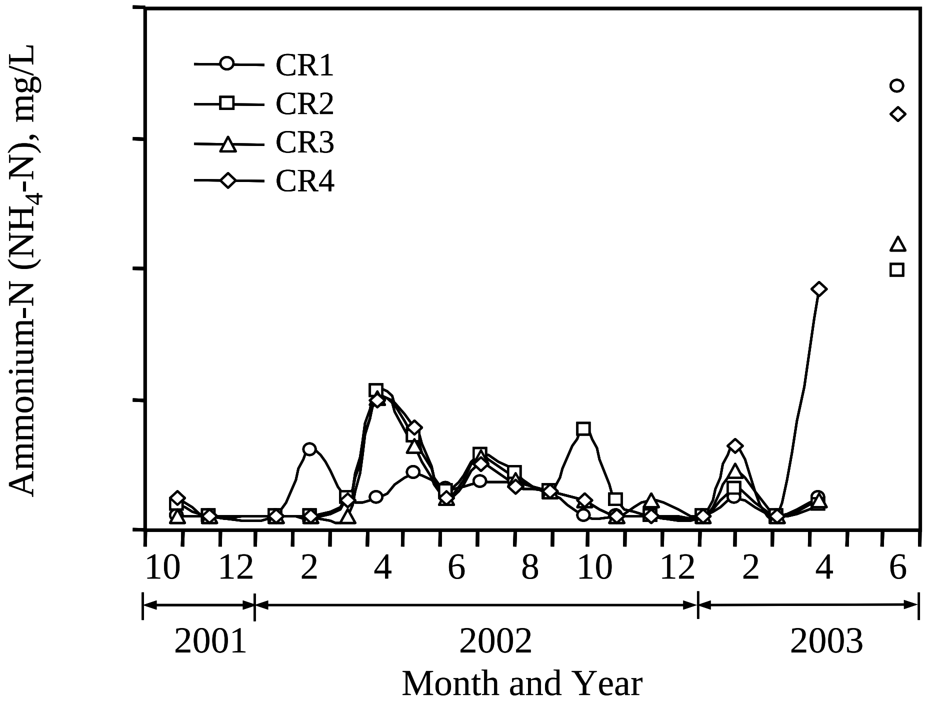

Figure 16. Ammonium-N (NH_4-N) concentrations in water at four locations in the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

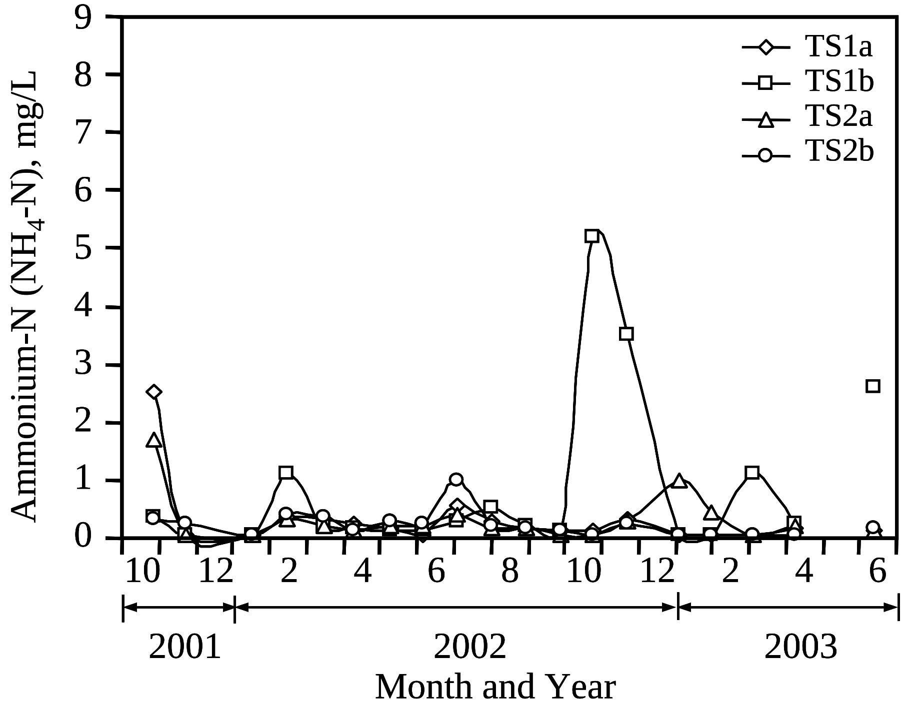

Figure 17. Ammonium-N (NH_4-N) concentrations in soil water collected from two depths at two locations near the trenches of System 1. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

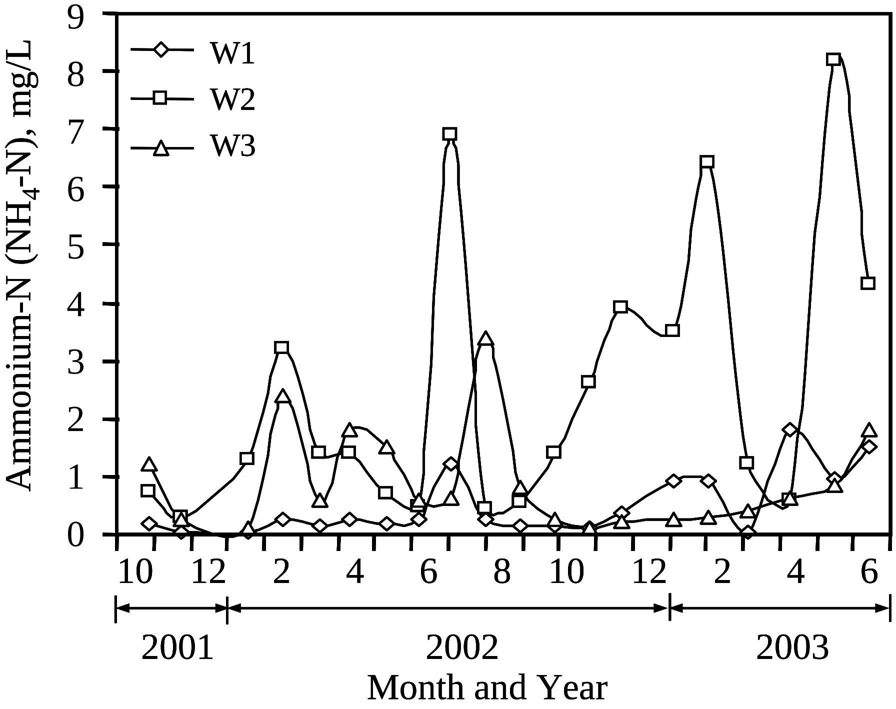

Figure 18. Ammonium-N (NH_4-N) concentrations in ground water collected from three sampling wells in the drainfield area of System 1. For sampling locations see Fig. 4.

The nitrate-N levels in the ground water samples from the wells and the tension samplers were substantially higher than their corresponding NH_4 levels (Fig. 19). Higher concentrations of nitrate was observed during the winter and spring than summer and fall. This is particularly true for ground water samples collected from Well #3 between the drainfield and the creek. In the creek, however, the NO_3-N levels remained below 0.5 mg/L for the duration of monitoring (Fig. 20). The nitrate levels in water samples collected from the piezometers installed adjacent to the drainfield on the creek side were substantially higher than the other locations (Fig. 21). In general, lower nitrate levels were observed during the summer months. This could be due to higher nutrient uptake of plants, or higher microorganism activities, although the possibility of higher leaching and a greater dilution due to summer rains cannot be ignored.

Phosphate -P (PO_4-P): The levels of PO_4-P in the ground water or soil solution samples collected from the wells and tension samplers rarely exceeded 1 mg/L. With one exception, the levels of PO_4-P in the samples collected from the piezometers remained below 0.25 mg/L during the monitoring period. The total P concentrations in the water samples from the wells or tension samplers were less than 1 mg/L for most of the times. The total P levels in samples from the piezometers exceeded 1 mg/L a few times, and in general had high variability during the sampling period. The concentrations of PO_4-P and total P in the creek samples were less than 0.1 and 0.16 mg/L, respectively, for the entire monitoring period. Concentrations of PO_4-P and total P in all the samples from creek, wells, piezometers and tension samplers are presented in Appendix A.

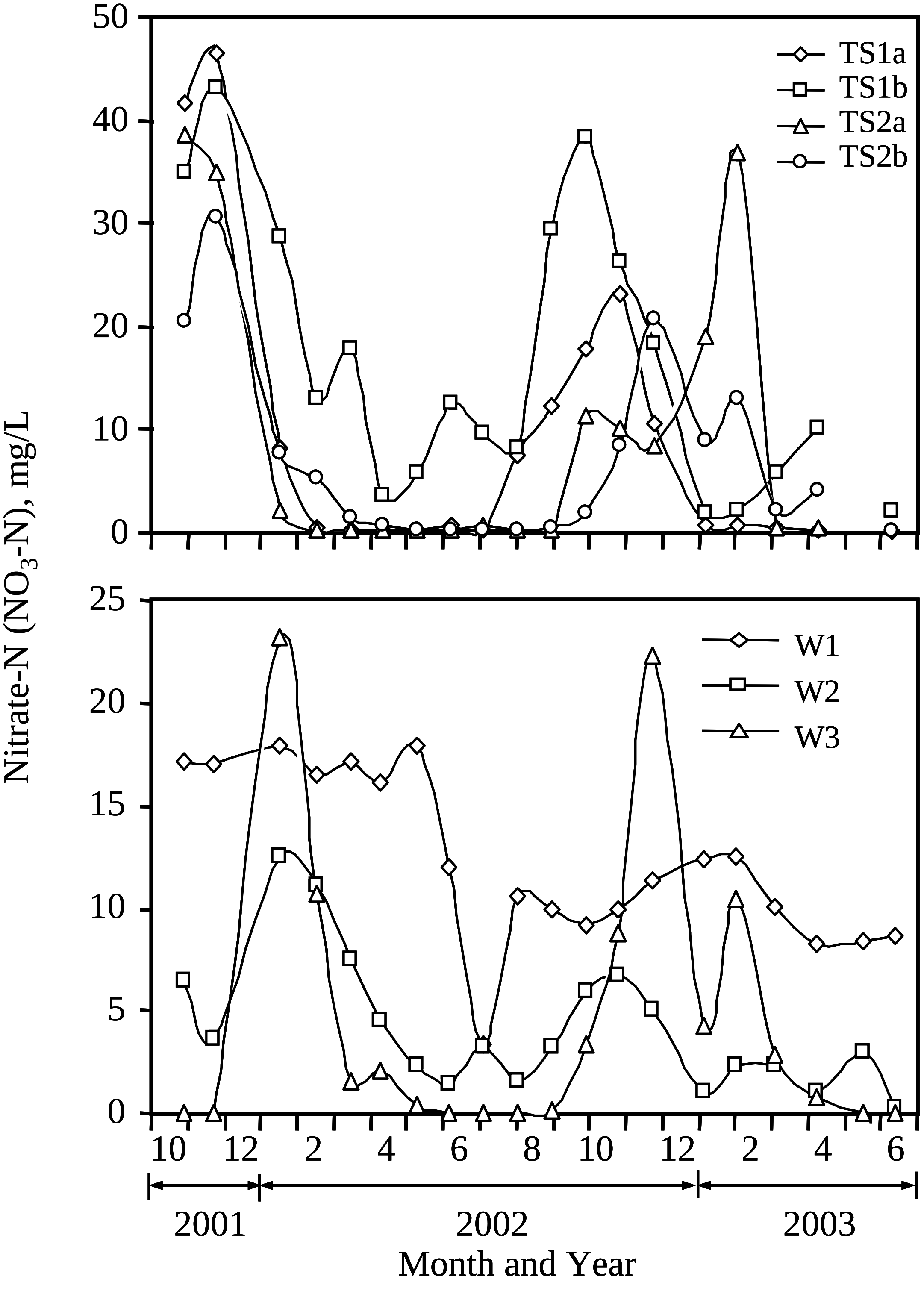

Figure 19. Nitrate-N (NO_3-N) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 1. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

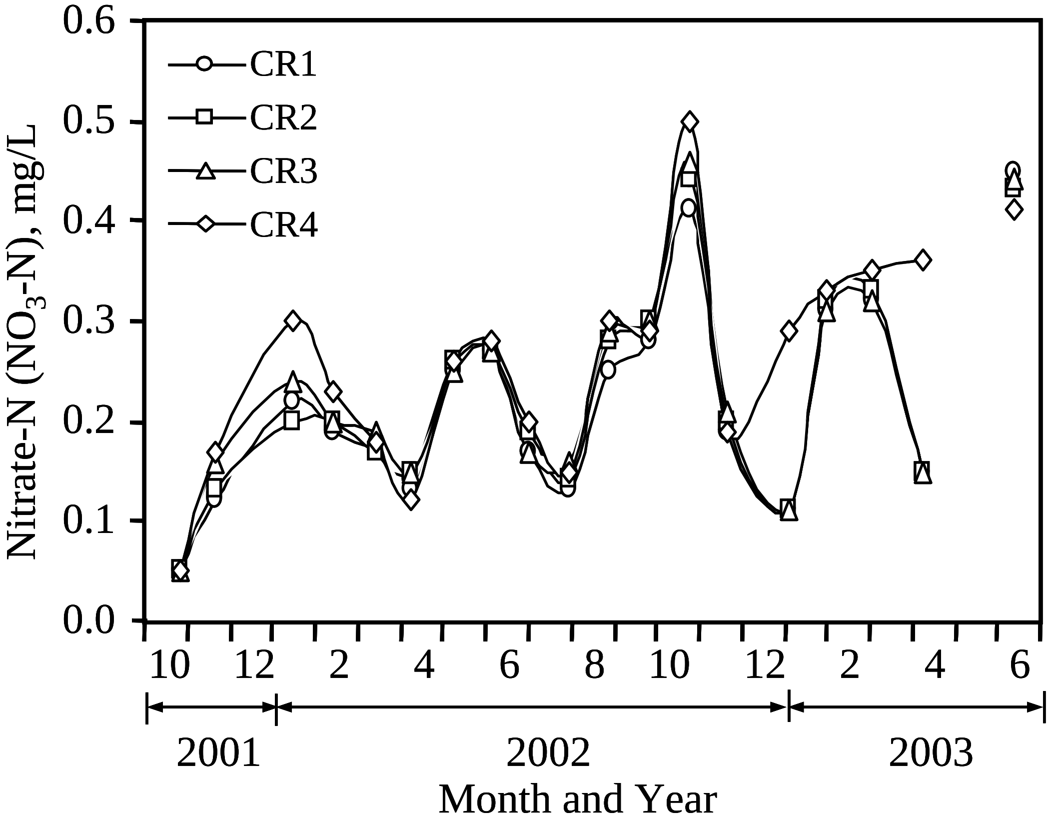

Figure 20. Nitrate-N (NO_3-N) concentrations in water samples collected at four locations in the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

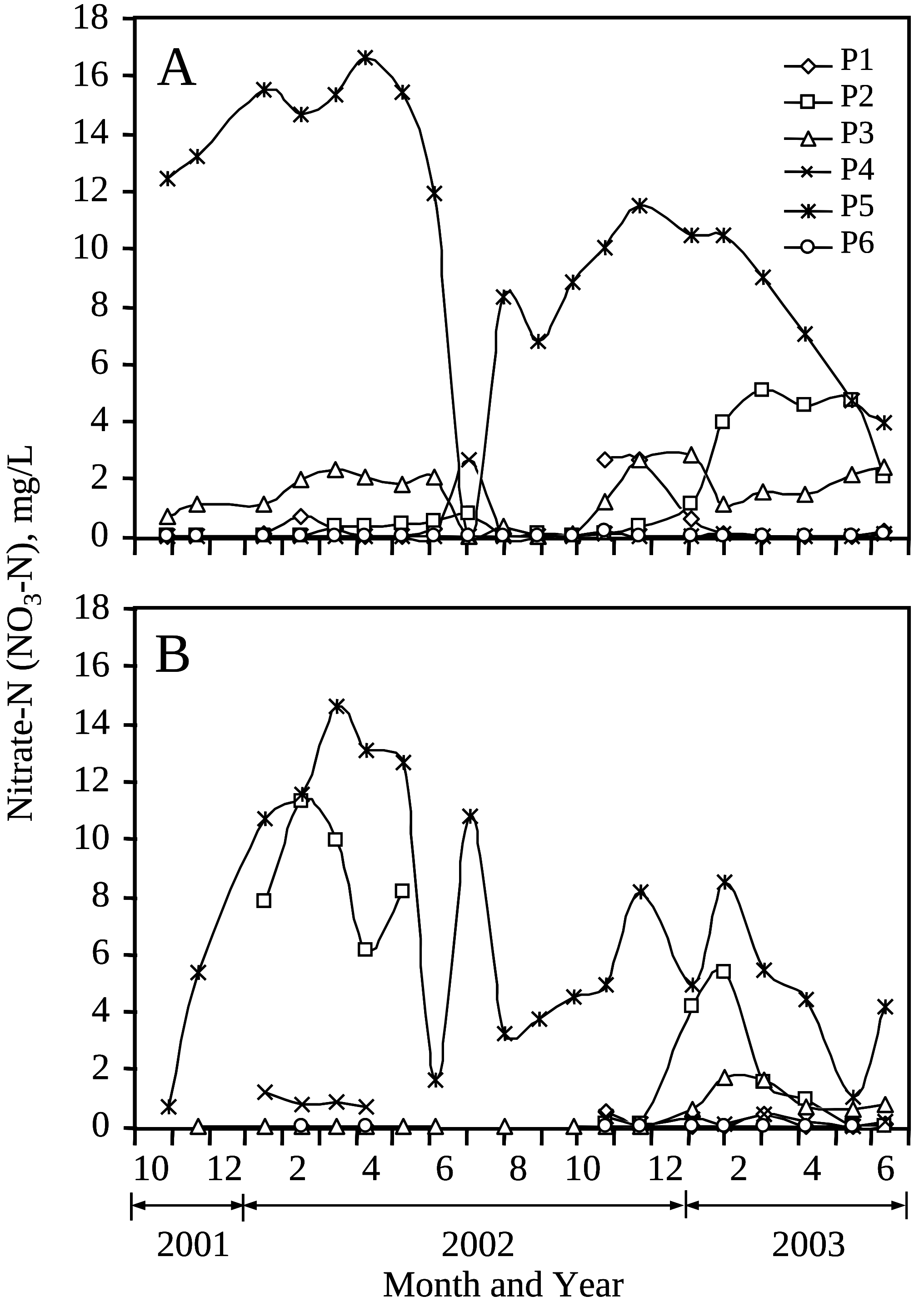

Figure 21. Nitrate-N (NO_3-N) concentrations of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

Total Organic Carbon (TOC): The concentrations of total organic carbon (TOC) showed an interesting trend for all the samples collected from the creek (CR), tension samplers (TS), wells (W), and piezometers (P) (Fig. 22, 23, and 24). In all cases, a significant increase in TOC concentration was observed from late September through December, 2002. Relatively higher concentrations were also observed for two sampling periods in late October and November of 2001, followed by a substantial reduction in TOC concentrations in January, 2002, sampling date. Because we do not have multiple year results, we cannot draw a firm conclusion as to the reason for such an increase. However, the same trends were observed in the TOC results for the other two sites. We revisited our sampling protocol and the analytical technique employed for analyzing TOC. Although we believe our sampling and analytical techniques were appropriate, we cannot rule out the possibility of invalid data. At the same time, we suspect that this could be a natural phenomenon and higher TOC values for samples were related to the actual high concentration of TOC in surface and ground water at all three sites.

Except for the two periods that showed high TOC levels in surface water, soil water, and ground water samples; the levels of TOC at Site 1 were mostly below 10 mg/L (see Figs. 22-24).

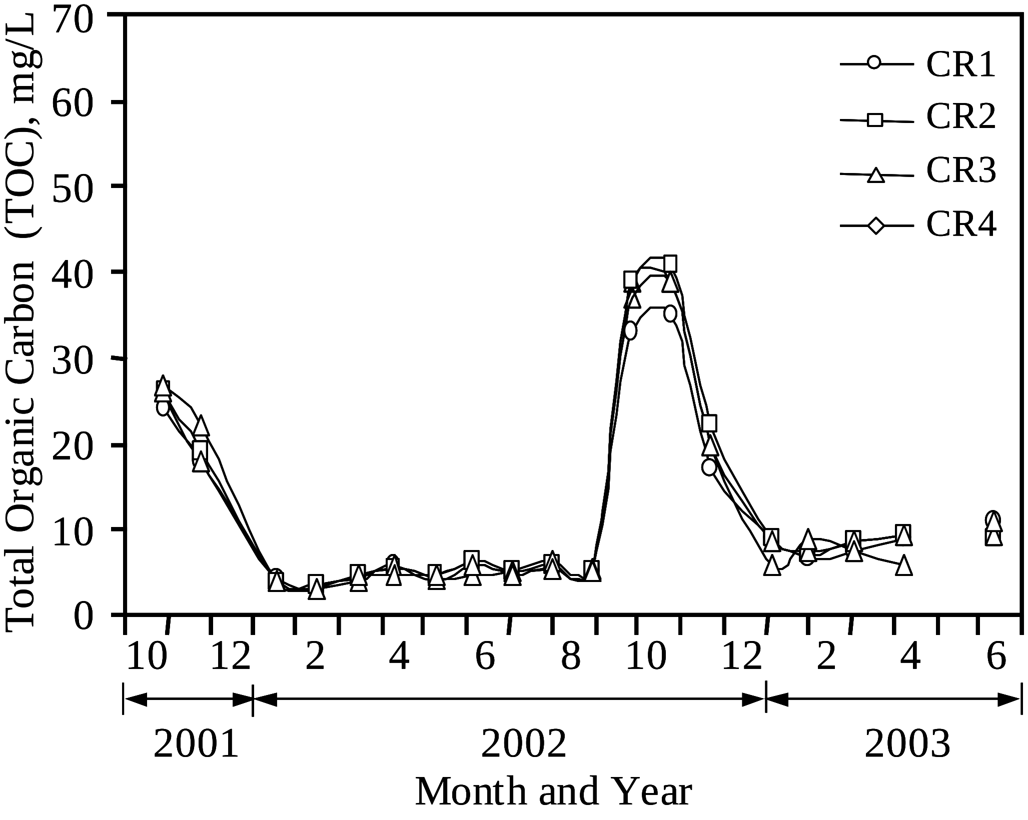

Figure 22. Total organic carbon (TOC) concentrations in water samples collected at four locations in the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

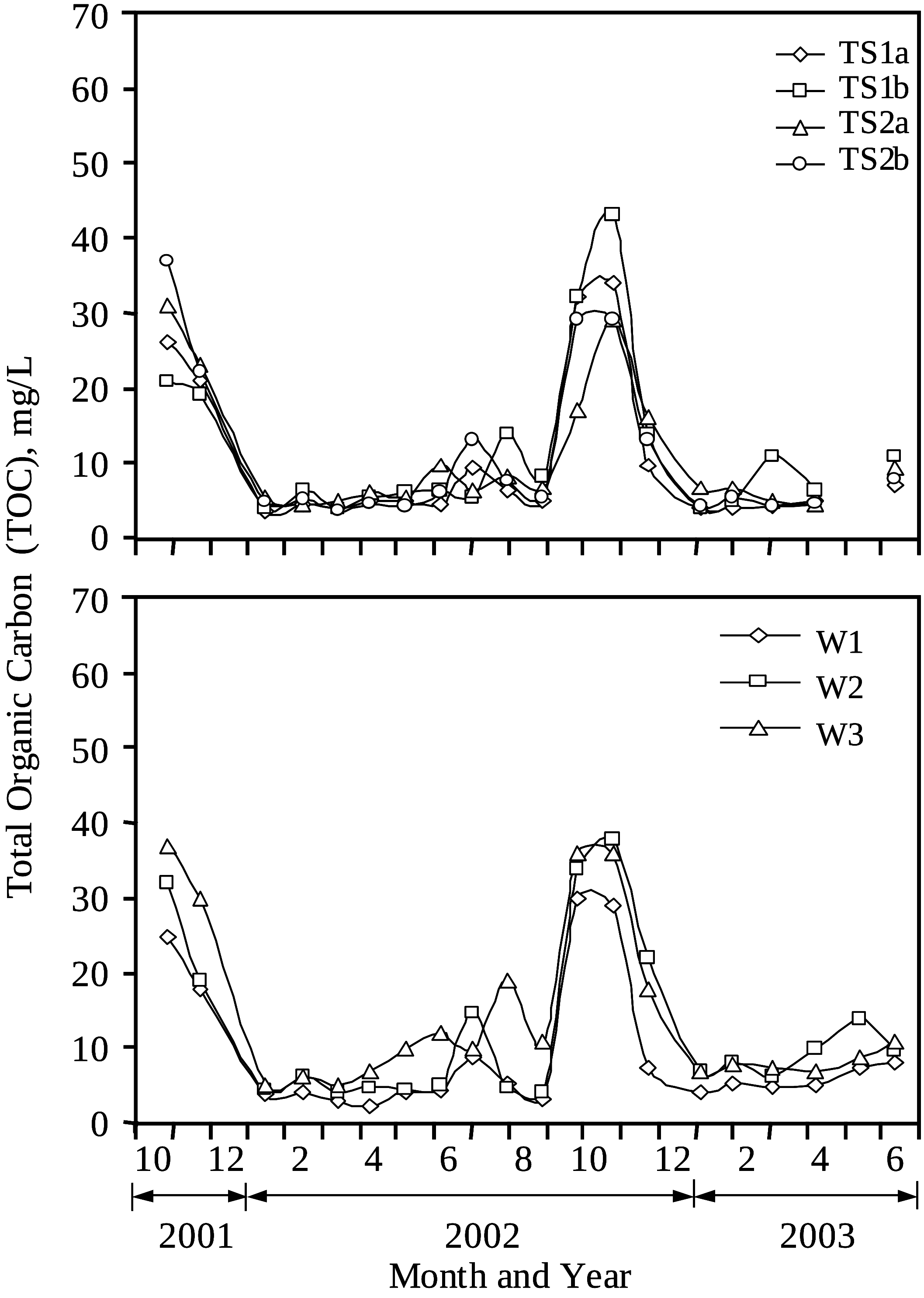

Figure 23. Total organic carbon (TOC) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 1. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

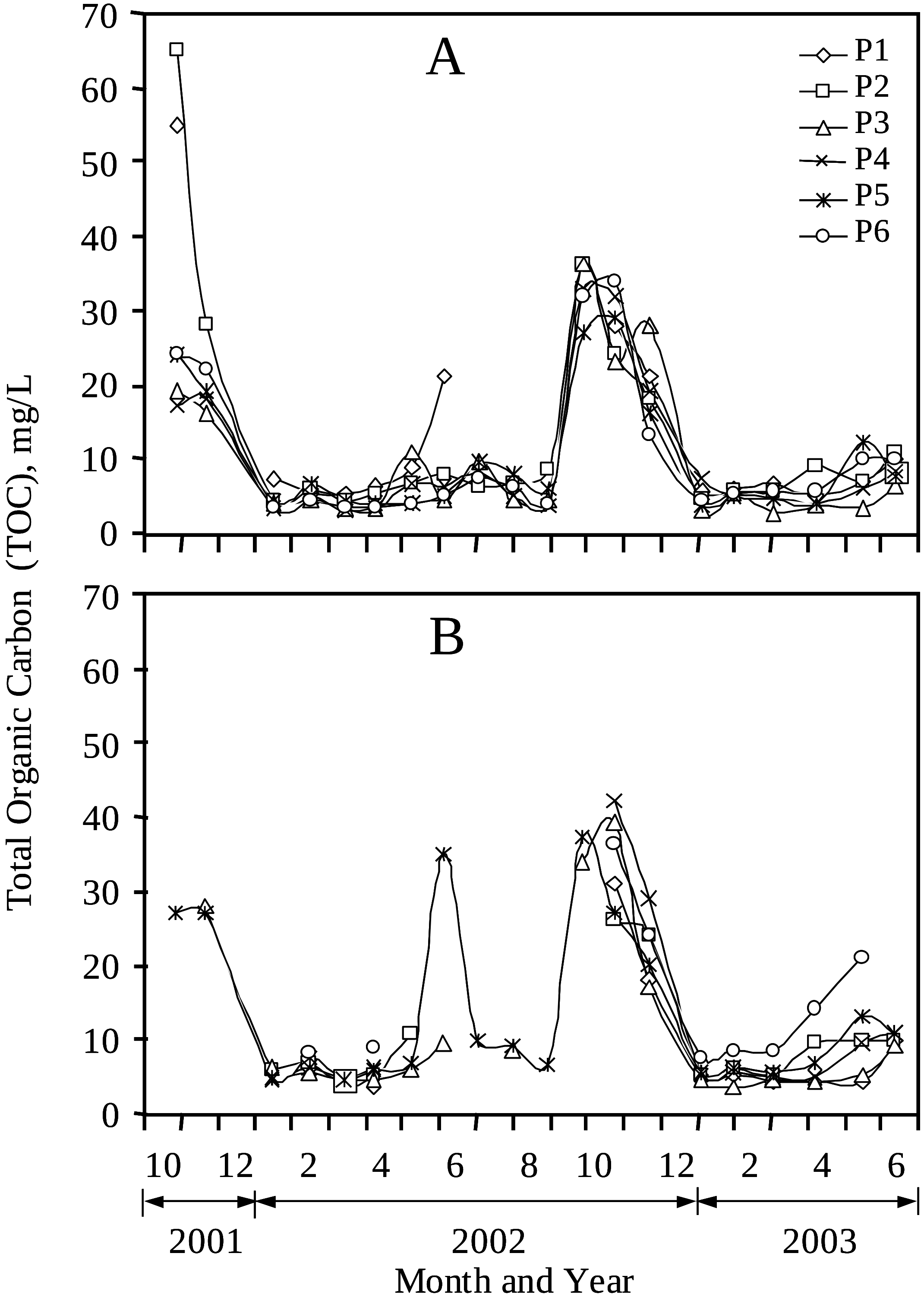

Figure 24. Total organic carbon (TOC) concentrations of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

System 2

From May 2001 through July 2003 an average of 640 L (170 gallons) of water was used by the residents. Except for the month of June, 2002, the average daily water use was between 430 and 760 L (115 to 200 gallons), and the maximum average daily water use for a two-week period in June, 2002, was 1,600 L (427 gallons). The septic system at this site was designed for 1,815 L (480 gallons) per day flow. Based on the biweekly average water use data (meter readings), this system did not exceed the design flow any time during the 2-year monitoring period. Based on the average daily water use, the actual loading rate for this system was 4.6 L/(m^2d) or 0.46 cm/d [equivalent to 0.11 gal/(ft^2d)].

Saturated Hydraulic Conductivity and Infiltration Rate

Saturated hydraulic conductivity of three depths at two locations are presented in Table 6. The lowest K_{sat} was 3.5 cm/d at 60 cm depth. The saprolite at approximately 105 to 120 cm depth interval had much higher saturated hydraulic conductivity. Based on the actual water use by the users of the system, the average for actual loading rate represents 13% of this K_{sat} value. In general, K_{sat} of soil at this site was high enough not to cause hydraulic failure.

The infiltration rate for 9 locations along two transects (see Fig. 5) are presented in Table 7. The infiltration rate for the area between the drainfield and the creek (locations 7-9) was relatively high. Over the drainfield, the infiltration rate ranged between 0.9 and 9.7 cm/h. Except for very high intensity rainfall, because of high infiltration rate in the area between the drainfield and the creek, we do not expect any potential runoff from the drainfield to flow directly into the creek. For low intensity rainfall we do not expect any runoff from the drainfield area.

Table 6. Saturated hydraulic conductivity (K_{sat}) of different depth intervals at two locations within the drainfield area of System 2.

LOCATION	DEPTH	K_{sat}	EQUIVALENT TO K_{sat}
	cm	cm/d	gal/(ft^2d)
1	46-62	9.4	2.3
	74-93	4.3	1.1
	107-122	33.5	8.3
2	45-60	3.5	0.9
	73-90	3.5	0.9
	103-119	127.9	31.5

Table 7. Infiltration rates at 9 locations within the drainfield area at Site 2.

Location	Infiltration Rate
	cm/h
1	7.4
2	4.3
3	9.7
4	2.4
5	1.0
6	0.9
7	17.5
8	29.2
9	68.1

Water Table Elevation

The relative water table elevations with respect to the bottom of the creek at a location near sampling point 4 (CR4 in Fig. 6) for three locations are presented in Fig. 25. In general there were little differences between the water table elevations at locations 1 and 3. Location 2, which was closest to the creek had consistently lower elevation than the other two locations away from the creek. Only for a short time during the August of 2002 did the water level elevation at location 2 fall below the bottom of the creek. These results indicated that ground water flow was in general from the drainfield area toward the creek. The direction of ground water flow based on measured water table elevation was consistent with the contour of the land and our observation of wetness at the upper part of the drainfield of System 1, which was adjacent to the drainfield of this system.

Except for the summer of 2002, the water elevations in the piezometer installed at 240 cm depth between the drainfield and the ditch on the north side of the drainfield (location 1) were slightly higher than the water level elevations at deeper depth. For the summer of 2002, the water table was deeper than the shallower piezometer (Fig. 26). At locations P2 and P4, on the other hand, there was little difference between the water level elevations in the piezometers installed at different depths (Fig. 27). This indicates that for each of these locations the pressure heads at two depths were very similar. Similar to location P1, water level elevations at location P3 were below the elevation of the bottom of the shallower piezometer during the summer of 2002. Overall, the piezometers results agree with the water table elevations obtained by measuring the water levels in wells. The piezometer data indicate that for most of the times, water from the drainfield area moved toward the creek.

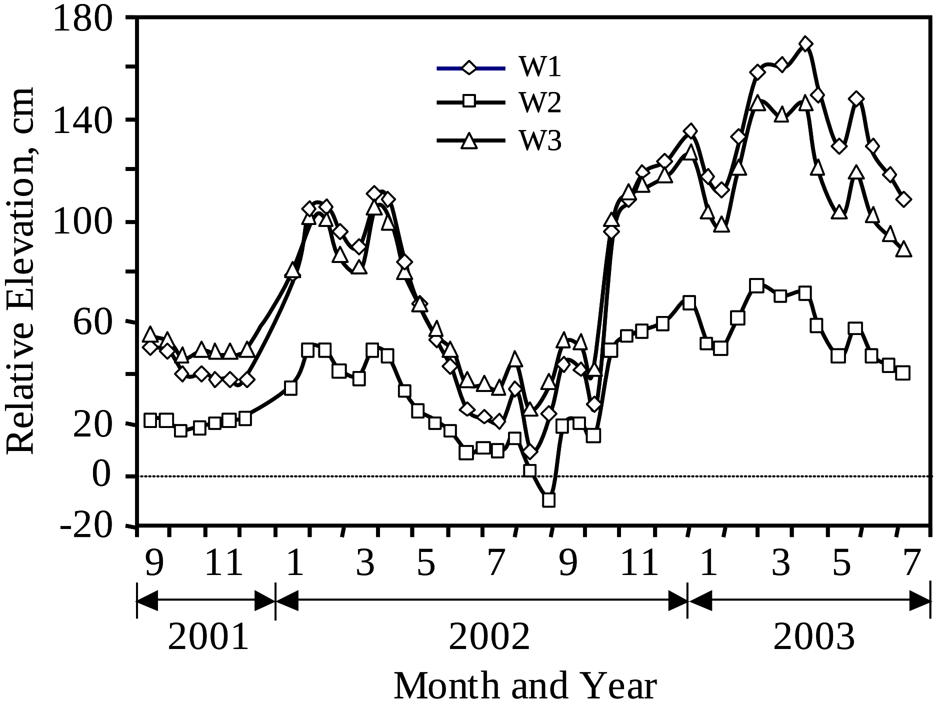

Figure 25. Water table relative elevations at three locations from September 2001 through June 2003 for Site 2. The elevation of the bottom of the creek at location marked CR4 in Fig. 6 was selected as the reference location with zero elevation (shown as dashed-line).

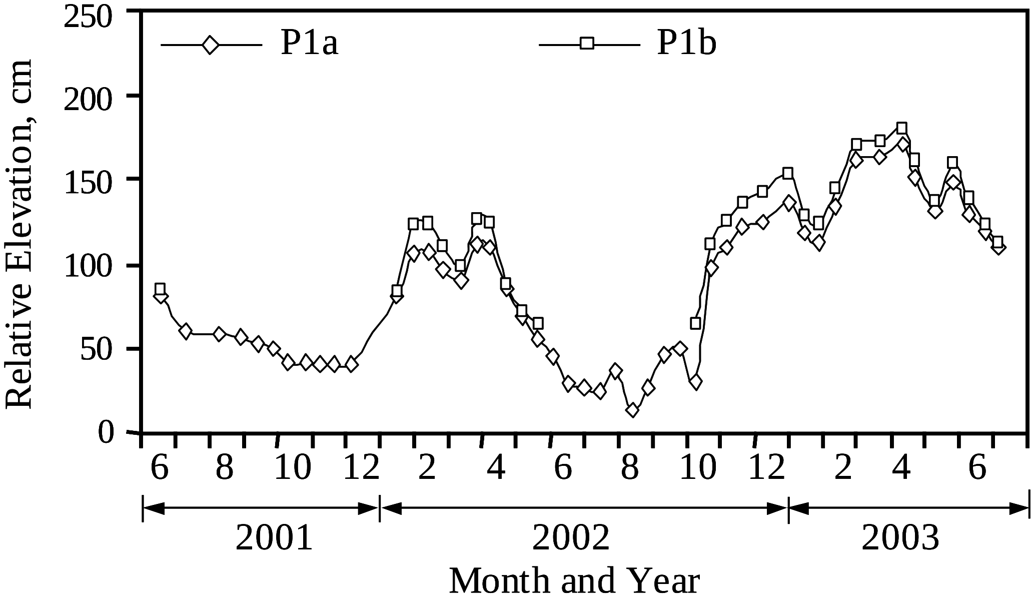

Figure 26. Relative elevations of the water level in the piezometers representing the relative pressure heads for two different depths at location P1 below the drainfield of System 2. In this figure "a" represents the deeper and "b" represents the shallower piezometers.

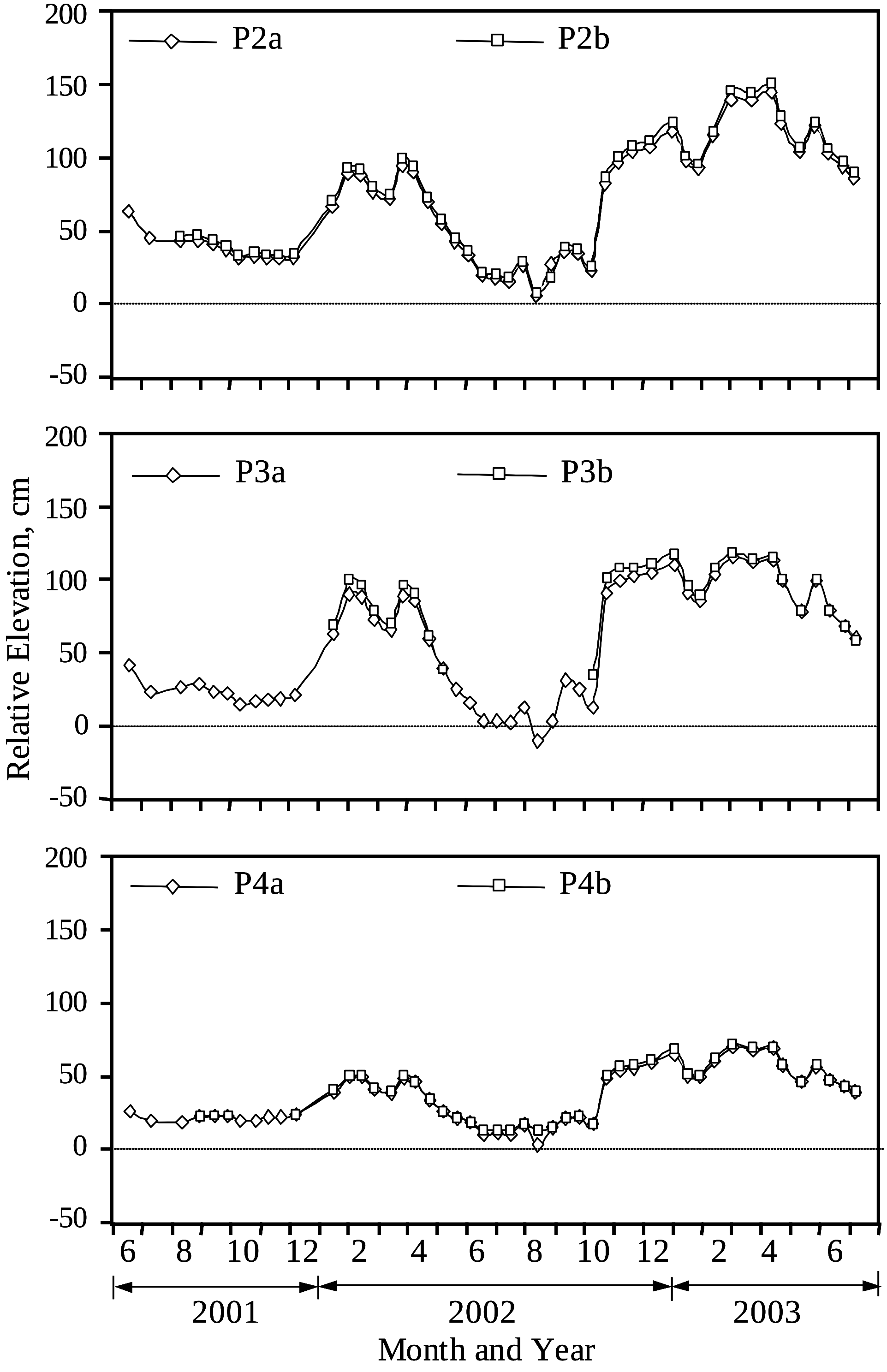

Figure 27. Relative elevations of the water level in the piezometers along a transect perpendicular to the drainlines between the drainfield and the creek (locations P2, P3 and P4 in Fig. 6). The water levels represent the relative pressure heads at the tip of the piezometers below the water table for two different depths. In these figures "a" represents the deeper and "b" represents the shallower piezometer at each location.

Soil Water Content and Pressure Head

The soil water contents measured in situ by TDR for five depth intervals at three locations (see Fig. 6) are shown in Fig. 28. As indicated before, because we did not calibrate the TDR system for our sites, the measured TDR values may not represent the actual soil water content at the given depth intervals. However, the relative values among the measured values for each depth interval show the actual variation of soil water content with time.

At location 1 above the drainfield (TDR1), the soil water contents at all depth intervals varied with the season. In all cases, higher soil water content was measured during winter months compared to summer. The highest variability among the measured values for individual depth intervals was for the 60 to 90 cm depth interval above the drainfield with a CV of 45%. The CV for the other depth intervals at location 1 varied between 21 and 32%. Inside the drainfield (TDR2), The soil water content variation with time at each depth interval was substantially less than the corresponding depth interval at the other two locations. The highest CV (18%) was for the 0 to 15 cm depth and the CV’s for measurements below 30 cm depth were 6 to 8%. Inside the drainfield, there was not a substantial difference between the summer and winter months, which is due to the fact that wastewater is applied to this drainfield throughout the year. Similar to location 1 (TDR1), the differences between summer and winter water content below the drainfield (TDR3) were substantial.

Overall, the water content values in the upper 15 cm of the soil were slightly higher than the water content in the middle of the drainfield, but they were substantially higher than the corresponding water content in the surface layer below the drainfield. Inside the drainfield, the water content between 15 and 90 cm depth interval was higher than the water content both above and below the drainfield. Comparing the upper and lower parts of the drainfield, the soil was wetter in the upper 30 cm in the upper part of the drainfield. Below the 60 cm depth, the soil was wetter below the drainfield than above the drainfield. These results are consistent with the location of the drainfield on the landscape and the functioning of the drainfield.

The soil water pressure head measured at three depths above, in the middle, and below the drainfield near the beginning of the trenches (adjacent to the TDR rods) corresponded fairly well with the soil water content measured by TDR (Fig. 29). There were significant differences between the soil water pressure heads measured during winter and summer months for each depth above (T1) and below (T3) the drainfield. Inside the drainfield (T2), the variation in soil water pressure head was much less from winter to summer.

Similar results were obtained along the transect perpendicular to the drainlines in the middle part of the drainfield (Fig. 30). Above the drainfield (at T4), there was a substantial difference between the soil water pressure head reading in summer and winter months. Moving inside the drainfield (T5 and T6, see Fig. 6), the temporal variability of soil water pressure head at each depth was reduced substantially. The driest part during summer was the 60-cm depth. The 60-cm depth was also the wettest during winter. At location 6 on the transect (T6) there was little difference between the soil water pressure head at three depths, but there was noticeable differences between summer and winter months. The fourth location on the transect was below the drainfield. Soil water pressure heads at all three depths had a similar trend, with a substantial

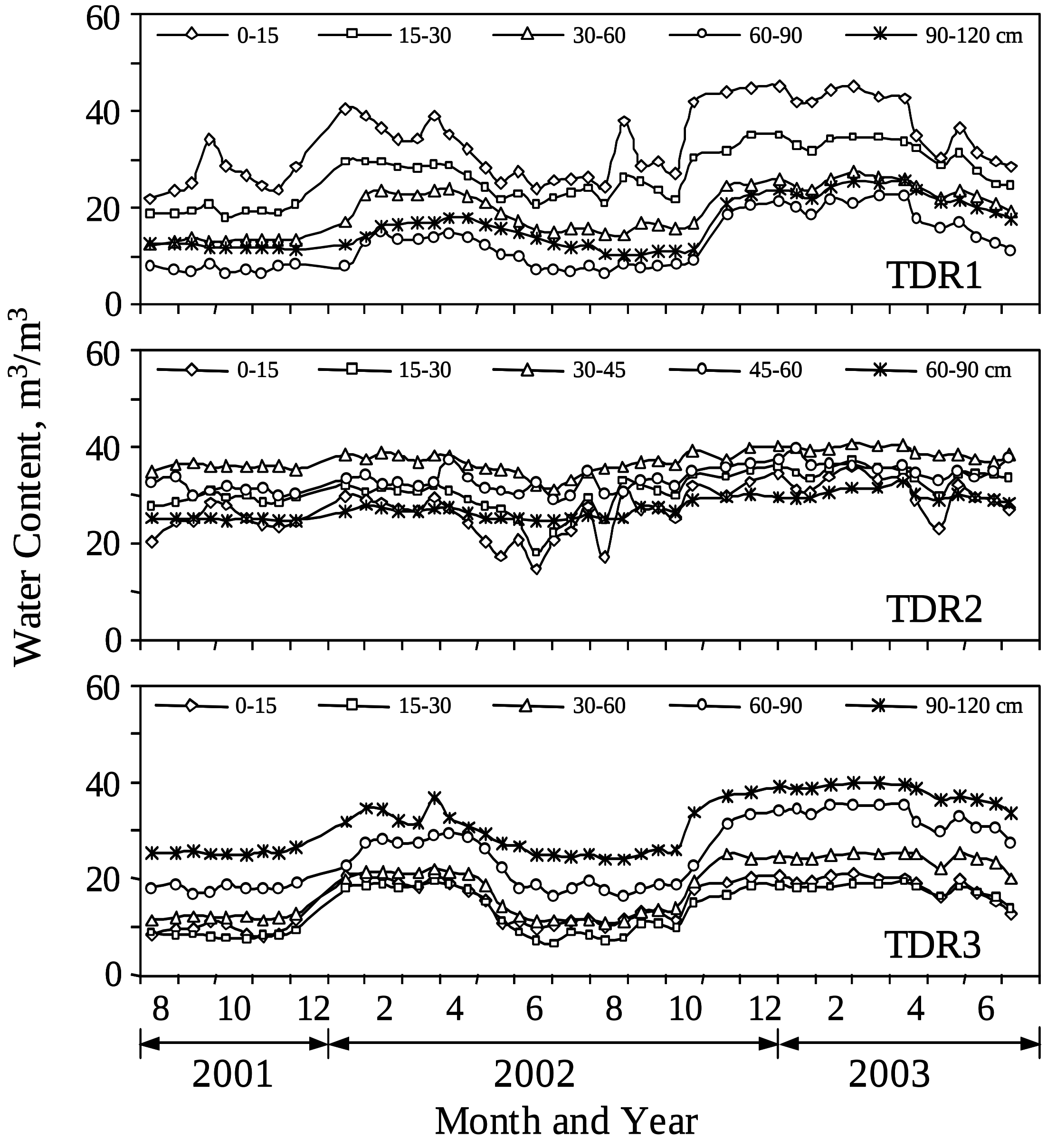

Figure 28. Soil water contents at five depth intervals measured in situ by the TDR technique at three locations. For locations of the TDR measurements see Fig. 6.

difference between summer and winter months. At the last location, the soil profile during summer months became drier than the locations inside or close to the drainfield. Overall, the tensiometer results at this site corresponded fairly well with the TDR results. Except for a few short periods, the soil in the drainfield area remained unsaturated during the monitoring period. As indicated earlier, this system received approximately 1/3rd of the daily design flow of 480 gallons/day. Also, the drainfield was located on a side slope and ground water within the drainfield was relatively deep. Hydraulically, this system functioned properly by maintaining an unsaturated zone below its trenches.

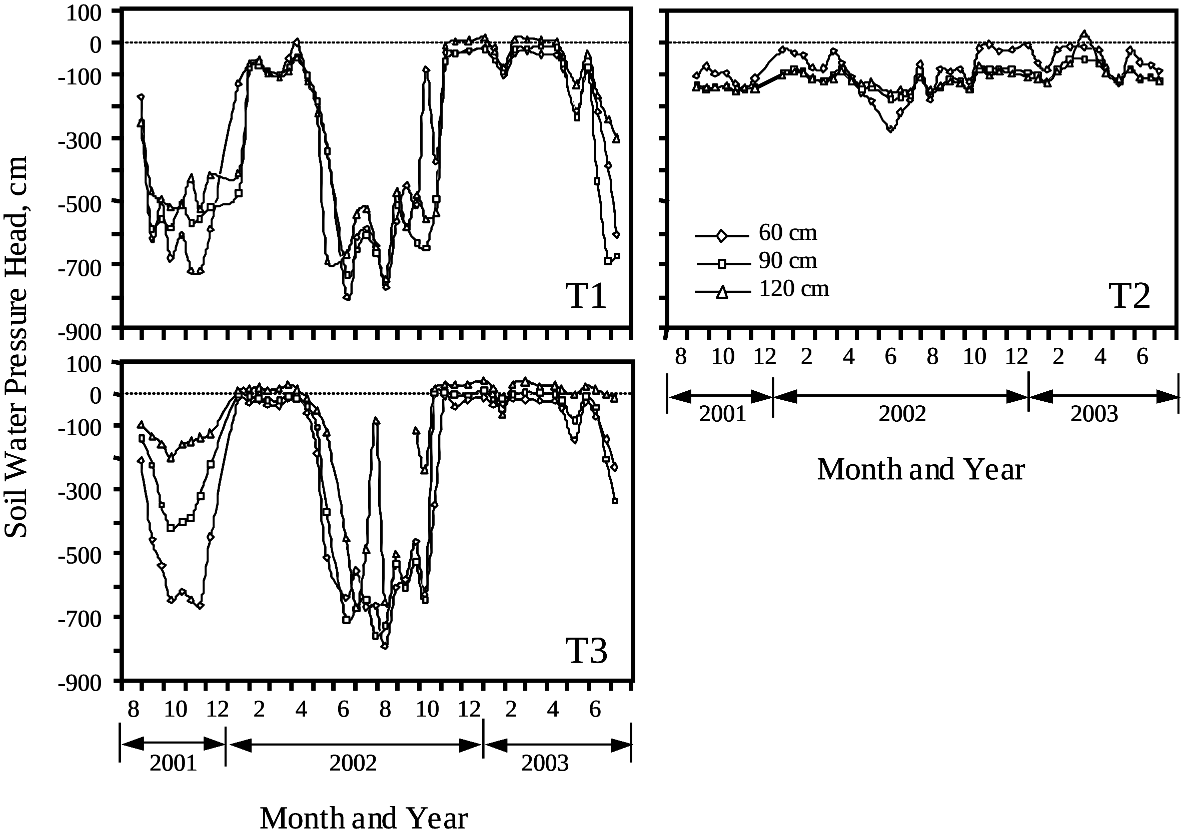

Figure 29. Soil water pressure heads for three depths at three locations along a transect going through the drainfield near the beginning of the trenches at Site 2. The dashed line represents zero tension or pressure head. The number in each graph represents the location of the tensiometer bank (see Fig. 6).

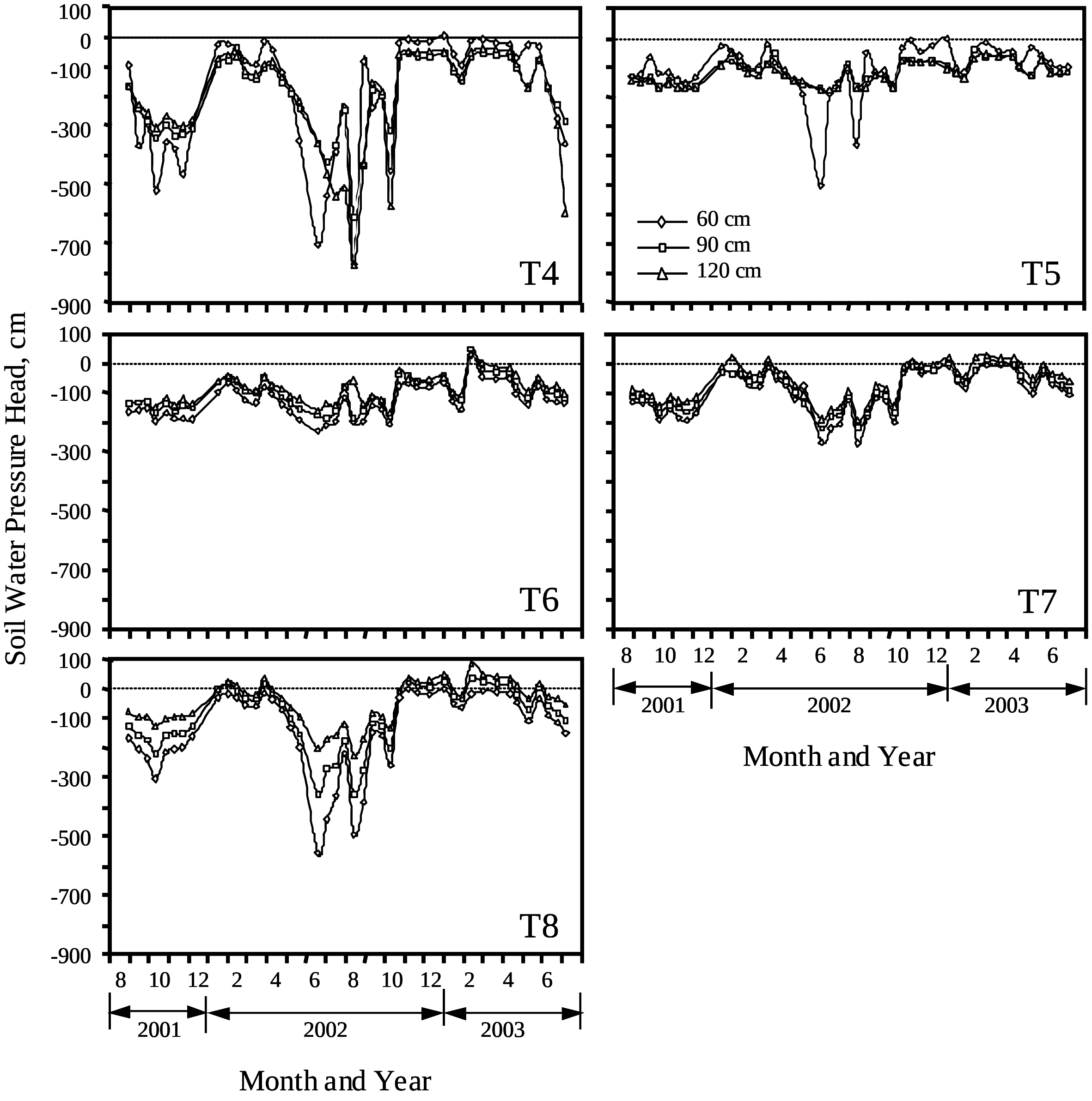

Figure 30. Soil water pressure heads for three depths at five locations along a transect going through the drainfield near the middle of the trenches at Site 2. The dashed line represents zero tension or pressure head. The number in each graph represents the location of the tensiometer bank (see Fig. 6).

Distribution of Chemical Constituents

Acidity (pH) and Electrical Conductivity (EC): The pH of the water in the creek adjacent to the drainfield varied between 5.7 and 6.7 for the duration of monitoring period (Fig. 31). As expected, these results are very similar to the pH of the water downstream adjacent to the drainfield of System 1 as presented earlier. In general, the pH of the ground water samples from the wells was lower than the pH of the stream water. The average for Well #2, which was closest to the drainfield varied between 4.2 and 5.6 with an average of 4.7. Overall, the pH of the water samples collected from the other two wells were greater than the corresponding values for Well #2, but the pH variation trends for all three wells were fairly similar. The pH of the soil solution samples varied between 4.4 and 5.9 for all four samplers. For the piezometers, the pH varied between 3.9 and 6. Except for the deeper piezometer at location 3 (P3a), which had a coefficient of variability of 14%, the variability of pH values for each sampling location/device was low (CV < 10%). The pH values for the water samples collected from the wells, tension samplers, and piezometers are presented in Appendix B.

With one exception, the EC of the water samples collected from 3 locations in the creek adjacent to the drainfield (see Fig. 6) varied between 40 and 80 µS/cm during the monitoring period. Overall, the EC of the water in the creek remained fairly constant during the monitoring period (Fig. 32). The EC of the well samples was in general higher than the EC of the creek samples. Overall, there was good agreement between the well water samples and samples collected from the piezometers near the wells. Soil solution samples had higher EC than either the well or piezometer samples. Lower solute concentration in the ground water than soil solution could be

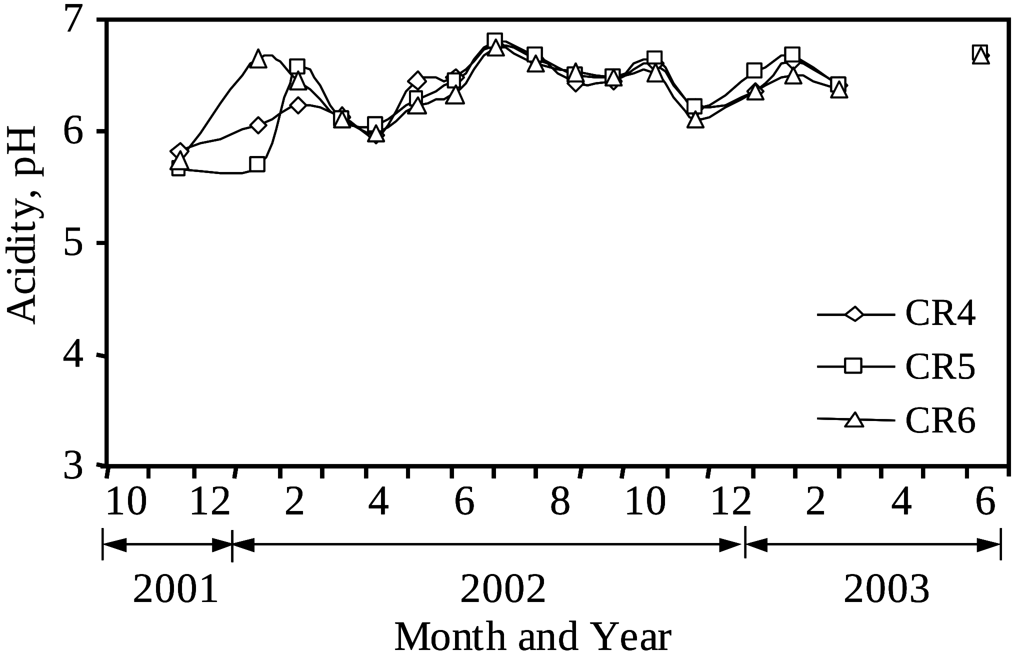

Figure 31. The acidity (pH) of the water at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

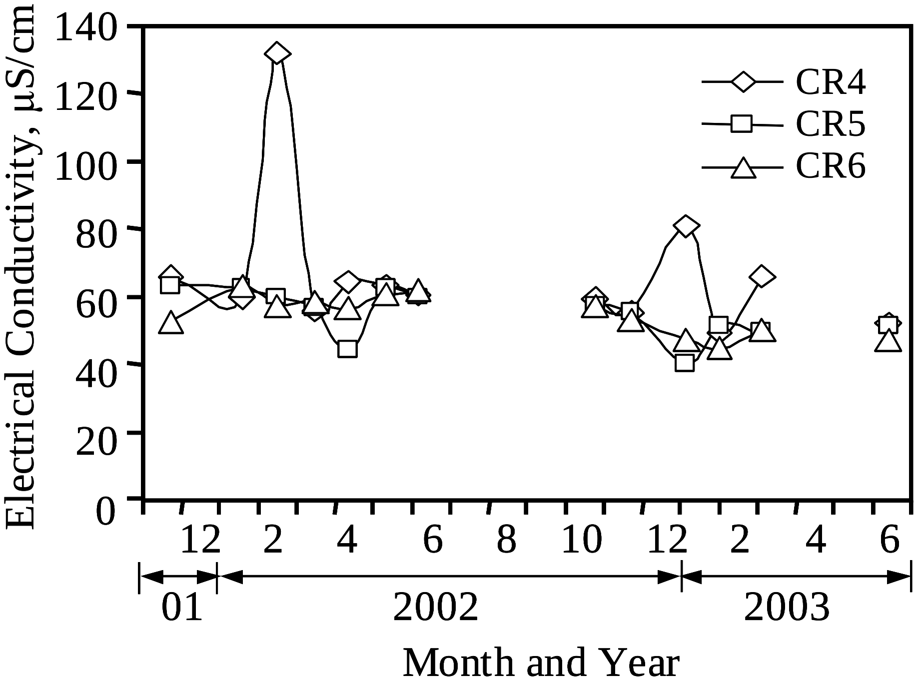

Figure 32. Electrical conductivity of water at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

attributed to the dilution of soil solution once it reaches ground water (i.e., after it enters the water table). The EC values for the wells, tension samplers, and piezometers at this site are presented in Appendix B.

Ammonium (NH_4-N) and Nitrate Nitrogen (NO_3-N): The NH_4-N levels in the creek were generally below 0.5 mg/L, and only two samples had more than 1 mg/L during the entire sampling period (Fig. 33). In Fig. 33 all values reported as 0.05 mg/L were below the detection limit of our analytical procedure. The samples collected from the soil solution by the aid of tension samplers had less than 1 mg/L NH_4-N for the entire sampling period (Fig. 34). Low levels of NH_4 in the soil solution collected near the trenches indicate that the environment around the trenches remained aerobic during our study. The ground water samples collected from the wells also had low NH_4-N concentrations. Except for one sampling date during summer of 2002, the concentrations of NH_4-N remained below 0.75 mg/L (Fig. 35). The only sample with 2 mg/L NH_4-N was collected from the well near the drainfield of the system. This high concentration in the ground water could be due to leaching of the vadose zone. The levels of NH_4-N in the piezometer tubes were generally less than 1 mg/L. A close examination of data, however, shows that the NH_4 levels in all four longer piezometers was increased slightly during the same time when a relatively high level of ammonium was found in the ground water sample. The concentrations of NH_4-N at two different depths below the water at four different locations are presented in Appendix B.

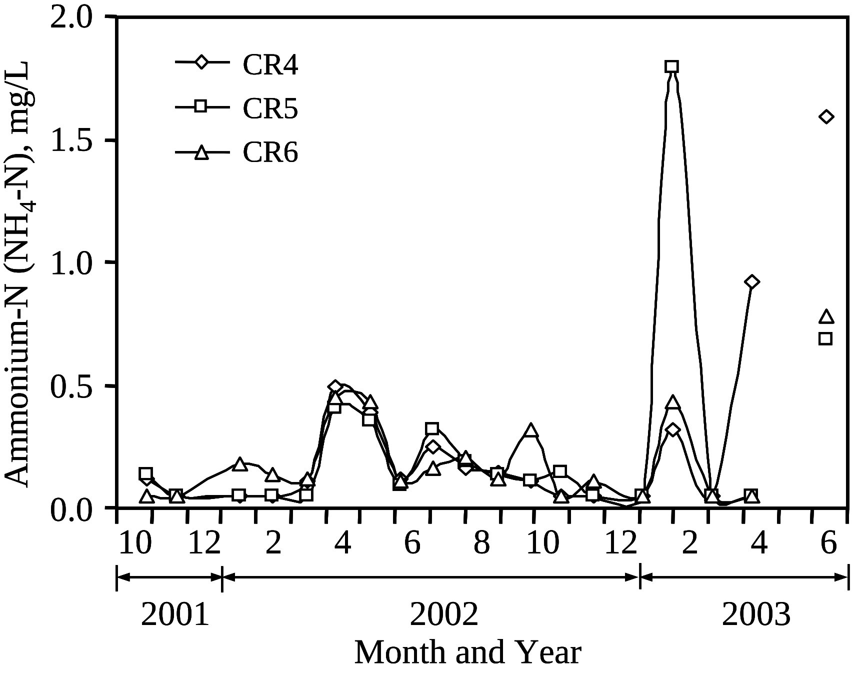

Figure 33. Ammonium-N (NH_4-N) concentrations in water at three locations in the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

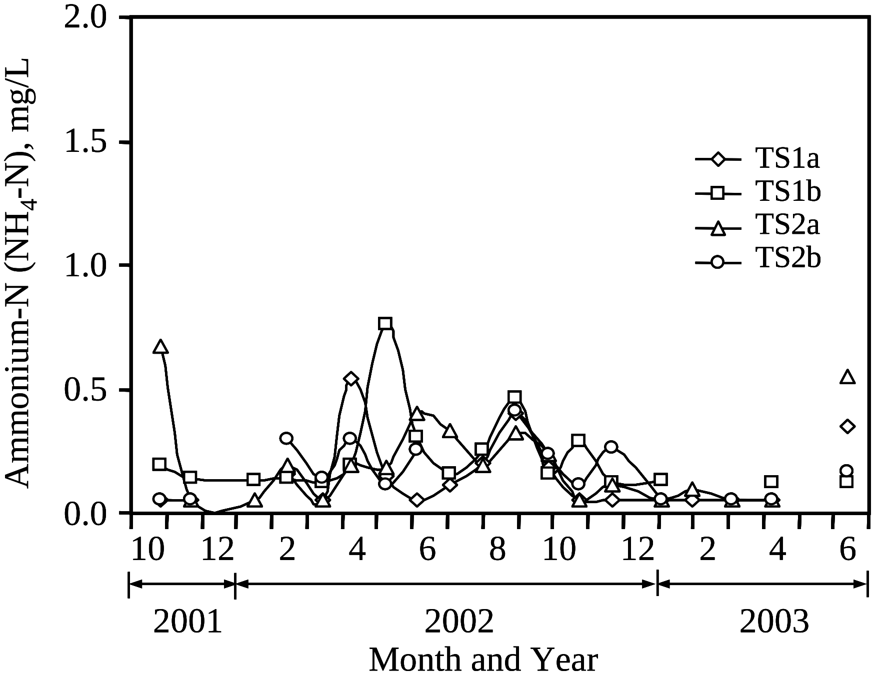

Figure 34. Ammonium-N (NH_4-N) concentrations in soil water collected from two depths at two locations near the trenches of System 2. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

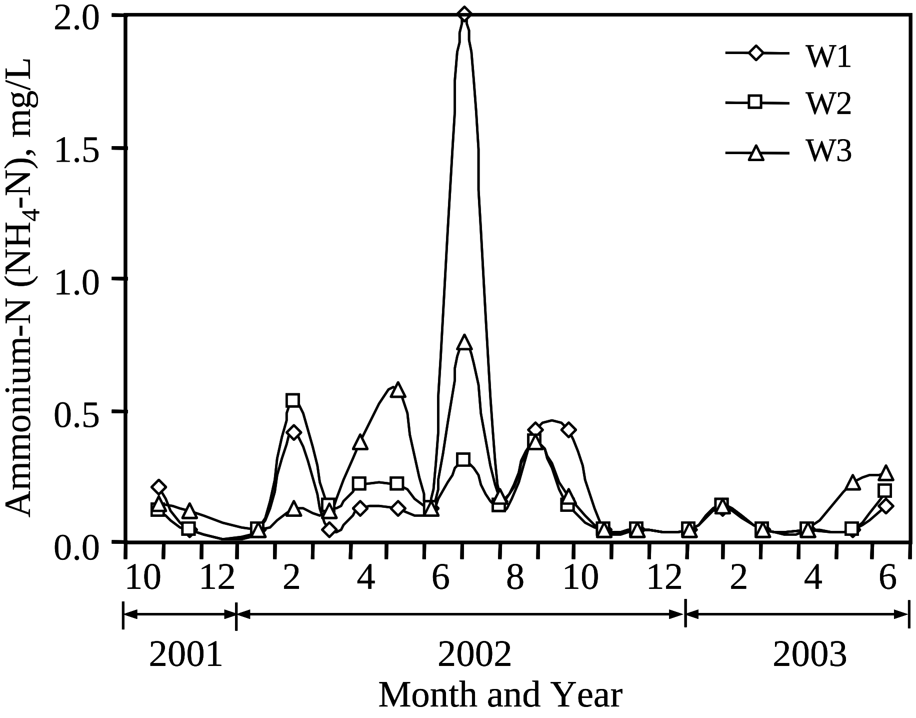

Figure 35. Ammonium-N (NH_4-N) concentrations in ground water collected from three sampling wells in the drainfield area of System 2. For sampling locations see Fig. 6.

The levels of nitrate-N in the water in the creek were relatively low and had the same trend as the locations along the creek adjacent to the drainfield of System 1 (Fig. 36). The highest concentration of NO_3-N measured in the creek near the drainfield of this system was 0.5 mg/L. The levels of NO_3-N in the soil solution collected from near the trenches by the tension samplers, on the other hand, were substantially higher, but did not show any specific trend (Fig. 37). Indeed, the variability among samples collected from each location was relatively high with CV values ranging between 87% for the tension sampler TS1a to 282% for TS2b. The average NO_3-N concentrations in the samples collected from under the trenches were 11.1 and 15.7 mg/L for locations TS1b and TS2b, respectively. The NO_3-N concentrations in the ground water samples collected from the wells was generally low and reached 25 mg/L in two of the wells only once during the summer of 2002 (see Fig. 37). The average NO_3-N concentration in the ground water samples for all three wells ranged between 1.3 and 2 mg/L for the entire monitoring period. Overall, the concentrations of nitrate in the soil solution and in ground water under this system was lower than the corresponding values for System 1.

Except for the piezometer P1a installed deeper near the beginning of the trenches in the area between the drainfield and the ditch (see Fig. 6), the levels of nitrate in the samples collected from the piezometers was rather low (Fig. 38). In the piezometer P1a, NO_3-N levels varied between 1 and 6 mg/L with an average of 3.3 mg/L for the monitoring period. Overall, low nitrate concentration in the piezometer samples can be attributed to dilution as well as the

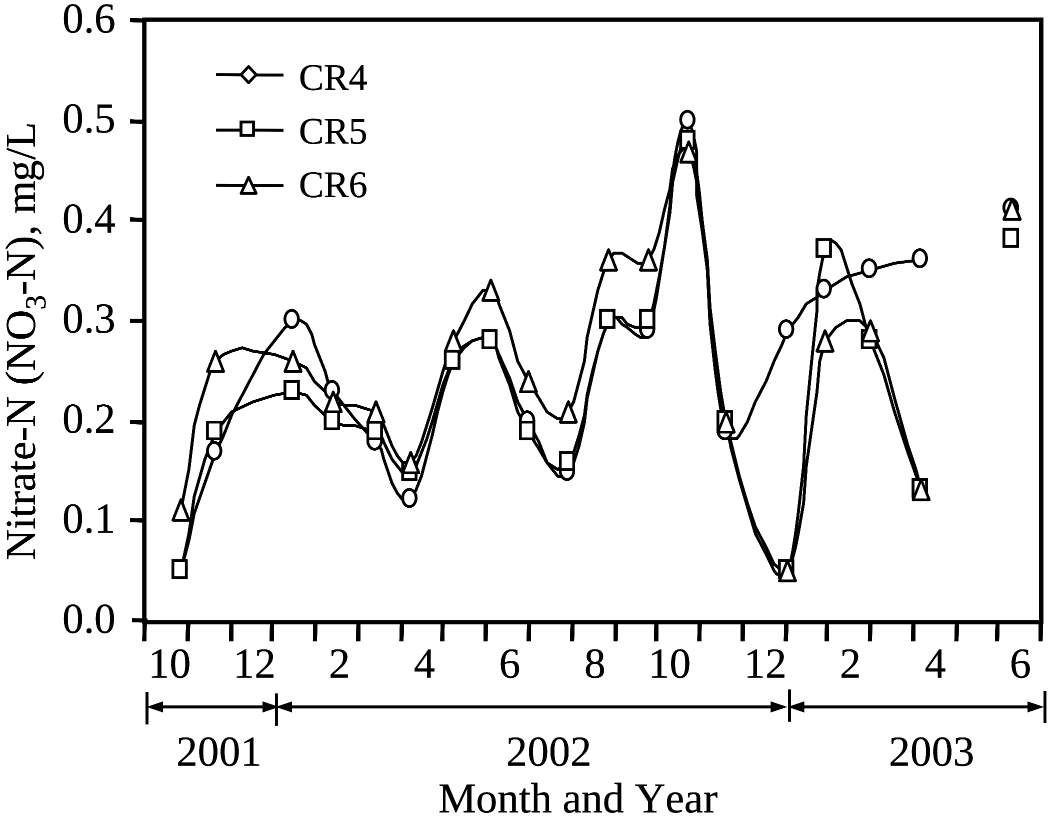

Figure 36. Nitrate-N (NO_3-N) concentrations in water samples collected at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

potential for a plum from the drainfield moving on top of the ground water. Relatively high levels of nitrate in piezometer P1a installed deeper than the other piezometer below the water table could be related to the fact that this system had a conventional drainfield with a pressure manifold distribution. Wastewater applied to the beginning of the trenches could enter ground water and be captured by extraction through the piezometer.

Phosphate -P (PO_4-P): Except for a few occasions, the PO_4-P concentrations in soil solution or ground water for the duration of monitoring period was less than 0.1 mg/L. The PO_4-P concentrations in the water from the creek were less than 0.05 mg/L. The total P concentration in the creek reached 1.3 mg/L only once. For other times, the total P concentration remained below 0.17 mg/L. For the samples collected from the wells and tension samplers, the total P concentrations remained below 1.6 mg/L with a majority of values being below 0.5 mg/L. Higher concentrations of total P were observed in the ground water samples collected by the piezometers, but the values generally remained below 2 mg/L. The concentrations of PO_4-P and total P (TP) for the creek, soil water and ground water are presented in Appendix B.

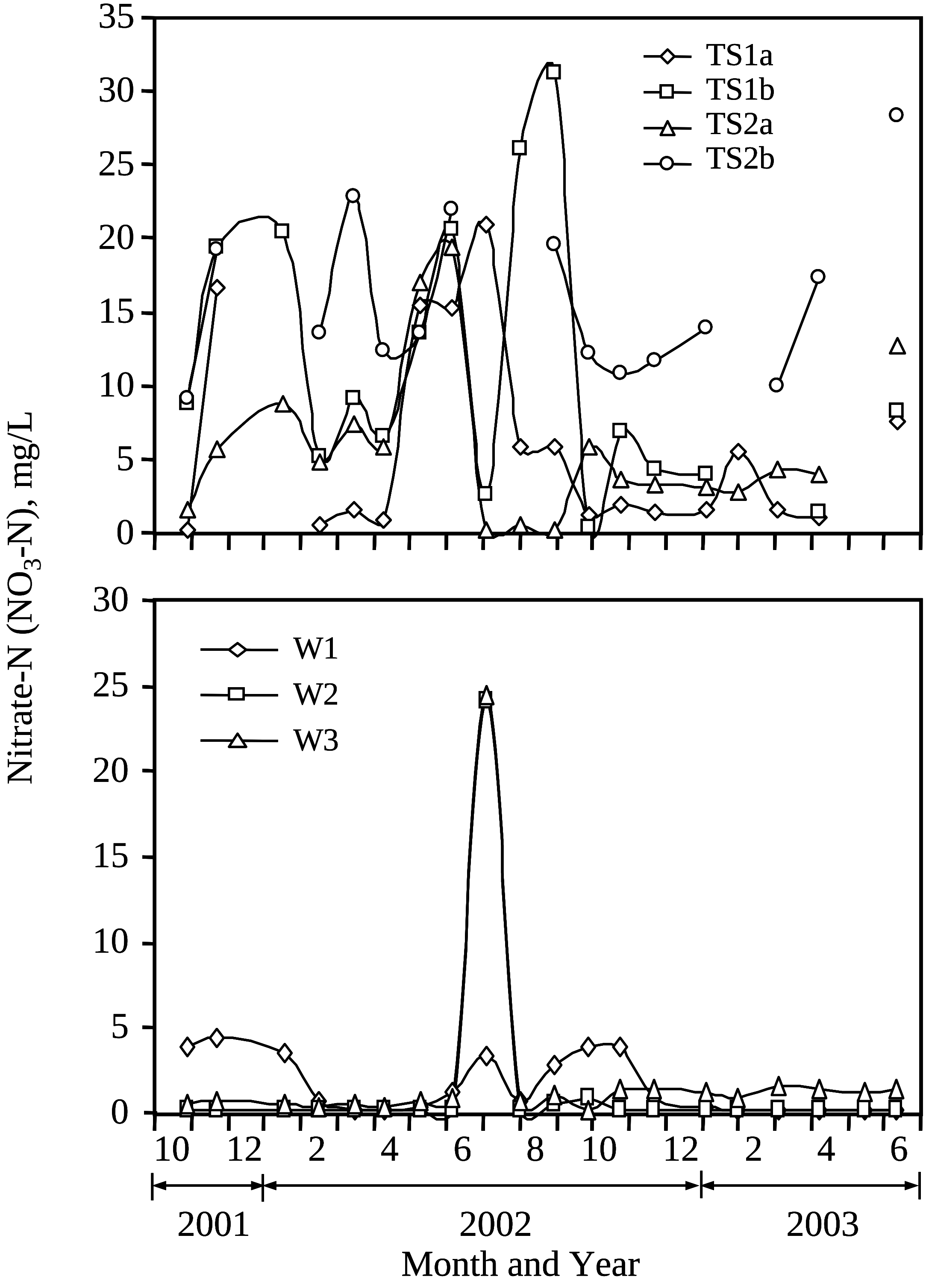

Figure 37. Nitrate-N (NO_3-N) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 2. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

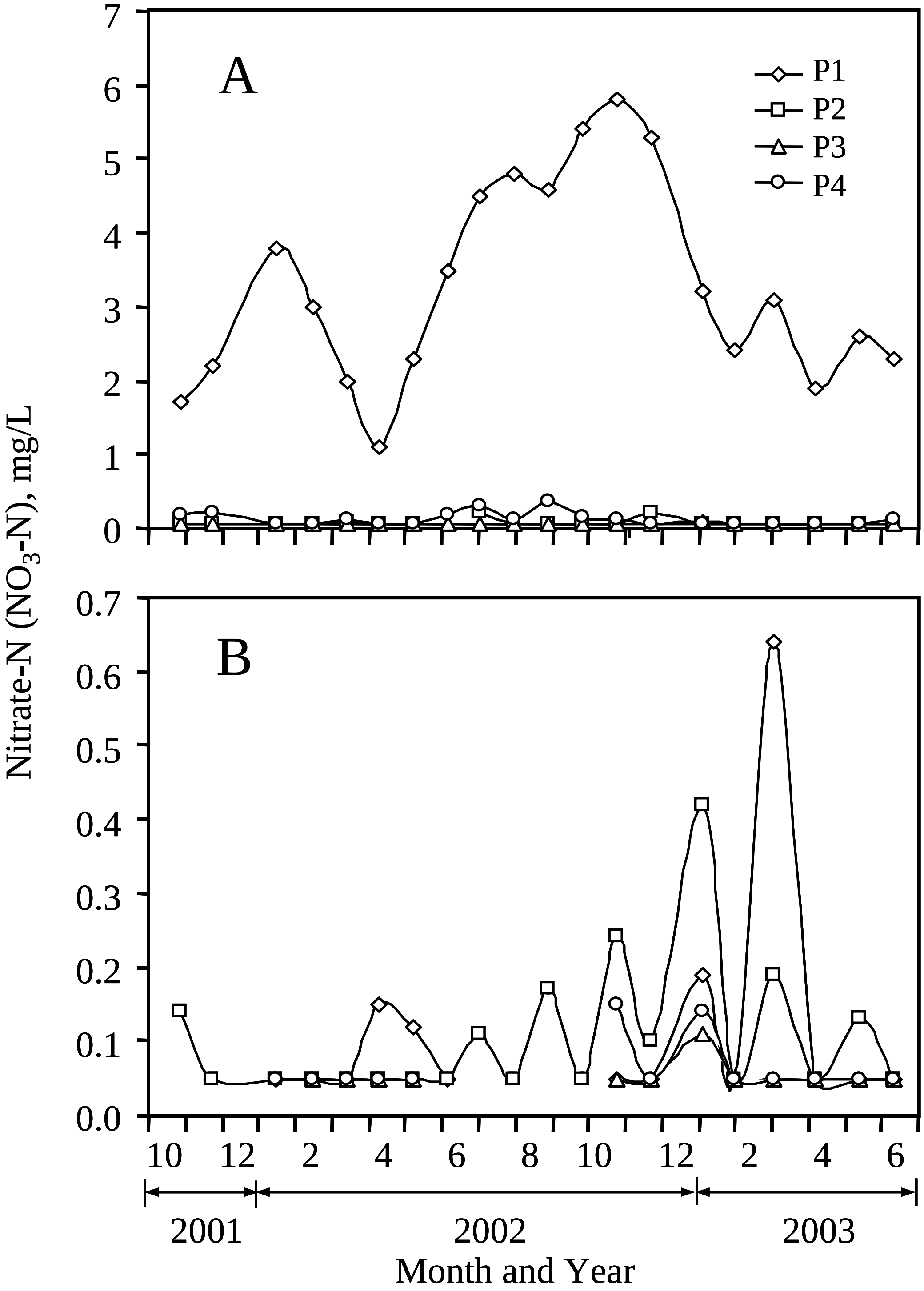

Figure 38. Nitrate-N (NO_3-N) concentrations of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 6.

Total Organic Carbon (TOC): Similar to System 1, the concentrations of total organic carbon (TOC) showed an interesting trend for all samples (Figs. 39, 40, and 41). In all cases, a significantly higher TOC concentration was detected in the samples that were collected in late 2001 and again from late September through December 2002. As we discussed earlier, we do not know the exact reason for these trends. However, these could be natural trends occurring during the fall season (when leaves fall) and a more comprehensive evaluation is needed to determine if the trend is real.

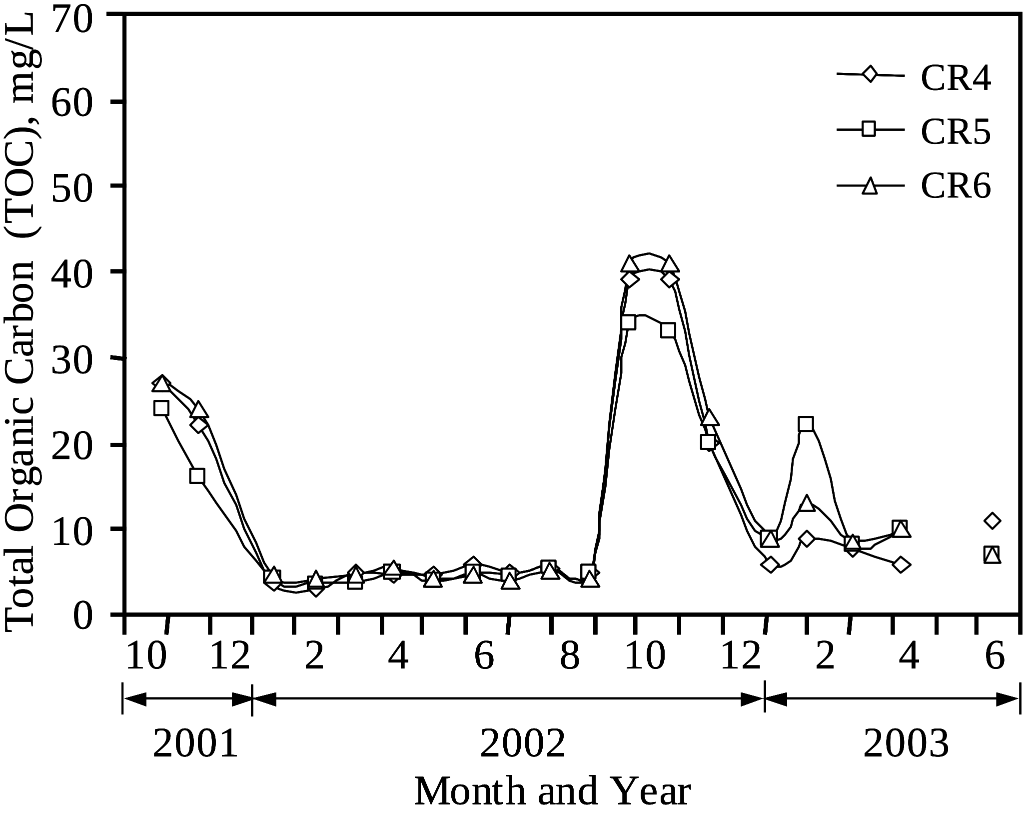

Figure 39. Total organic carbon (TOC) concentrations in water samples collected at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

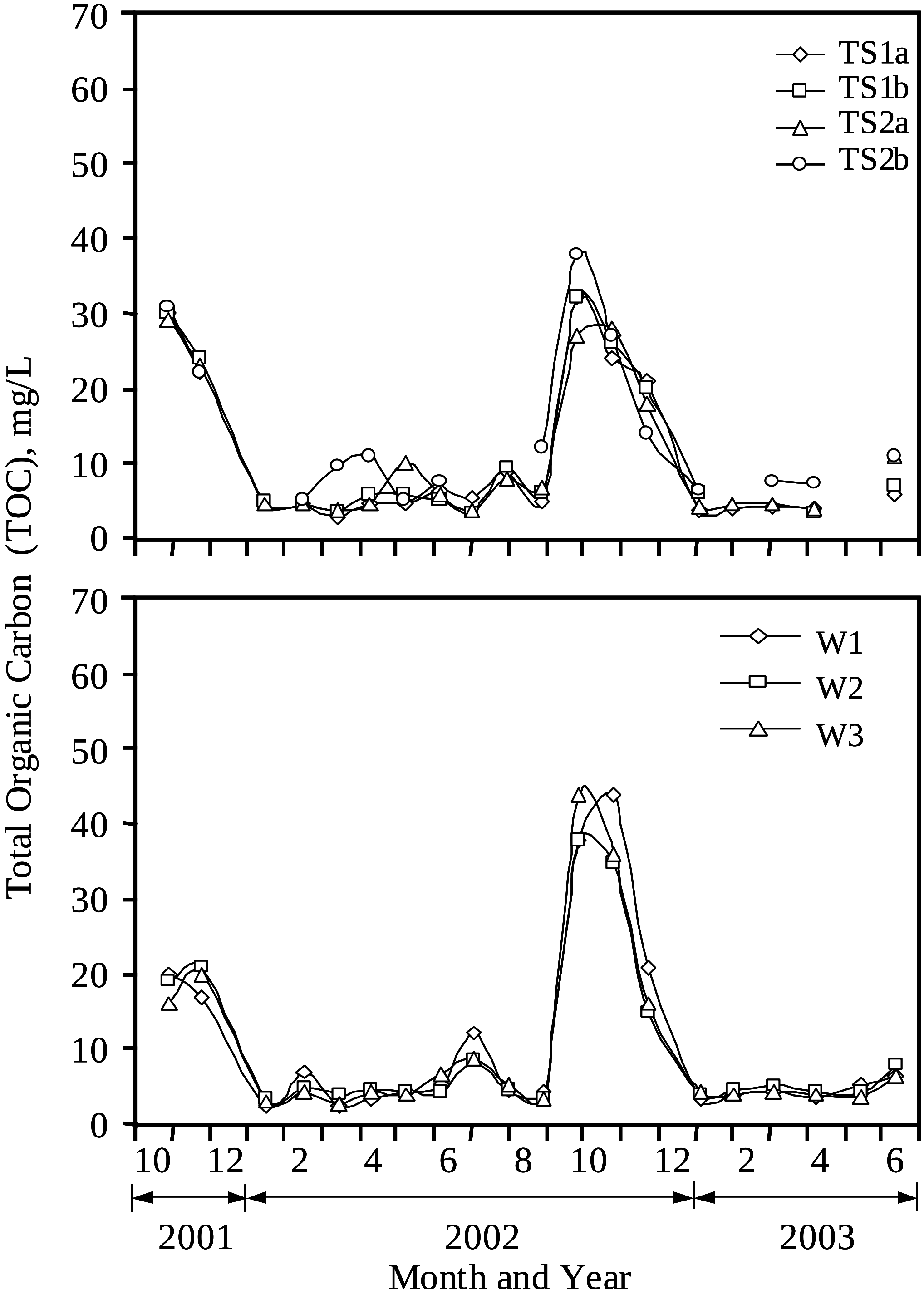

Figure 40. Total organic carbon (TOC) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield of System 2. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

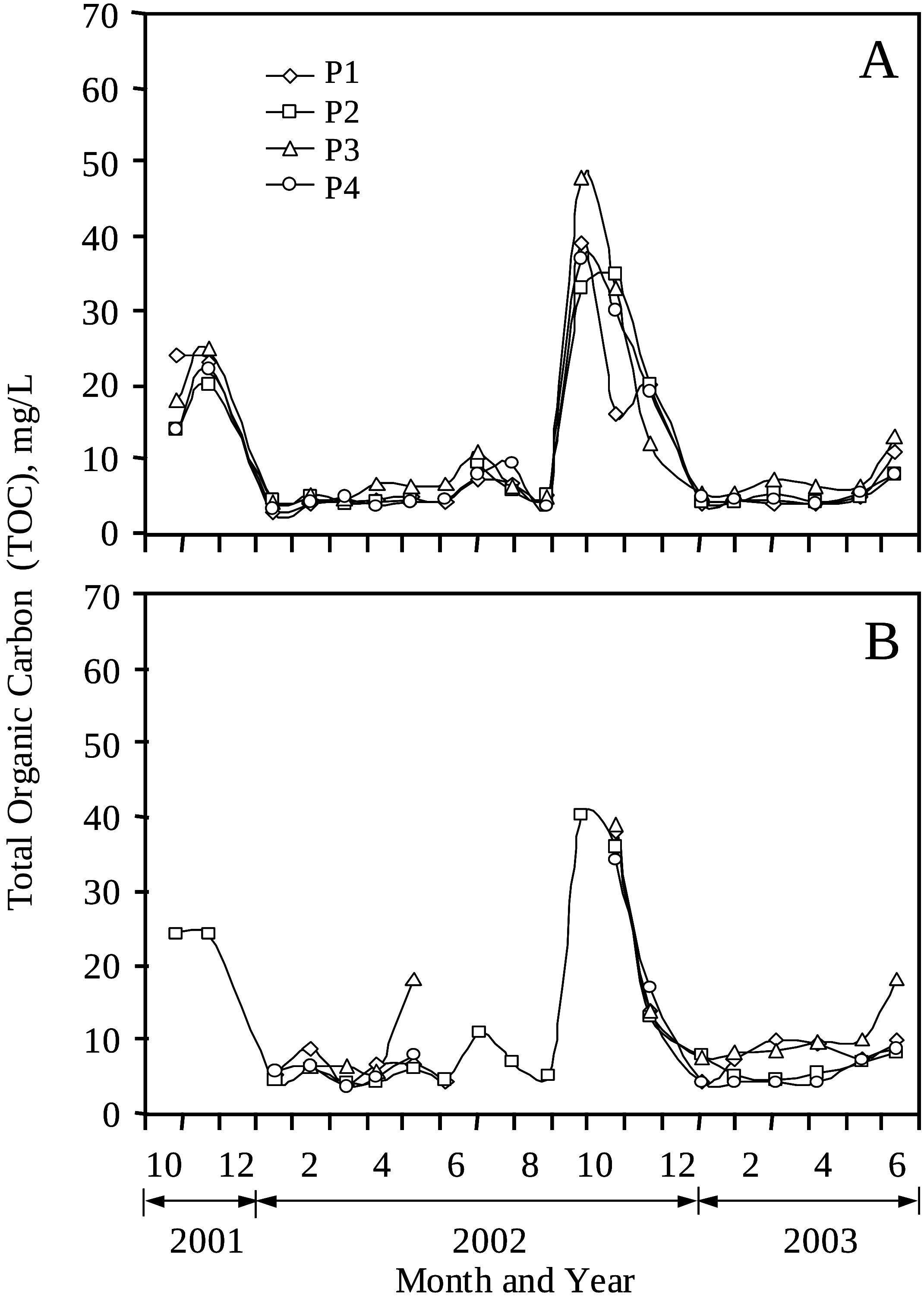

Figure 41. Total organic carbon (TOC) concentrations of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 6.

System 3

This was a conventional (gravity fed) septic system designed for 480 gallons per day wastewater flow. Based on the water meter readings, the average daily water use by the homeowners from September 2002 through June 2003 was 608 L (161 gallons). For the summer months the meter readings indicated high volume of water use. The high volume of daily water use was perhaps due to irrigation of lawns and ornamental plants at this site. The average daily water use in winter months is typical for households with two or three occupants. Based on the 608 L average daily water use, this system received 1/3rd of the design flow rate for most of the year.

Ponding in Trenches

The level of ponding at seven locations inside the trenches of this conventional septic system was measured from November 2002 through July 2003 (Fig. 42). [For locations of the observation wells (OW) in the trenches see Fig. 8.] Locations 1 and 2 were at the beginning of the trenches. The depth of wastewater ponding at location 1 varied between 2 and 8 cm. There was a lesser amount of ponding in the lower trenches at location 2. The highest level of ponding,

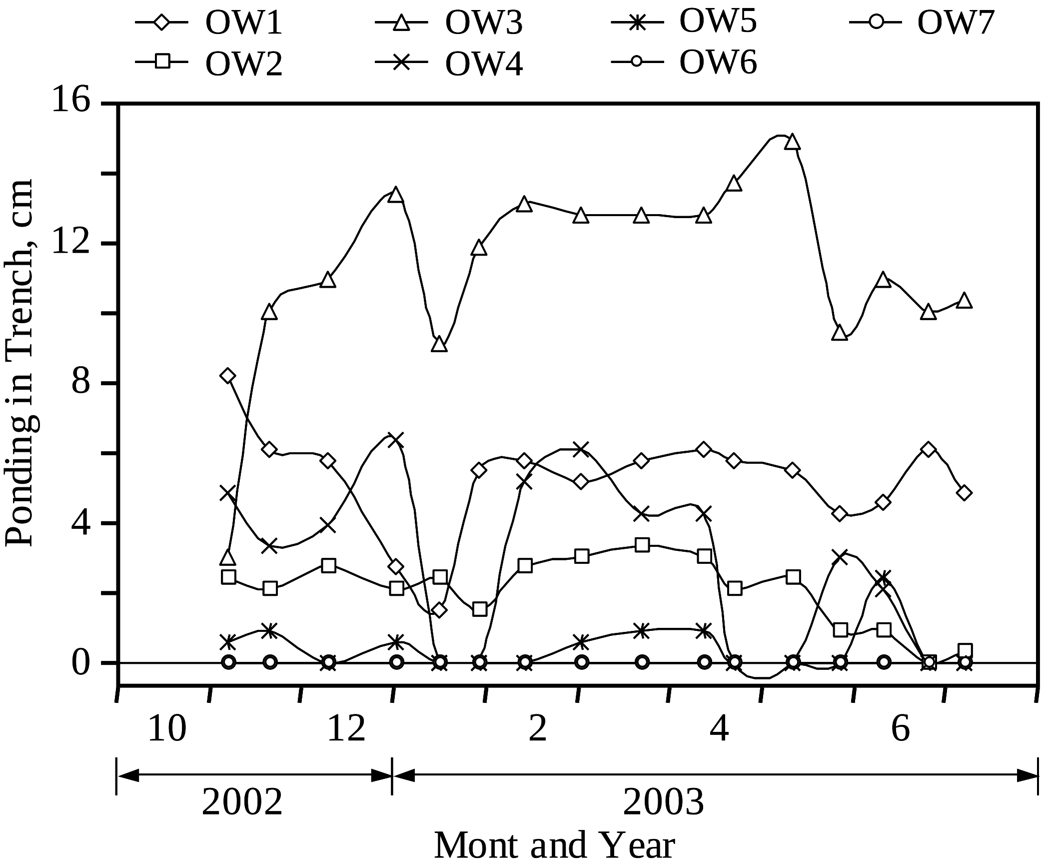

Figure 42. Wastewater ponding in the trenches of System 3. For locations of observation wells in the trenches see Fig. 8.

approximately 15 cm, was measured at location 3 in the upper drainline. This location is near the driveway and may receive runoff from paved areas. There was little ponding at location 5 and virtually no ponding at location 6 at the end of the trenches. The trenches of this system had a step down, and no depth of ponding was measured in the observation well that was installed near the step down. Although ponding was observed continuously in part of each trench, this system appeared to function properly. Both trenches received wastewater (although we cannot verify that they receive equal amount of wastewater). Ponding in the trenches was forced because of the step down. Since no ponding was observed at the end of one of the trenches, it is possible that all the applied wastewater infiltrate the soil within the upper part of the trenches before getting to the step down. Also, keep in mind that this system routinely received 1/3rd of the daily design flow.

Water Table Elevation

The distances between the drainfield of this system and the creek on the south and the creek on the west (see Fig. 8) were more than 150 and 60 m, respectively. The water level elevations in the wells are presented with respect to a bench mark, therefore, they are relative with each other rather than being relative to the bottom of the creek. All three wells at this site were below the drainfield. Except for a short time, the water level elevation in Well #2 was always higher than the others (Fig. 43). Except for January 2002, the water level elevations in Well #3 were lower than the other wells. Wells #1 and #2 were located at about the same land elevation. The difference in the water level in these two wells indicated that ground water moved from north-west toward south-east direction. It appears that ground water from this system does not move directly toward the creek on the south side.

The water elevations in the piezometers indicate the relative soil water pressure head at the bottom end of the piezometers. The patterns for the water level elevation in the three piezometers were similar to the patterns for the water table elevation (see Fig. 43). From March through June, 2003, there was little difference between the water table elevations in the well and the piezometers at any of the three locations. During winter months, water level in the piezometer was higher than the water table at location 2 and lower than the water table at location 3. Overall, the results for water level in the piezometer tubes corresponded fairly well with the water table elevations at three locations.

Soil Water Content and Pressure Head

The soil water contents at five depth intervals measured at four locations on a transect perpendicular to the drainlines (see Fig. 8) of this system are presented in Figs 44 and 45. Except for the upper 15 cm, the soil water content above the drainlines (location TDR1 in Fig. 8) did not change substantially during the monitoring period (Fig. 44). Inside the drainfield, the water contents at 60 to 90 and 90 to 120 cm depth intervals remained relatively high at all times. The soil water content in the upper 60 cm showed little difference between summer and winter months. At the third location (TDR3), also inside the drainfield, the soil in the upper 60 cm appear to be drier than the other two locations above it. At 90 to 120 cm depth interval, the soil water content remained around 46% with a small temporal variation. The driest location was below the drainfield. Relatively high soil water content at location TDR1 above the drainlines is perhaps due to runoff that comes from a rather large driveway sloping toward the drainfield area. Because of gravity distribution, it is hard to estimate the amount of water that infiltrates the soil in the area where monitoring devices were installed. Inside the drainfield, the highest soil water content was at 90 to 120 cm depth interval. This could be explained if the trenches were 90 cm deep. Also, the highest level of ponding in the trenches was observed at this location.

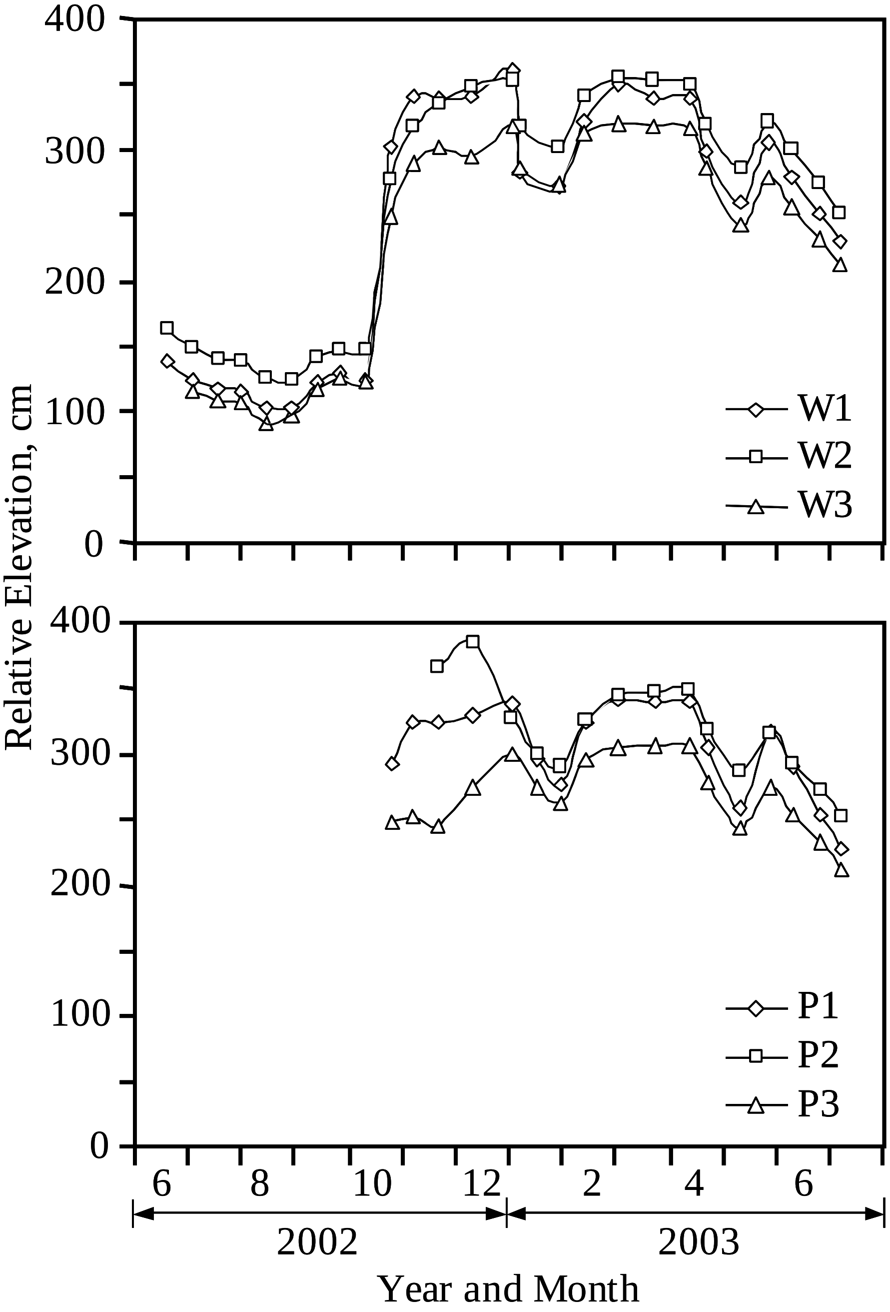

Figure 43. Relative water table elevations in the wells (W) and piezometers (P) at three locations from June 2002 through July 2003 for Site 3.

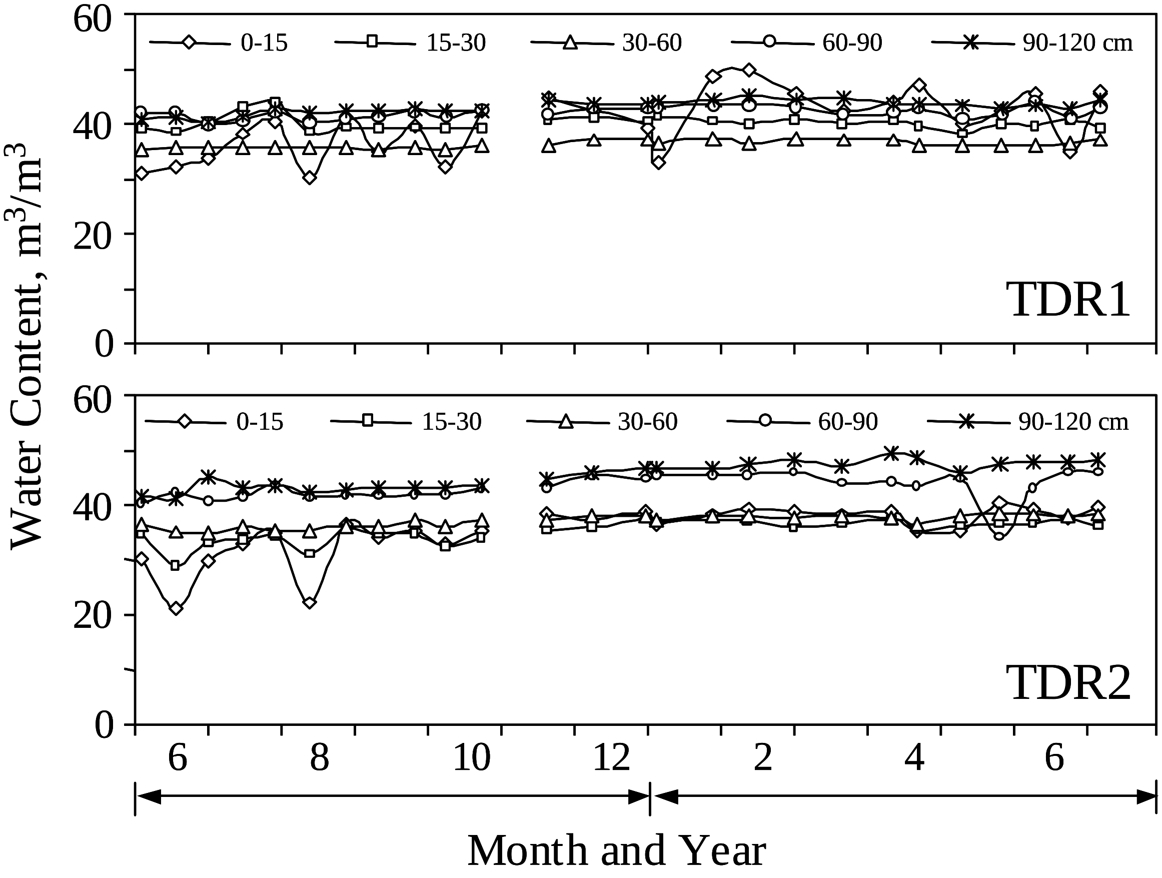

Figure 44. Soil water contents at five depth intervals measured in situ by the TDR technique at locations 1 and 2 at Site 3. For locations of the TDR measurements see Fig. 8.

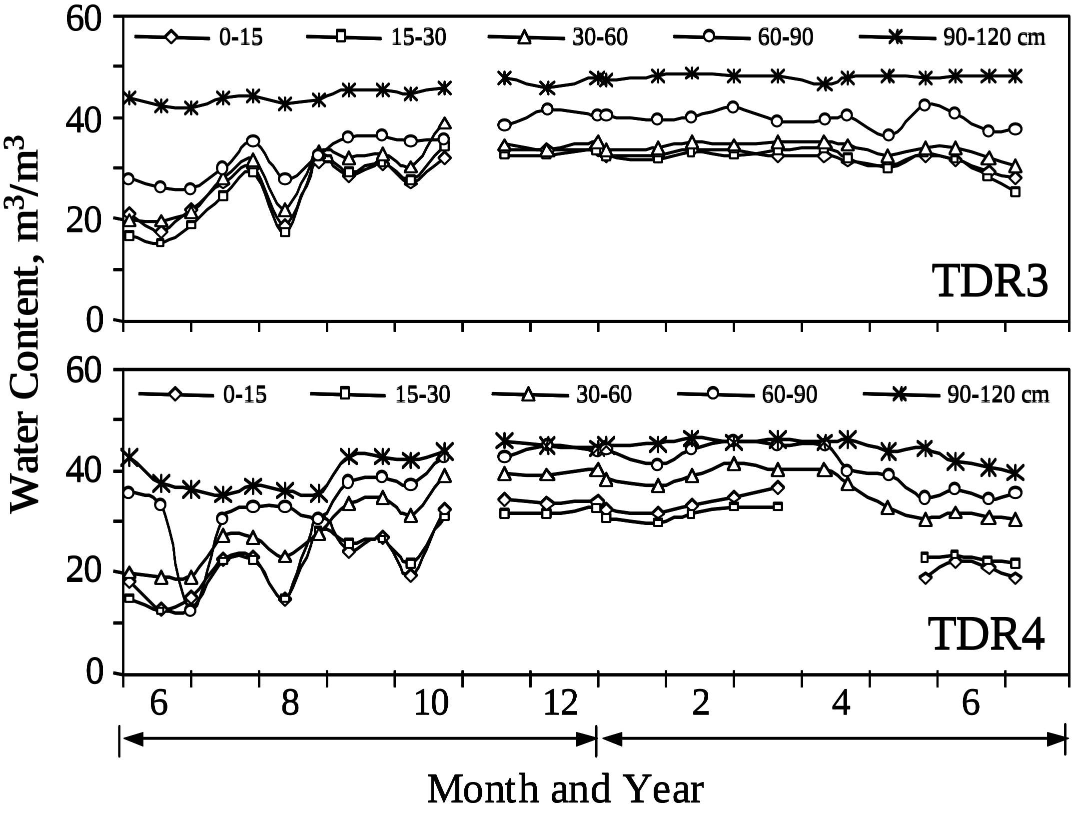

Figure 45. Soil water contents at five depth intervals measured in situ by the TDR technique at locations 3 and 4 at Site 3. For locations of the TDR measurements see Fig. 8.

The pressure heads for 3 depths at 12 locations were measured from June 2002 through July 2003 (Figs. 46, 47 and 48). At locations 1 and 2 the soil water pressure head remained fairly uniform and did not decrease below -60 cm at any depth/location, indicating wet condition. The tensiometer results are consistent with the soil water content values obtained by TDR, and the level of wastewater ponding in the upper trench at this location. Because the trenches were 60 to 90 cm deep and contained water at all times, it is very possible to have zones of saturation around this area. In some instances, the soil water pressure head measured with tensiometer was positive indicating that the tensiometer cup was in the middle of a saturated zone (submerged below a perched water table). We should also mention that readings of soil water pressure head by a tensiometer could become positive when a macropore that intercepts the tensiometer cup becomes filled with water. If this happened, the tensiometer will read a positive pressure head value even though the soil matrix around the tensiometer cup may be unsaturated.

At location 3 between the two trenches on the east side of the drainfield (tensiometer T3) the soil water pressure head was also fairly constant after June, 2002 (Fig. 47). This location was near the end of the trenches before the step-downs. Based on the level of wastewater ponding in the

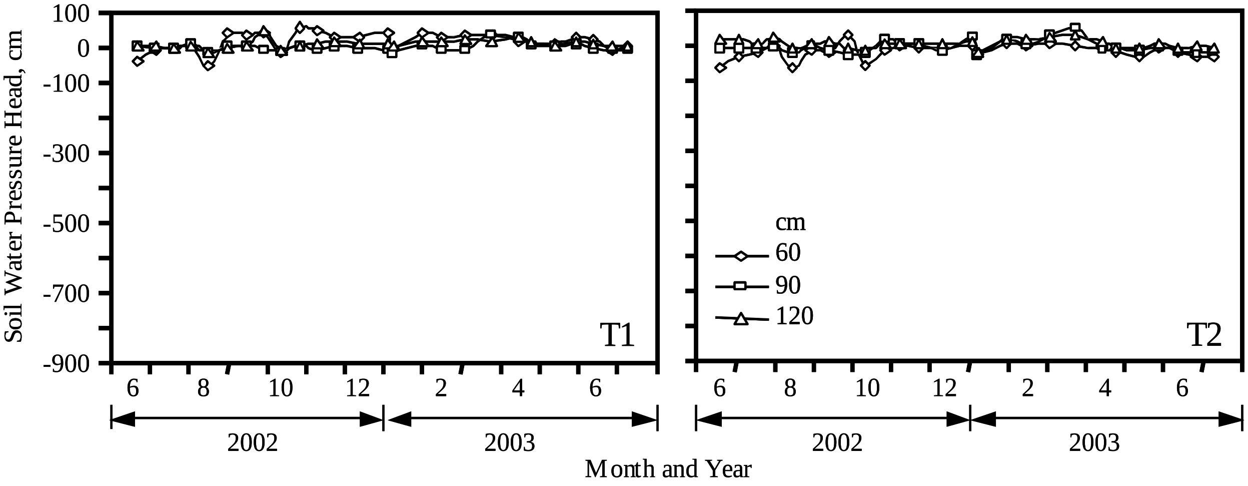

Figure 46. Soil water pressure heads for three depths at two locations around the upper trench at Site 3. For locations of the tensiometer banks see Fig. 8.

trenches at this area of the drainfield, it is possible to have zones of saturation or macropores filled with water during most of the year. Moving down on the landscape to the 4th location (T4) between the trenches after the step-downs, soil water pressure heads indicated near saturation conditions only some times during the late fall, winter, and early spring. Outside of the drainline at location 5 (T5), the soil water pressure head had a similar trend to location 4, but indicated a longer duration of unsaturated conditions. The results were consistent with the TDR readings, which indicate lower soil water content during summer months as compared to when evapotranspiration is low. Similar trends were obtained for sites 6 and 7, with lesser duration of near saturation than their corresponding locations higher on the landscape.

At location 8 above the drainfield near the beginning of the trenches soil water pressure head was near close to zero indicating near saturated conditions from October through June (Fig. 48). During summer of 2002, the soil water pressure heads, particularly for the 60 and 90 cm depths were below -100 cm. Moving down the landscape, the duration when soil water pressure head was less than -100 cm increased, and the soil became drier (see results for T10 to T12 in Fig. 48).

Overall, the tensiometer results corresponded fairly well with the soil water content variation with time and space as well as to the wastewater ponding levels in the trenches.

Distribution of Chemical Constituents

Acidity (pH) and Electrical Conductivity (EC): The pH values for the water at four locations in the two creeks adjacent to the property are shown in Fig. 49. The pH of the water in the creek varied between 6 and 7.2 for the monitoring period. The results are consistent with the pH for the surface water in the creek at the other two sites a few miles away. The pH of the soil solution

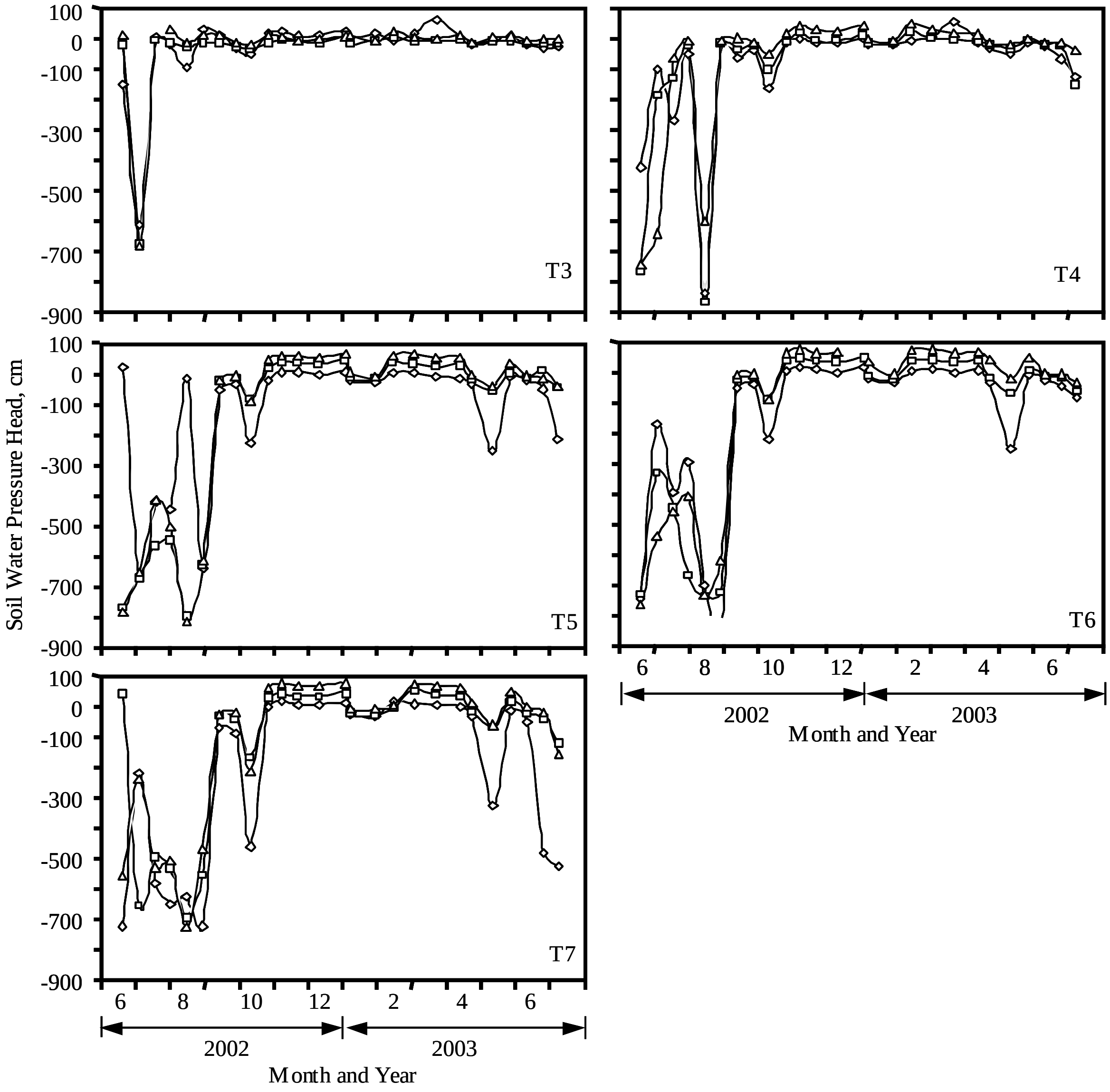

Figure 47. Soil water pressure heads for three depths at five locations along a transect perpendicular to the trenches at the end of the drainfield at Site 3. For locations of tensiometer banks see Fig. 8.

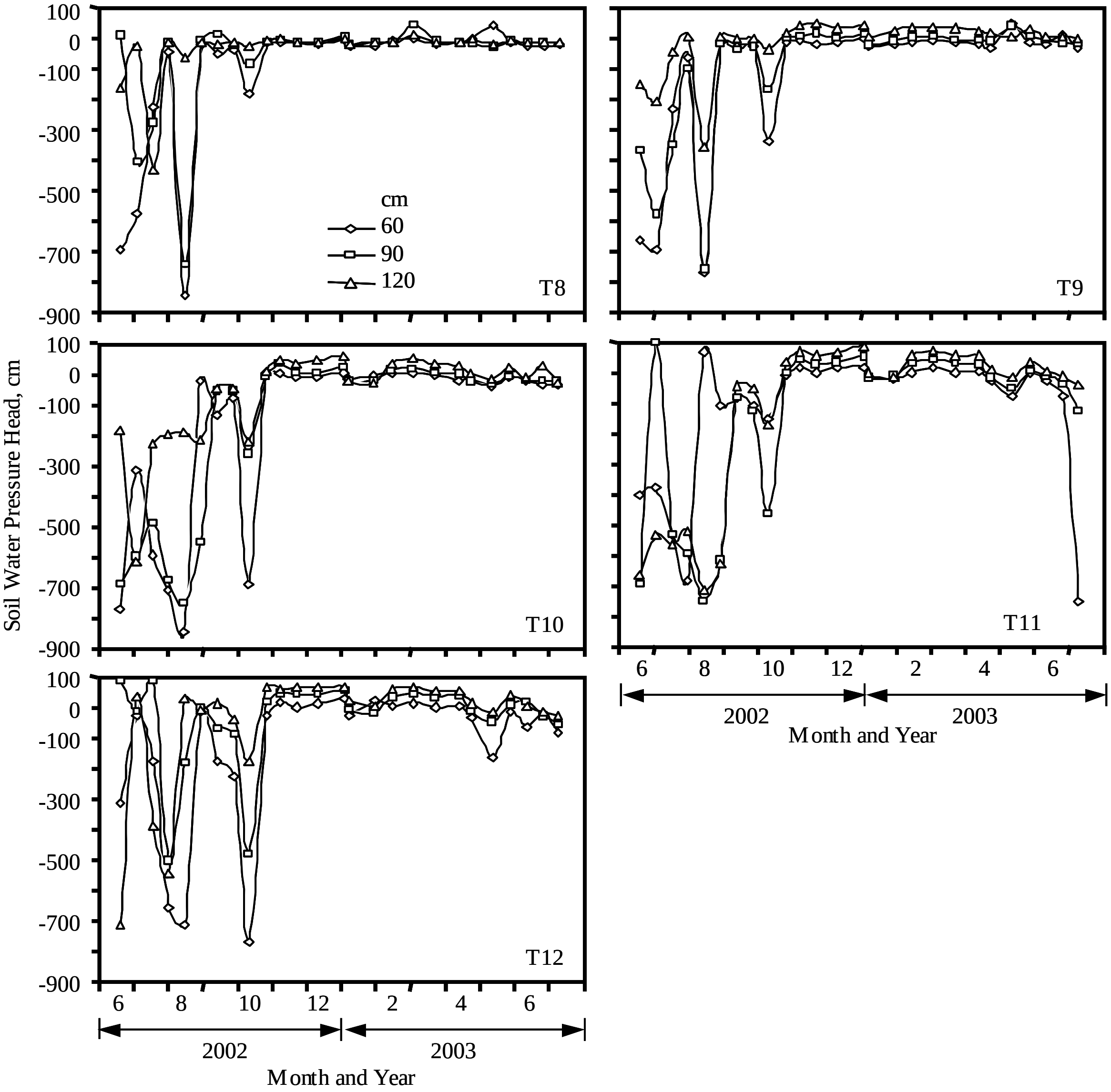

Figure 48. Soil water pressure heads for three depths at five locations along a transect perpendicular to the trenches at the beginning of the drainfield at Site 3. For locations of tensiometer banks see Fig. 8.

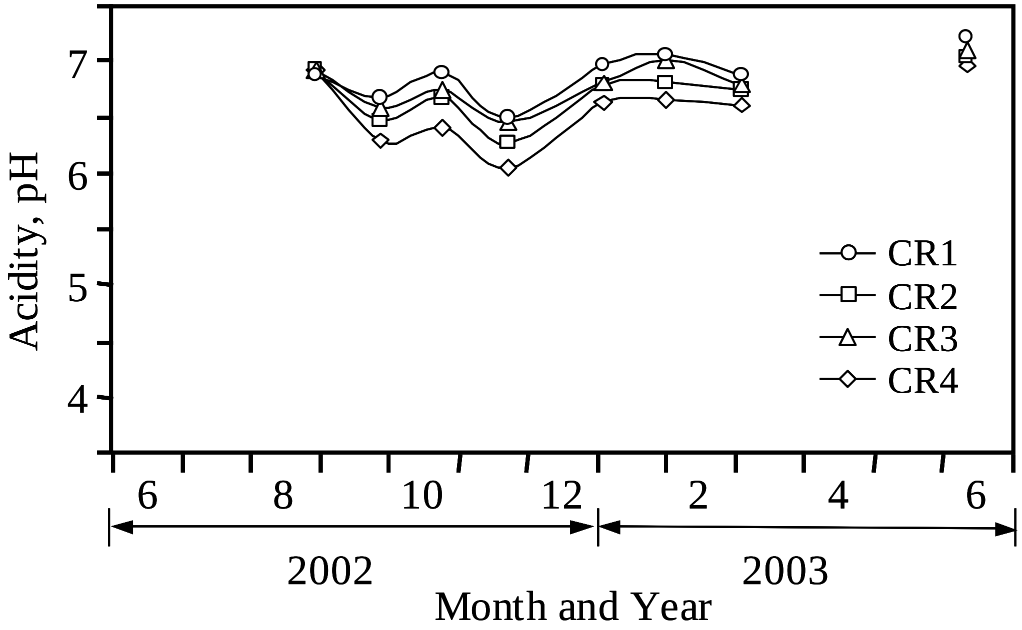

Figure 49. The acidity (pH) of the water at four locations in the creeks adjacent to the property for System 3. For sampling locations see Fig. 8.

samples collected by the tension samplers varied between 6 and 7.3. The ground water pH, however, was substantially lower and varied between 5 and 6.3. Similarly, the pH of the water samples collected from the piezometers remained below 6.5. Graphs showing pH for the soil solution and ground water samples are presented in Appendix C.

The electrical conductivity of water samples collected from the main creek on the south side of the property (average of 81 µS/cm at locations CR3 and CR4) was slightly higher than the water samples from the side creek (average of 61 µS/cm for locations CR1 and CR2). In general, the EC of the ground water samples collected at this site was relatively low. Occasionally, the measured EC of ground water samples was above 100 µS/cm. The EC of the samples of the soil solution collected from the unsaturated zone near the trenches at two locations was more than 100 µS/cm for most samples. The average EC values for the four tension samplers ranged between 131 and 225 µS/cm. The EC of all the water samples from the creek, ground water and soil solution are presented in Appendix C.

<u>Ammonium (NH_4-N) and Nitrate Nitrogen (NO_3-N):</u> The NH_4-N concentrations in the water samples collected in the creeks were relatively low and with one exception did not exceed 0.5 mg/L (Fig. 50). The NH_4-N concentrations in the well samples remained below 0.4 mg/L. Only during January 2003 the NH_4-N concentration in the well water samples was above 0.5 mg/L. A similar trend was observed in the samples collected from the piezometers. In general, NH_4 concentrations in the samples from the wells and piezometers had a similar trend. Ammonium-N concentrations in the soil solution samples collected by the tension samplers were generally less than 0.5 mg/L, but increased to more than 5 mg/L only once in two of the tension samplers. The NH_4-N concentrations in the ground water and soil solution samples are shown in Appendix C.

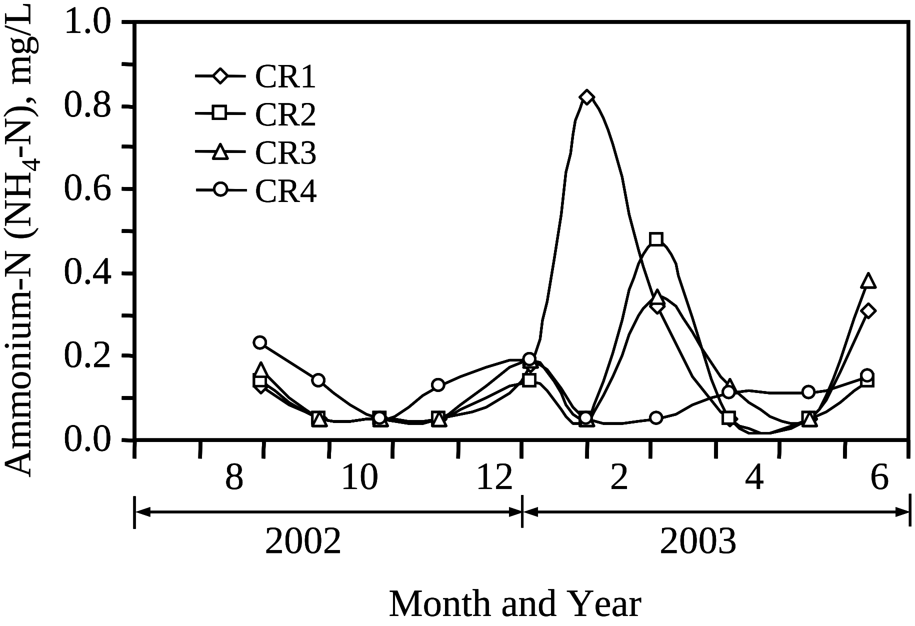

Figure 50. Ammonium-N (NH_4-N) concentrations in water at four locations in the creeks adjacent to the property for System 3. For sampling locations see Fig. 8.

The concentrations of NO_3-N in the creeks were also very low (Fig. 51) and did not exceed 0.4 mg/L during the monitoring period. In the soil solutions collected from the tension samplers, on the other hand, NO_3-N concentrations reached as high as 18.5 mg/L (Fig. 52). Overall, the soil solution had higher nitrate concentration than the ground water. Nitrate-N concentrations in the samples collected from the wells and piezometers remained below 7 mg/L, but showed relative increases during late spring 2003 (Fig. 53). The nitrate concentrations in piezometer samples were relatively low and showed a substantial increase after March 2003 for two of the piezometers (Fig. 53). Overall, based on the ammonium and nitrate in the samples from near the trenches it appears that this septic system is functioning properly by maintaining an unsaturated zone below the trenches and converting the ammonium in the septic tank effluent to nitrate. Lower nitrate concentration in the ground water compared to soil solution samples perhaps indicates reduction in nitrate concentration by dilution or denitrification.

Phosphate -P (PO_4-P): The PO_4-P concentrations in the creek samples were generally below the detectable limit and never reached 0.08 mg/L. For the soil solution phosphate concentration was also below detectable limit for most samples. Only for one sample collected by the tension samplers the PO_4-P level reached above 1 mg/L. Similarly for the ground water samples, the PO_4 concentration was very low during the monitoring period. The results for the creek water, soil solution and ground water are presented in Appendix C.

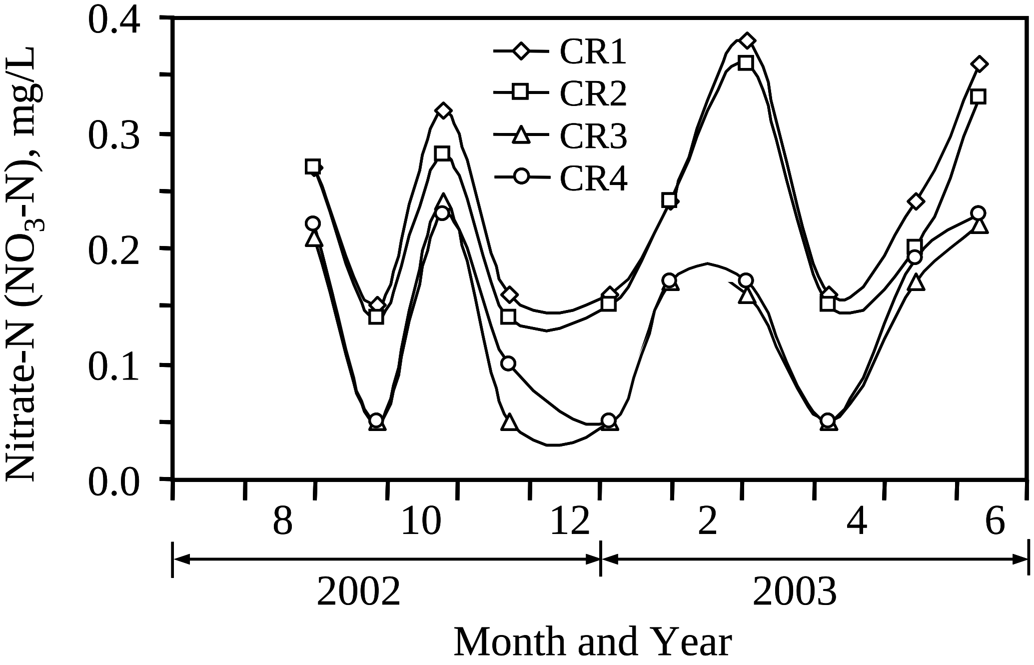

Figure 51. Nitrate-N (NO_3-N) concentrations in water samples collected at four locations in the creek adjacent to the drainfield of System 3. For sampling locations see Fig. 8.

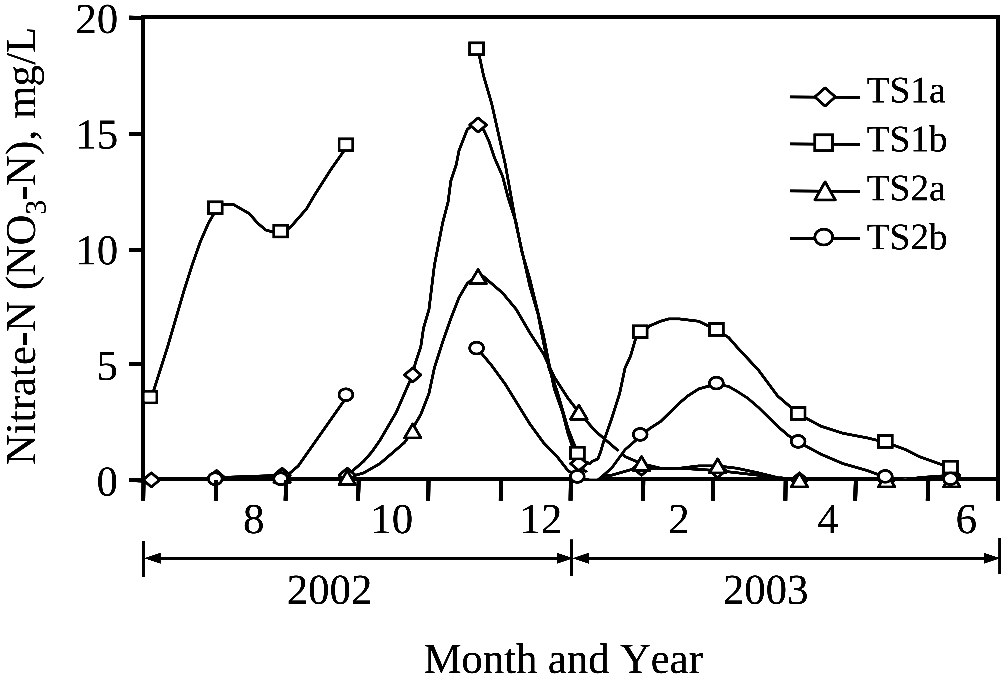

Figure 52. Nitrate-N (NO_3-N) concentrations in soil solution collected by tension samplers for System 3. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

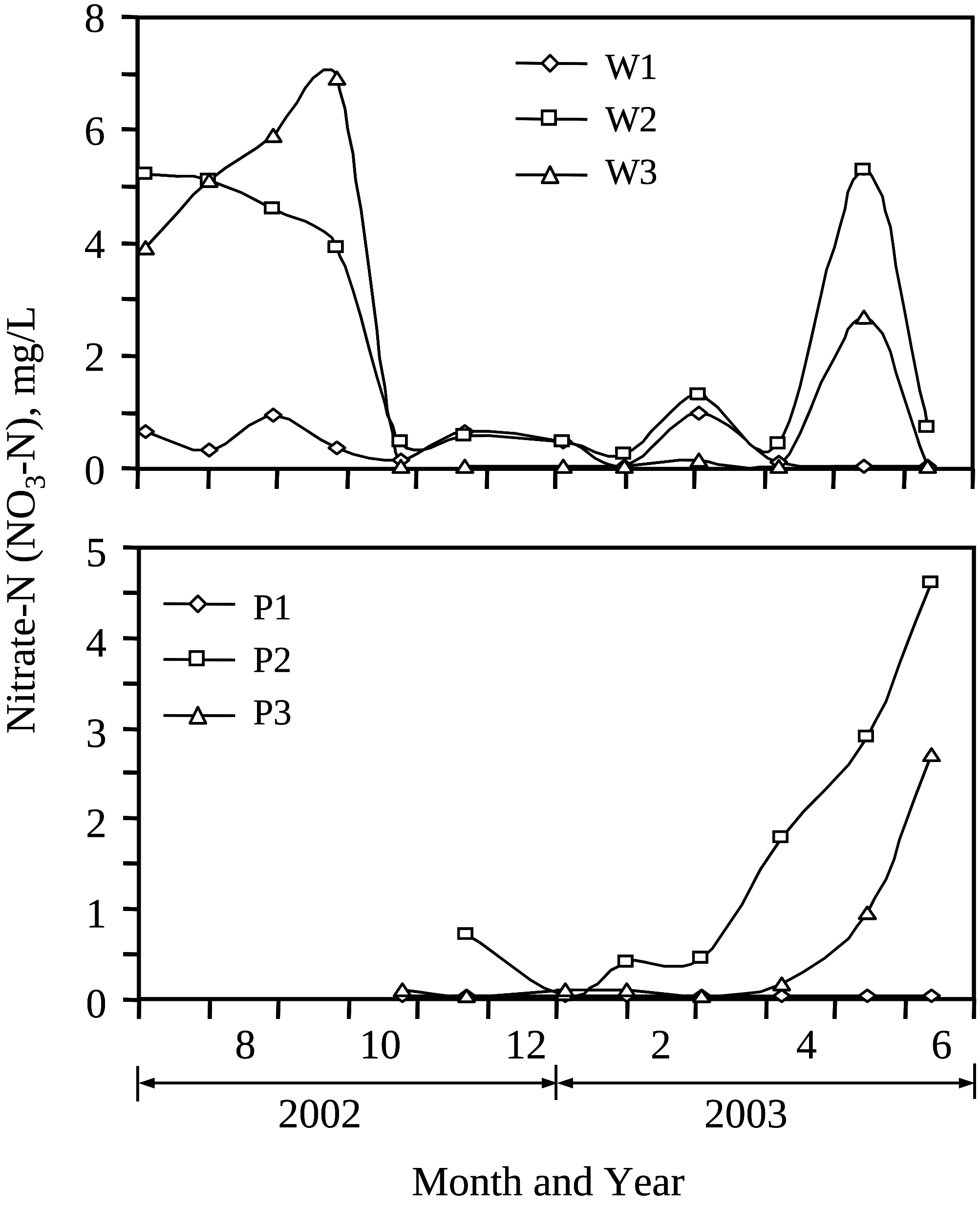

Figure 53. Nitrate-N (NO_3-N) concentrations of the ground water collected from the wells (W) and piezometers (P) at three locations at Site 3. For sampling locations see Fig. 8.

With one exception, the total P concentration in the samples collected from the creeks was less than 0.1 mg/L. The concentrations of total P in the soil solution samples for individual dates matched the phosphate concentration, indicating that most of the P in the soil solution was in the form of phosphate. The results for well and piezometers samples, however, were totally different. Much higher levels of total P than PO_4-P were observed in the well and piezometer samples. The concentration of total P in the samples collected from the creeks, tension samplers, wells, and piezometers are presented in Appendix C.

Total Organic Carbon (TOC): Similar to the other two systems, the TOC concentrations in the samples from the creeks, tension samplers, wells, and piezometers showed relative high concentrations during late September to December (Figs 54, and 55). In the creek, the highest TOC concentration was 32 to 35 mg/L for all four locations. After November, the concentration of TOC was generally lower than 10 mg/L. One sample from the creek (CR1), the samples collected from tension samplers and all the ground water samples showed another moderate increase in TOC concentration during January, 2003 (see Figs 54 and 55). We do not offer a conclusive explanation for higher TOC values during part of the year. Although we have confidence in our sampling and analytical procedure, we cannot discount the possibility of error in creating the high values. However, the trend that we have observed for all our samples would be very interesting if real. Therefore, we believe further investigation is needed to determine if the trend is natural.

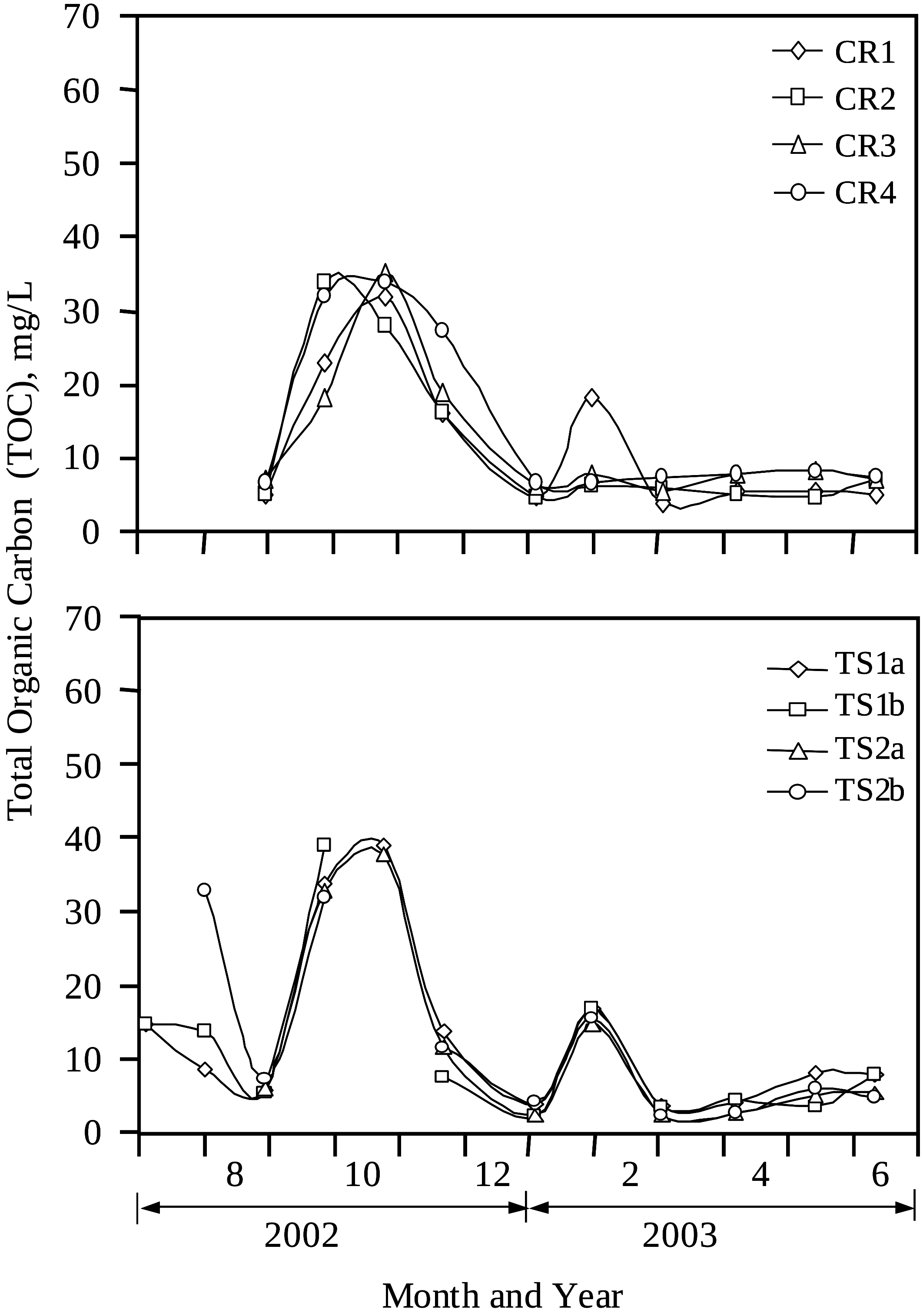

Figure 54. Total organic carbon (TOC) concentrations in the water at four locations along the creeks (CR) and in soil solution collected by tension samplers (TS) in the drainfield of System 3. For sampling locations see Fig. 8.

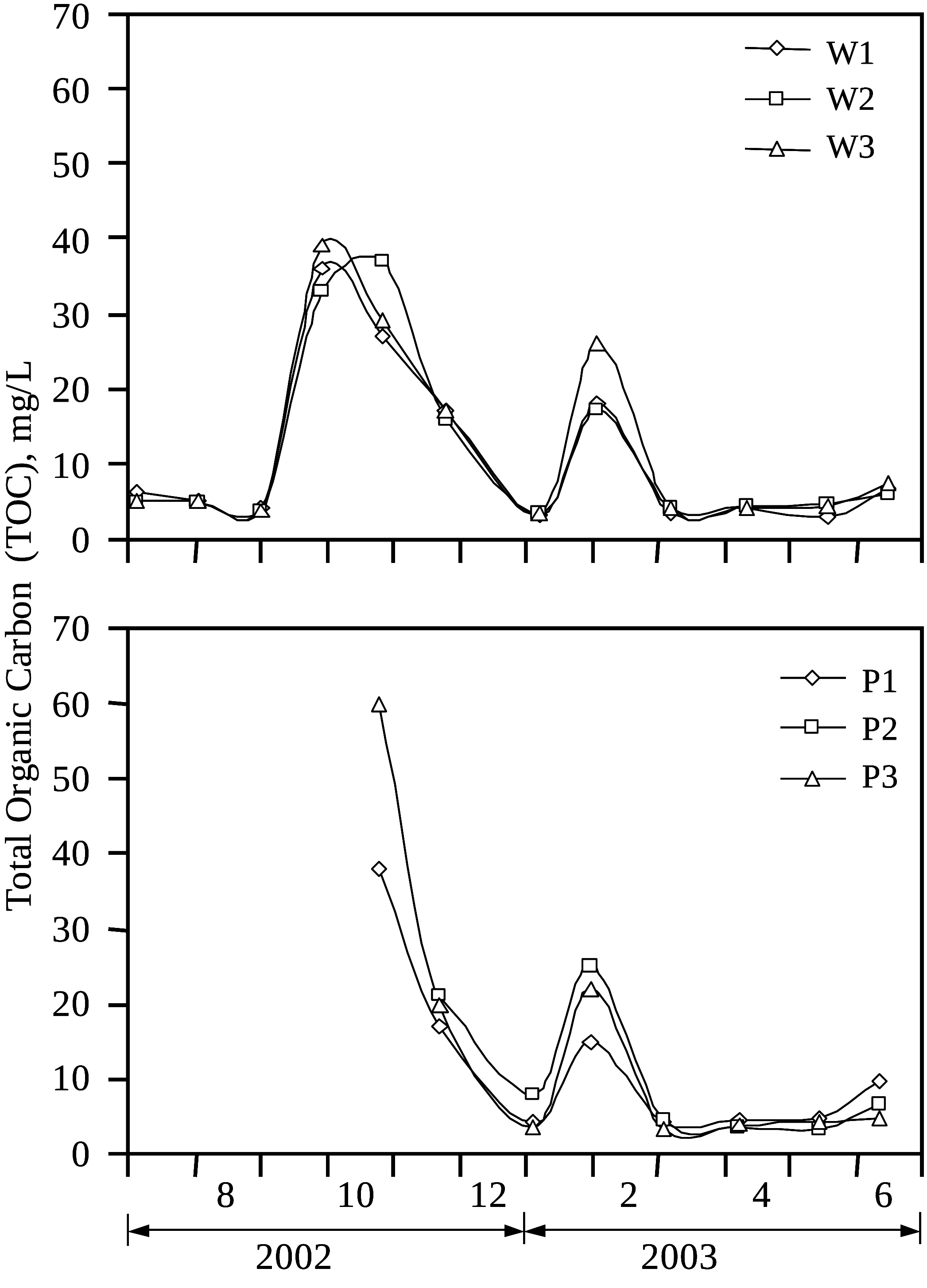

Figure 55. Total organic carbon (TOC) concentrations in ground water collected from three sampling wells (W) and three piezometers (P) in the drainfield area of System 3. For sampling locations see Fig. 8.

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GLOSSARY

Abbreviations

CR	Creek
CV	Coefficient of variability
EC	Electrical conductivity
ET	Evapotranspiration
H	Constant head (depth of water) in hole
K_{sat}	Saturated hydraulic conductivity
LPP (system)	Low pressure pipe (system)
LTAR	Long-Term Acceptance Rate
N	Nitrogen
NH_4	Ammonium
NH_4Cl	Ammonium Chloride
NO_3	Nitrate
NPS	Nonpoint source
OW	Observation well in trench
P	Phosphorus
P(i)	Piezometer (where i is the piezometer number)
pH	Hydrogen ion activity (level of acidity)
PO_4	Phosphate
Q	Steady-state rate of water flow from hole
r	Radius of hole
$\sinh^{-1}$	Inverse hyperbolic sine function

T	Tensiometer
TDR	Time domain reflectometry
TKN	total Kjeldahl nitrogen
TOC	Total organic carbon
TP	Total phosphorous
TS	Tension sampler
W	Well
π	Pi (=3.141593)

Units of Measurement

cm	centimeter
d	day
ft	foot
g	gram
gal	gallon
h	hour
ha	hectare
in	inch
kg	kilogram
L	liter
lb	pound
m	meter
mhos	units of electrical conductance (inverse of ohms)
mg	milligram

mL	milliliter
S	Siemens
μ	micro (as in micrometer, μm)

APPENDIX A

Chemical Characteristics of Surface Water, Ground Water, and Soil Water at Site 1

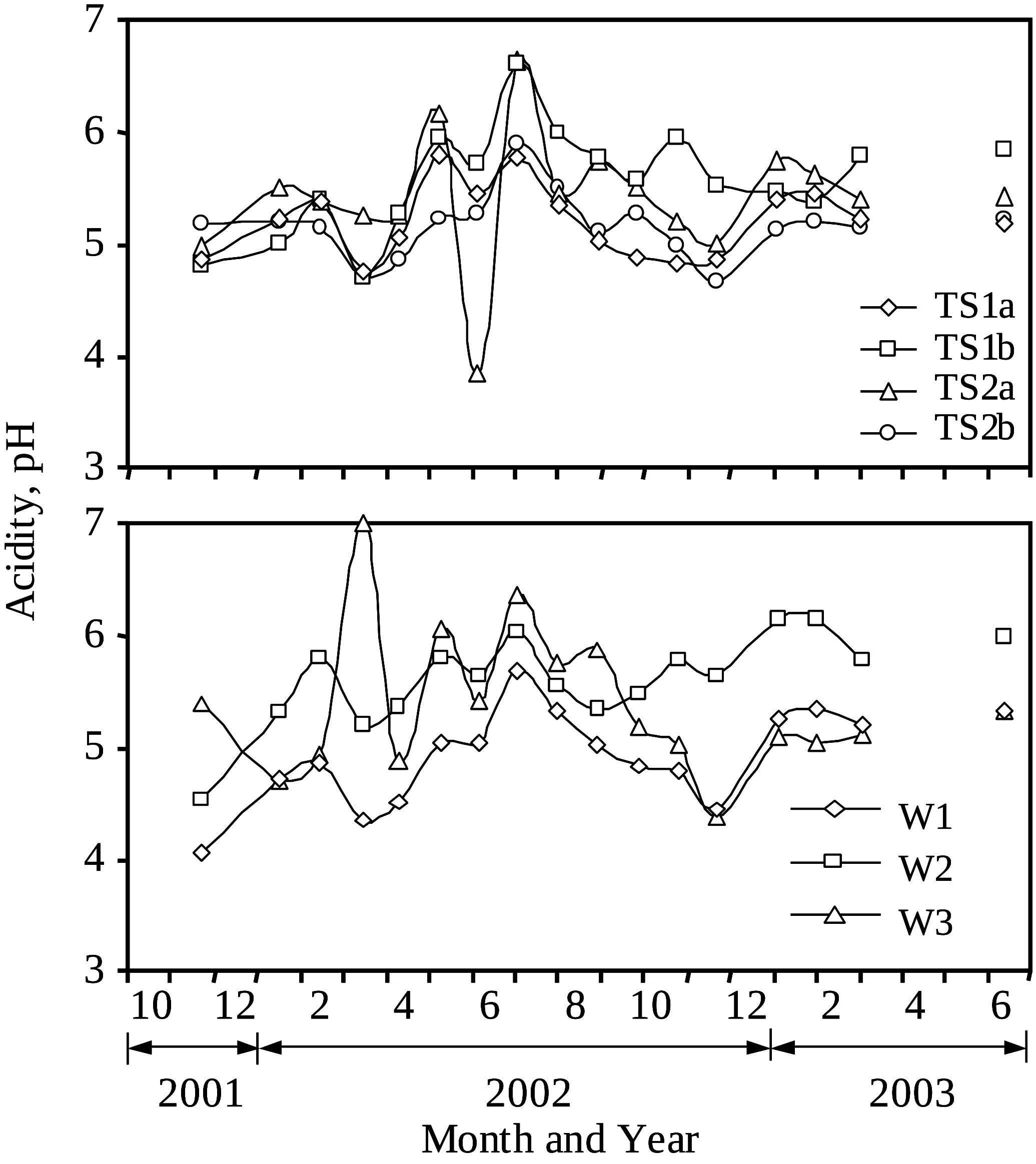

Figure 1A. The acidity (pH) of the soil solution collected by the tension samplers (TS) at two locations and ground water collected by the wells (W) at three locations in the drainfield area of System 1. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

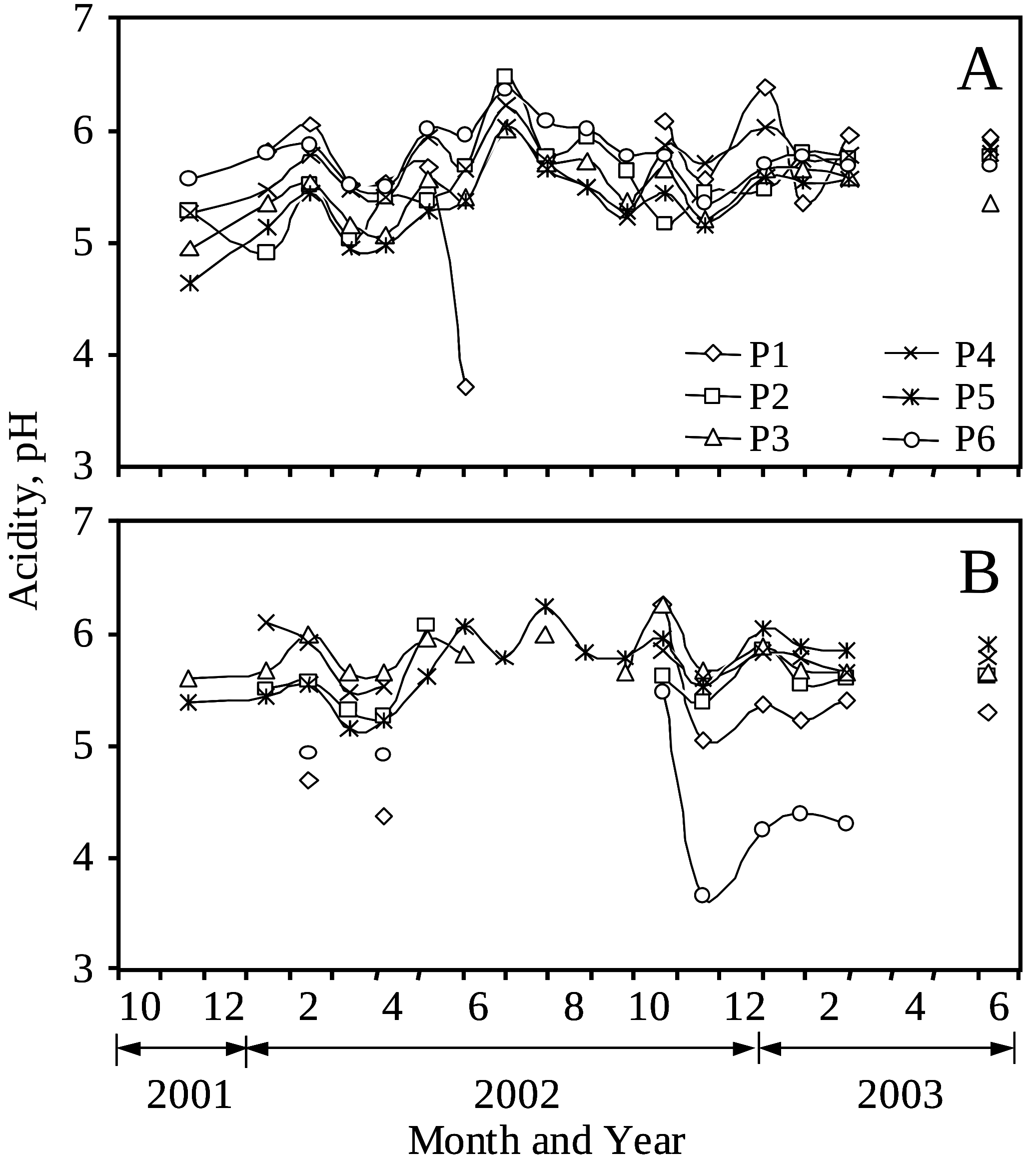

Figure 2A. The acidity (pH) of the ground water at two depths collected from six locations using the piezometers in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

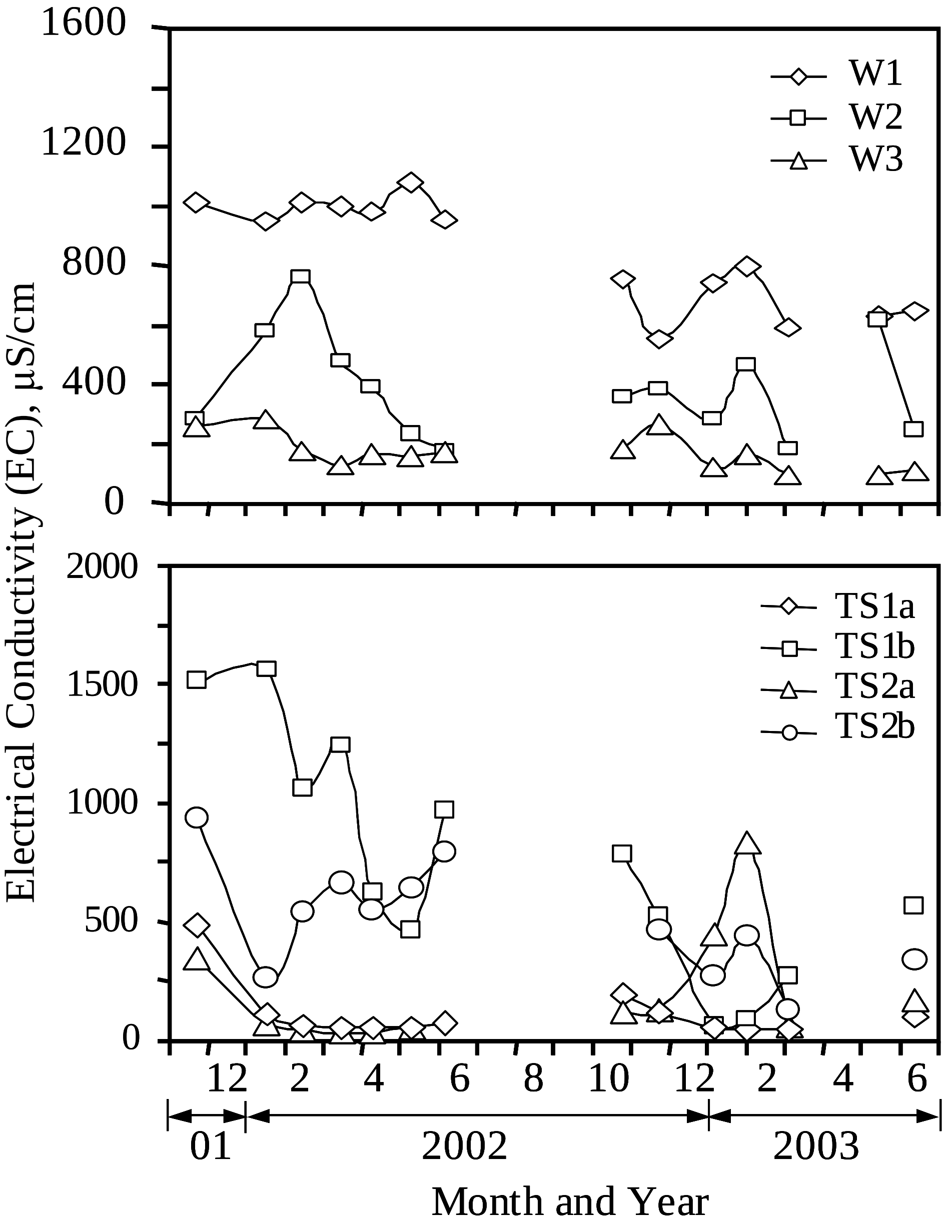

Figure 3A. Electrical conductivity (EC) of the soil solution collected by the tension samplers (TS) at two locations and ground water collected by the wells (W) at three locations in the drainfield area of System 1. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

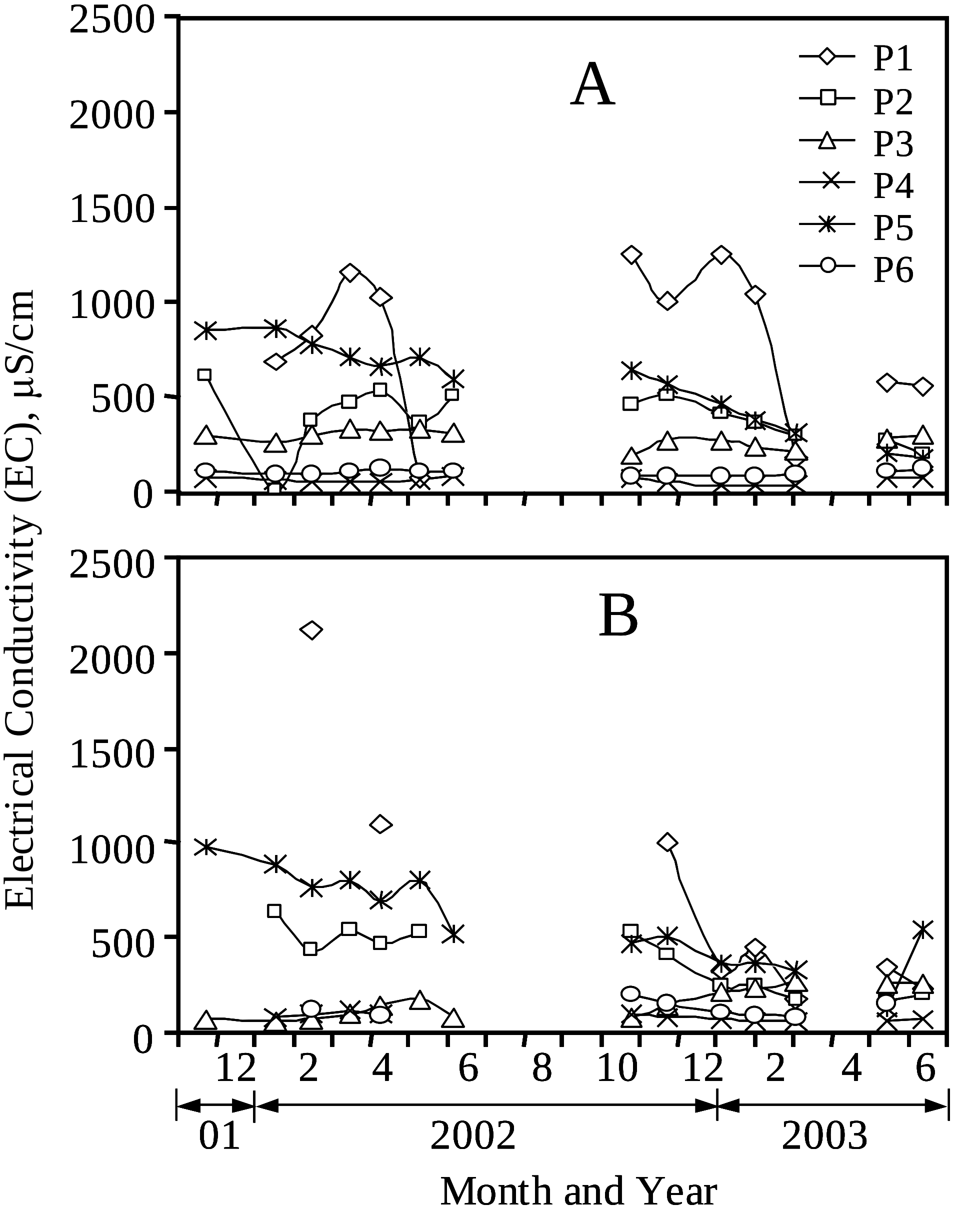

Figure 4A. Electrical conductivity (EC) of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

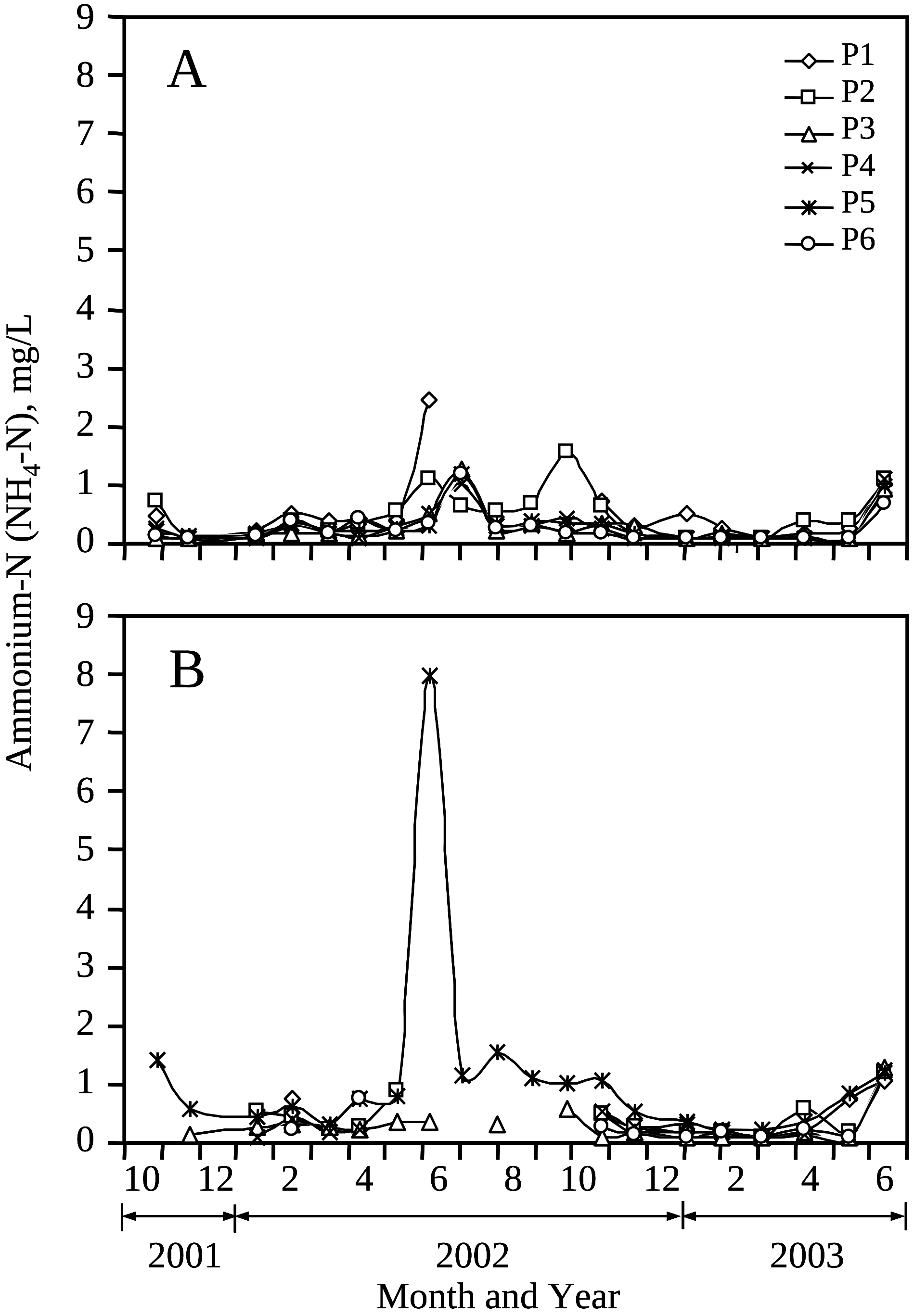

Figure 5A. Ammonium-N (NH_4-N) concentrations of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

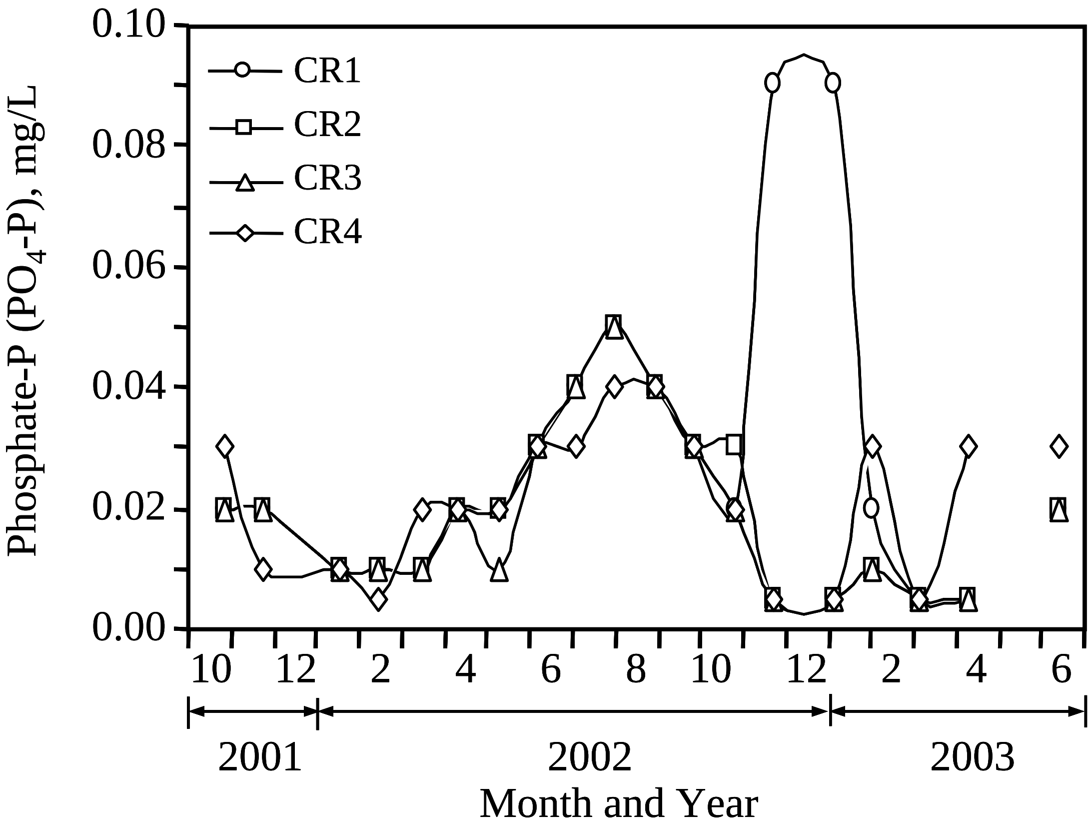

Figure 6A. Phosphate-P (PO_4-P) concentrations in water samples collected at four locations along the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

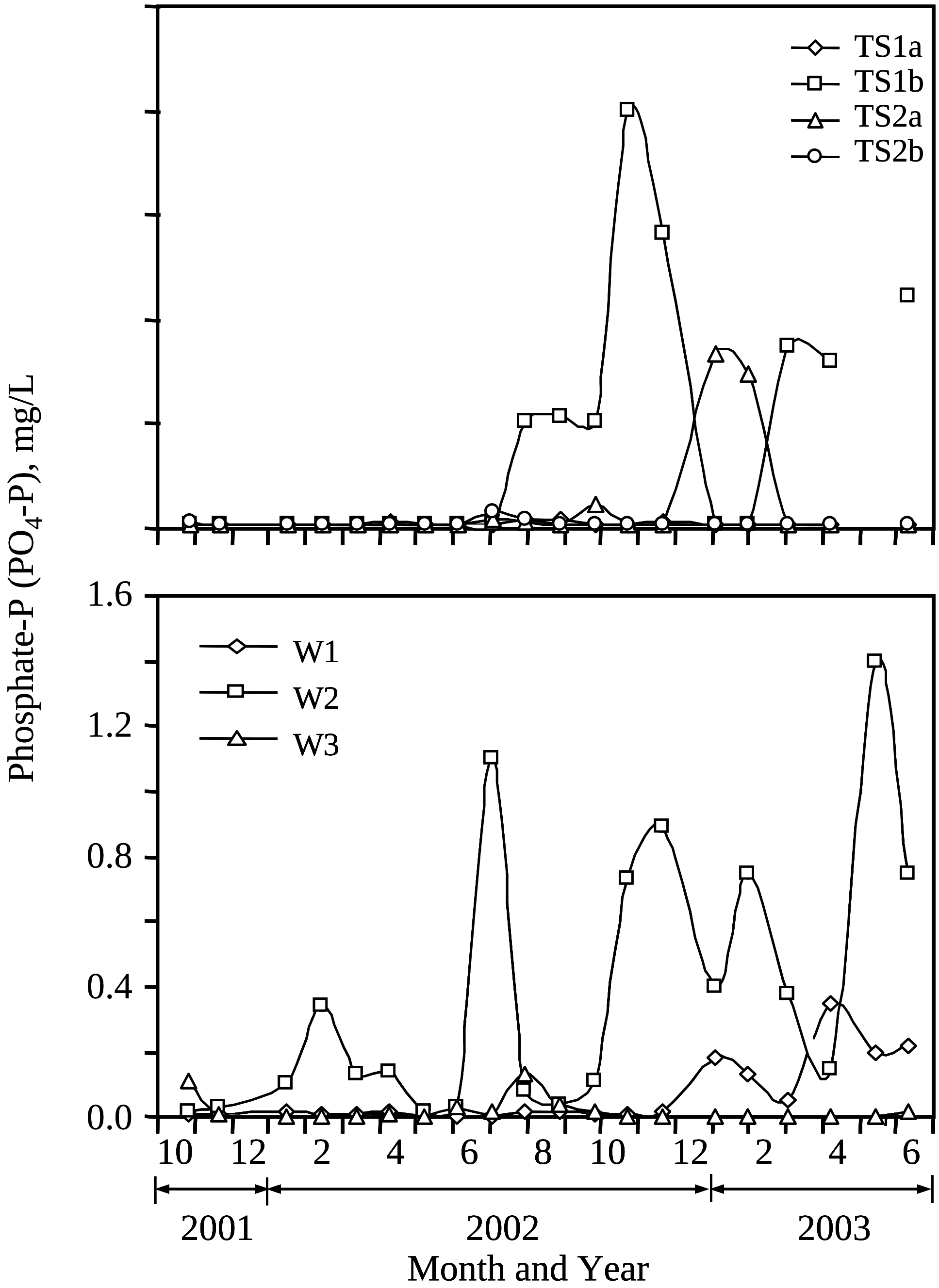

Figure 7A. Phosphate-P (PO$_4$-P) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 1. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

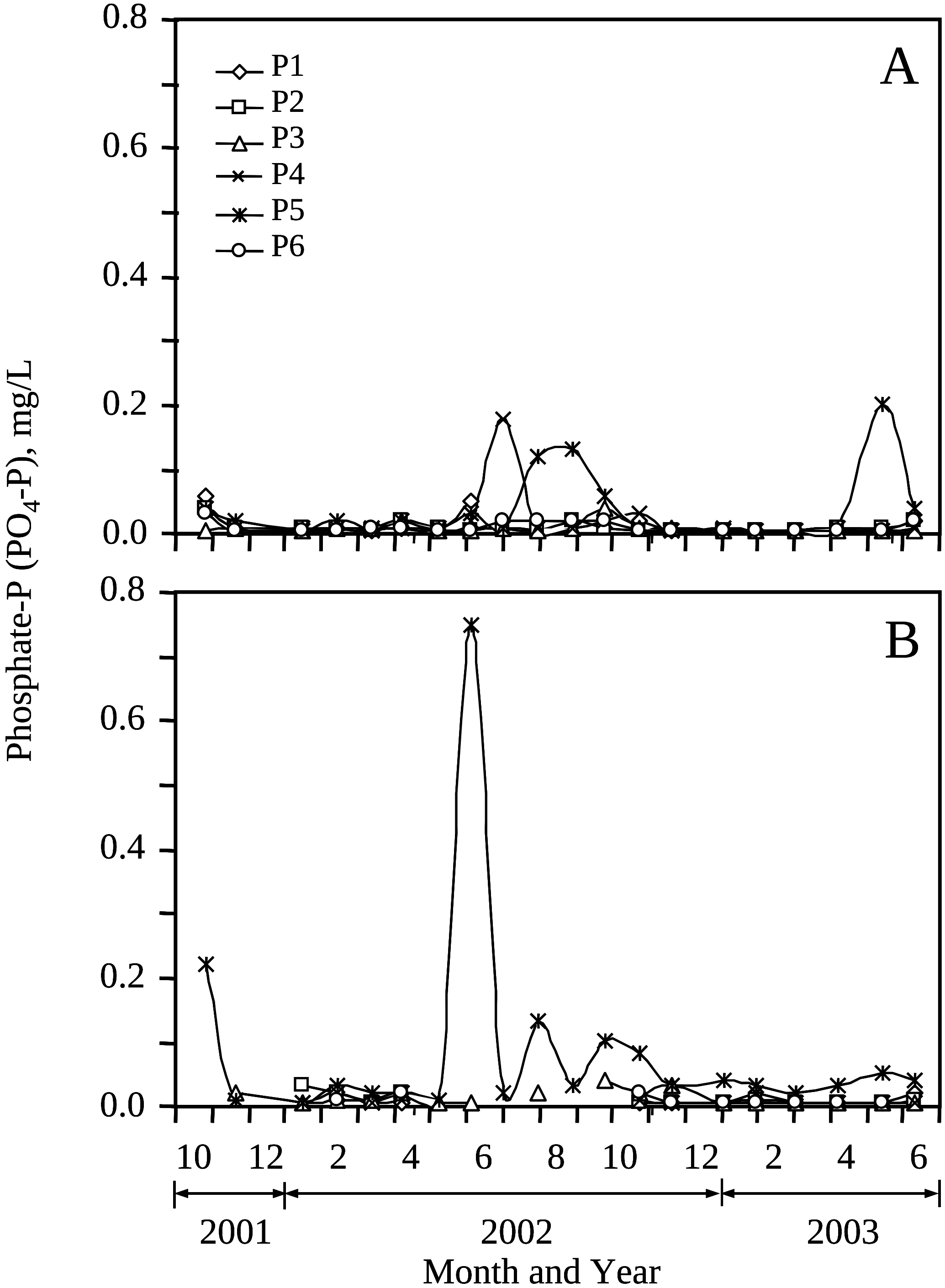

Figure 8A. Phosphate-P (PO$_4$-P) concentration of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

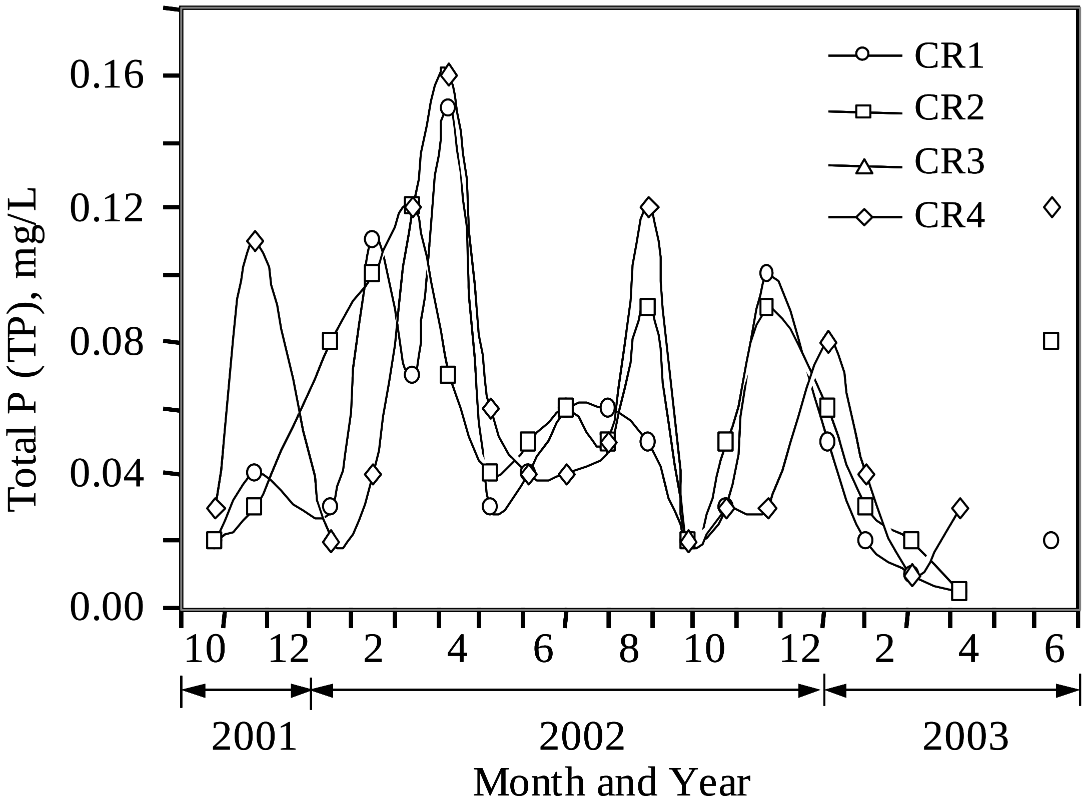

Figure 9A. Total phosphorus (TP) concentrations in water samples collected at four locations along the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

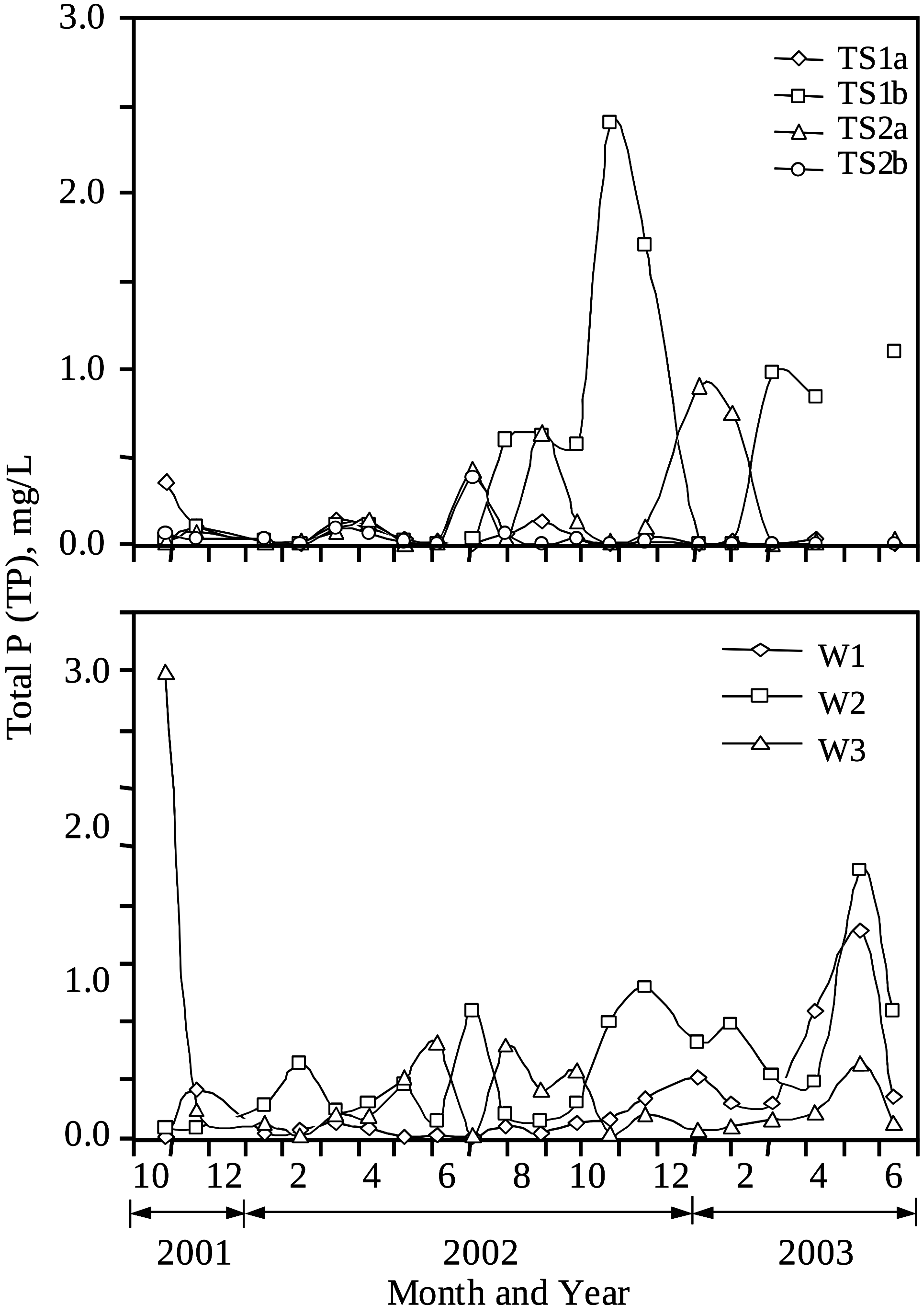

Figure 10A. Total phosphorus (TP) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 1. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

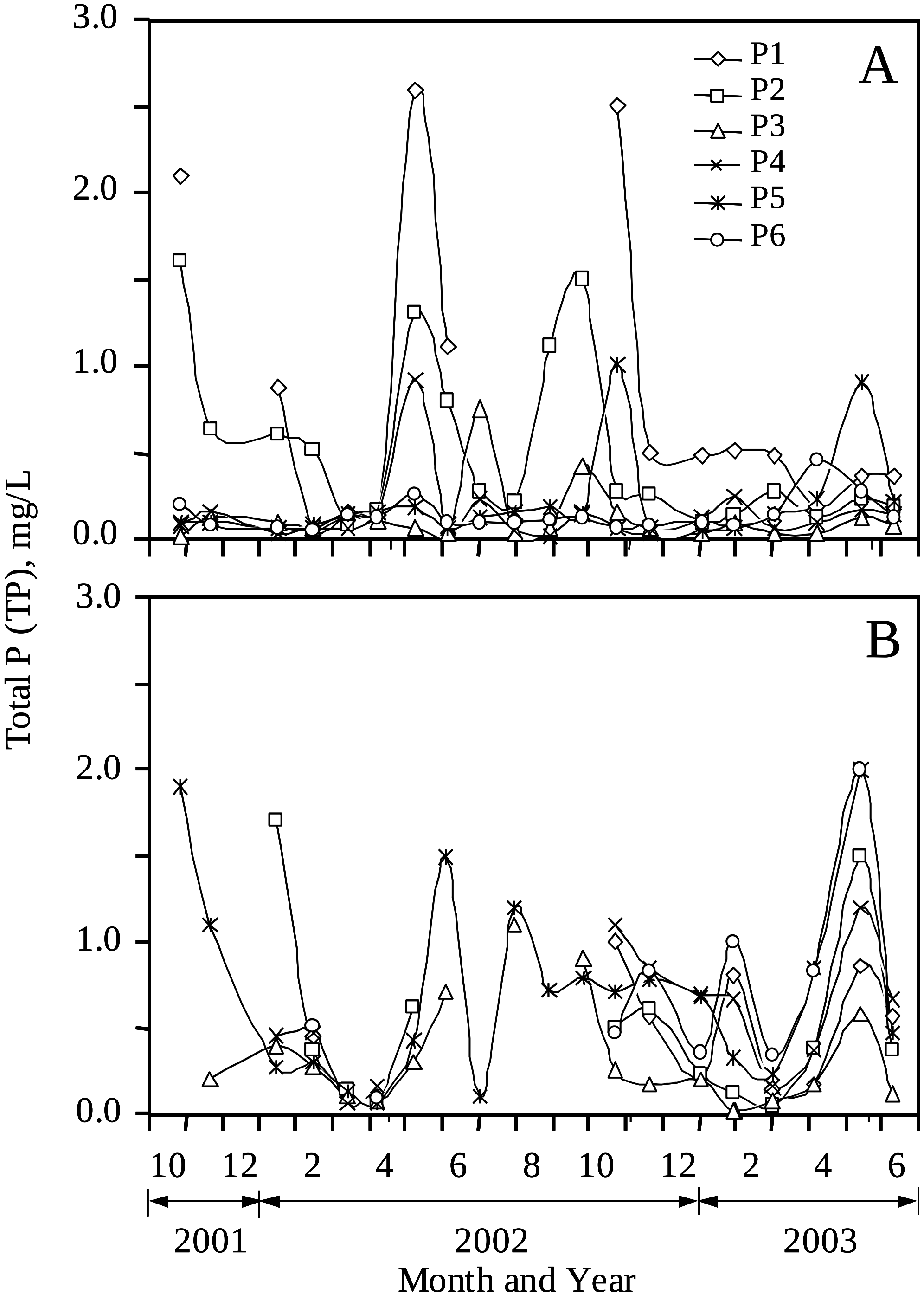

Figure 11A. Total phosphorus (P) concentrations of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

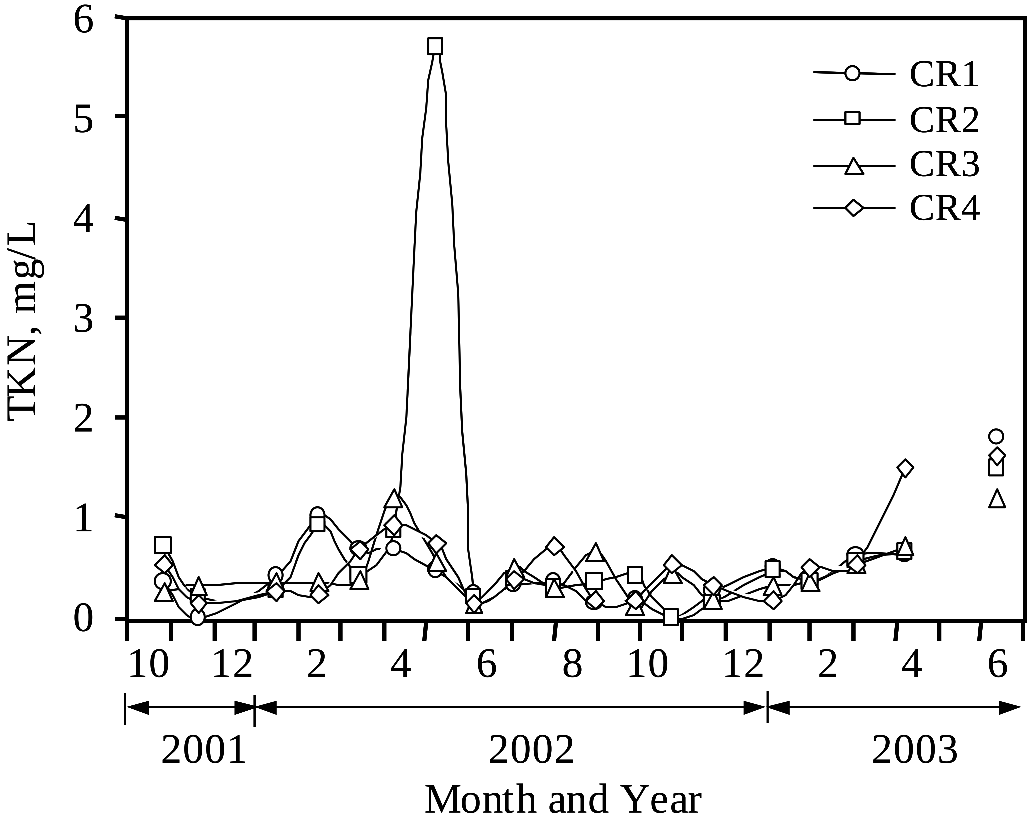

Figure 12A. Total Kjeldahl nitrogen (TKN) concentrations in water samples collected at four locations along the creek adjacent to the drainfield of System 1. For sampling locations see Fig. 4.

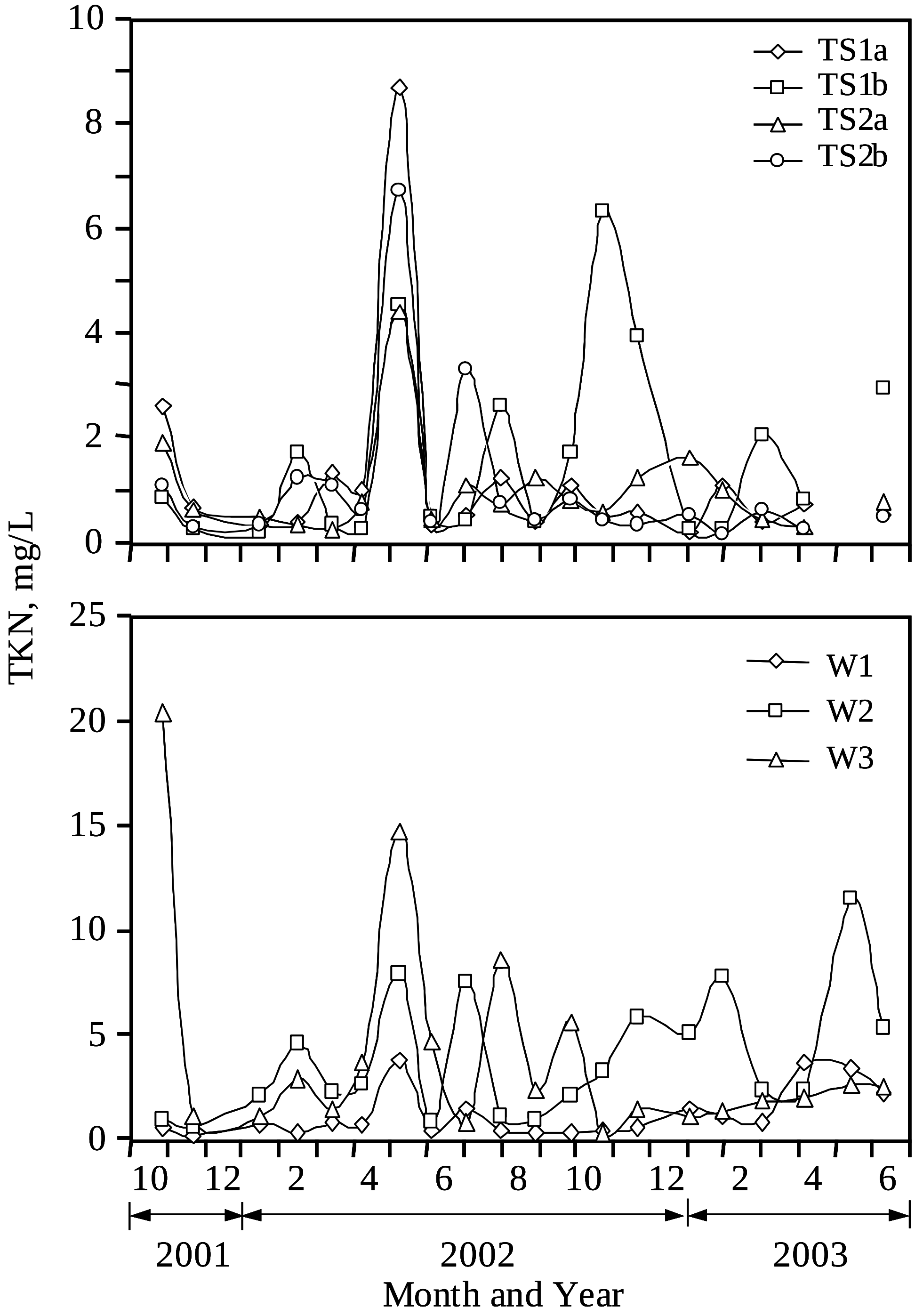

Figure 13A. Total Kjeldahl nitrogen (TKN) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 1. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 4.

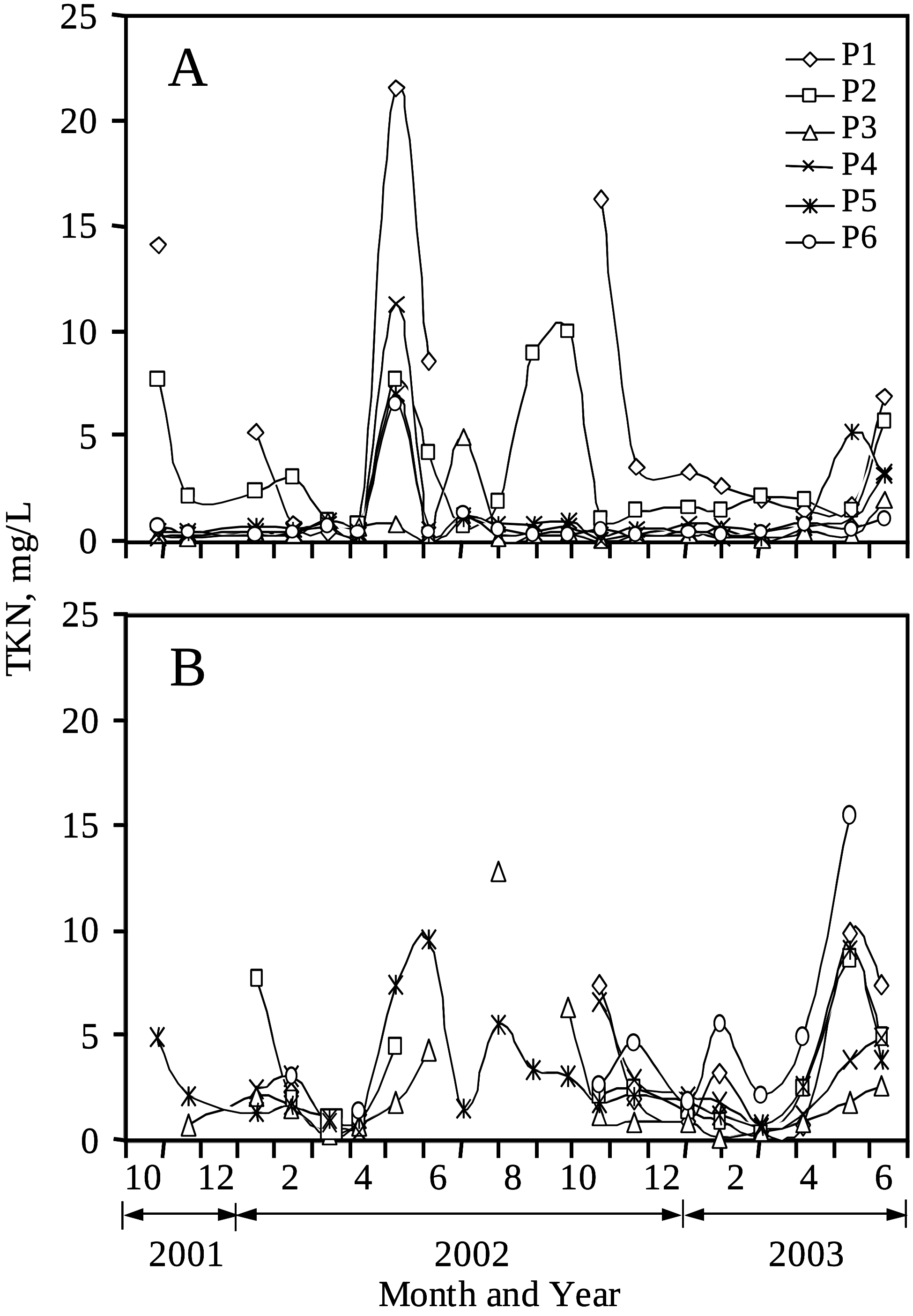

Figure 14A. Total Kjeldahl nitrogen (TKN) concentrations of the ground water collected from two depths at six locations using piezometers installed in the drainfield area of System 1. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 4.

APPENDIX B

Chemical Characteristics of Surface Water, Ground Water, and Soil Water at Site 2

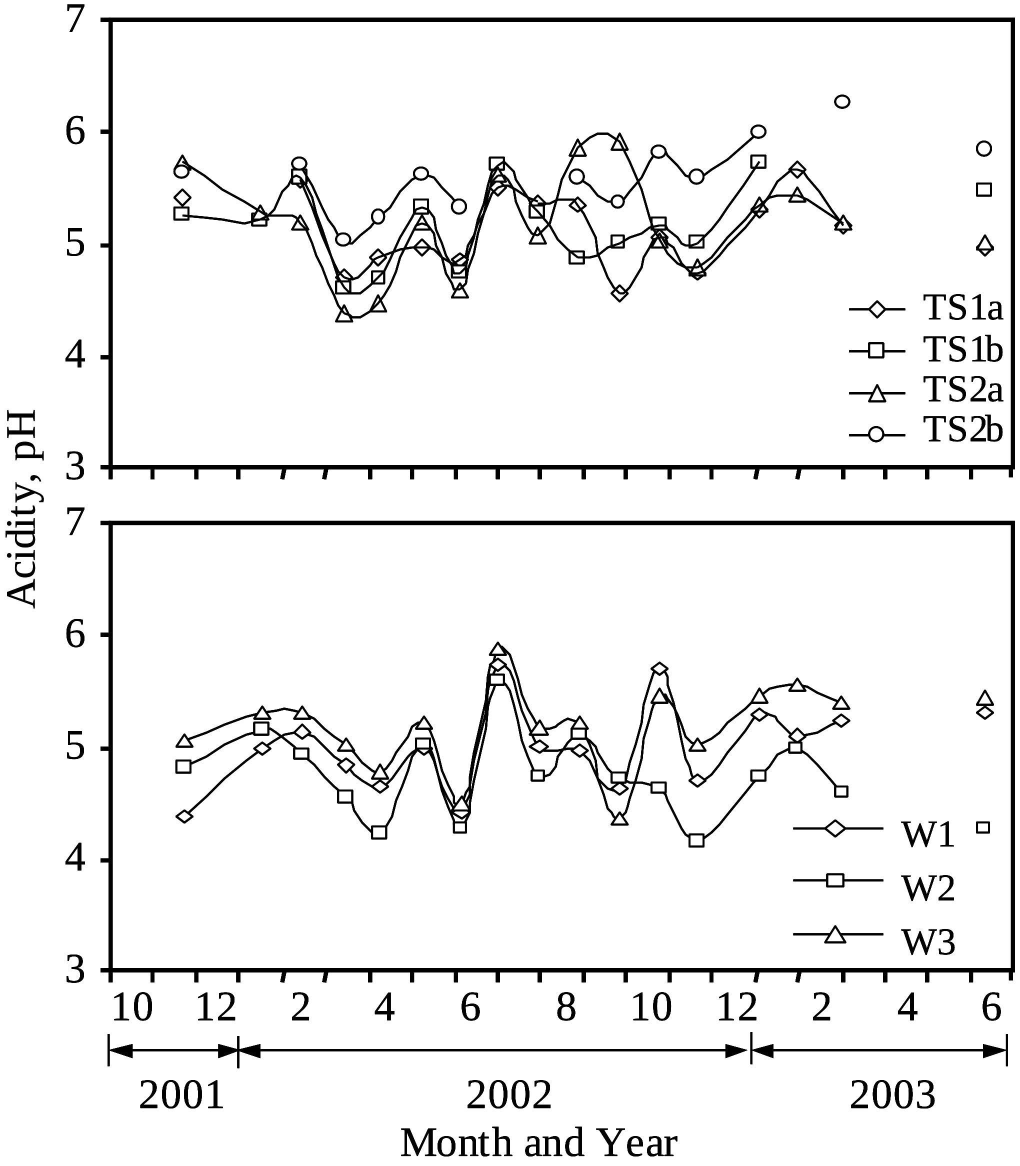

Figure 1B. The acidity (pH) of the soil solution collected by the tension samplers (TS) at two locations and ground water collected by the wells (W) at three locations in the drainfield area of System 2. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

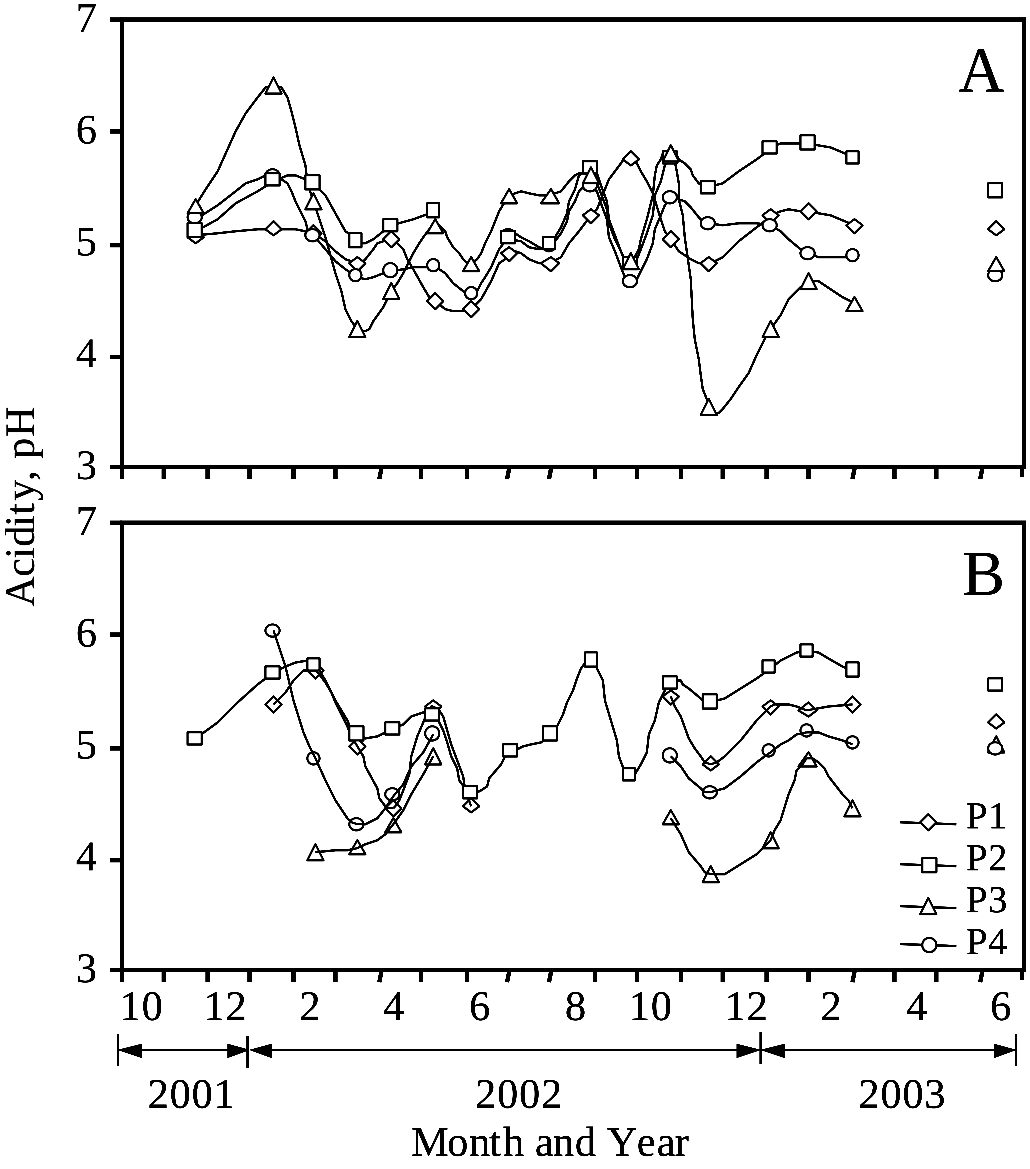

Figure 2B. The acidity (pH) of the ground water at two depths collected from four locations using the piezometers in the drainfield area of System 2. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 6.

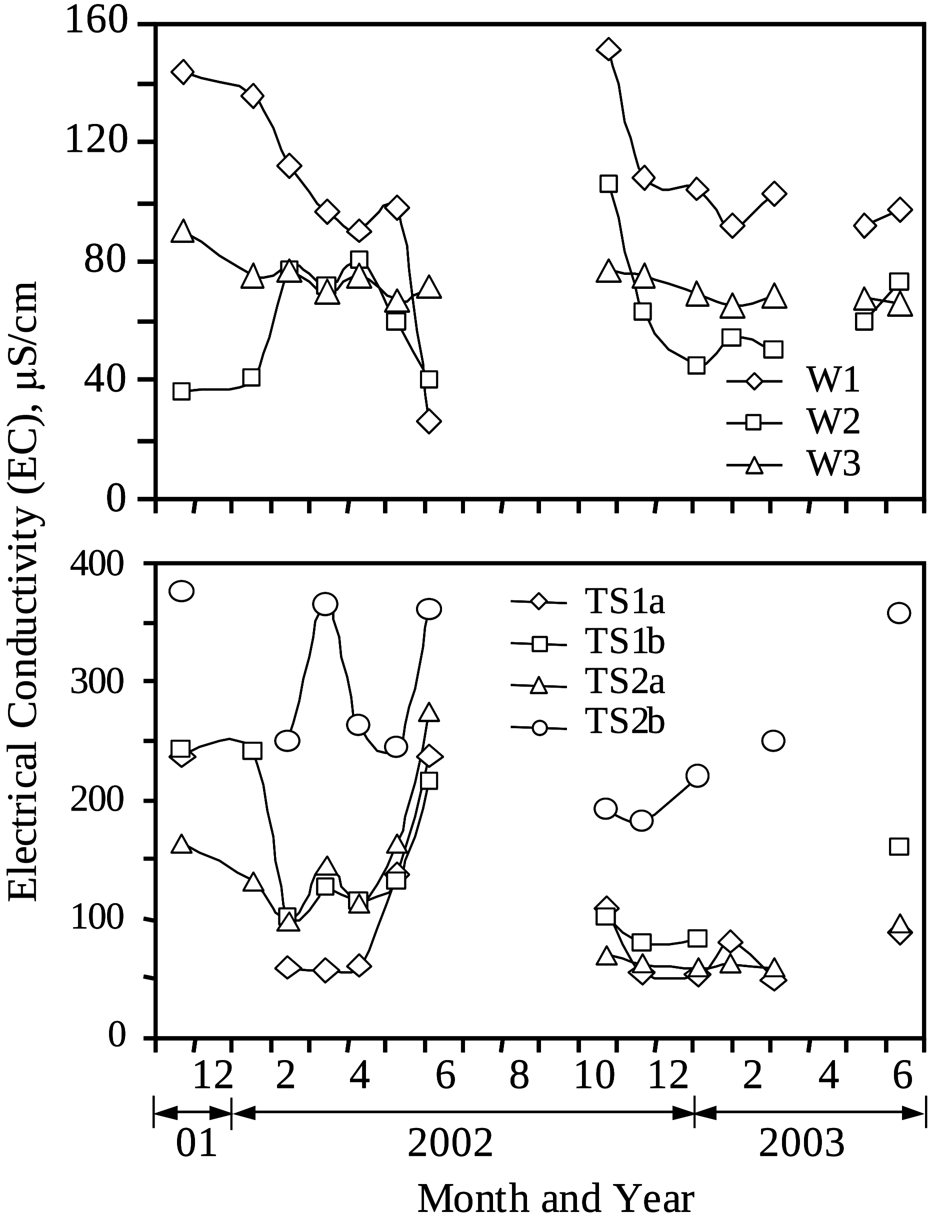

Figure 3B. Electrical conductivity (EC) of the soil solution collected by the tension samplers (TS) at two locations and ground water collected by the wells (W) at three locations in the drainfield area of System 2. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

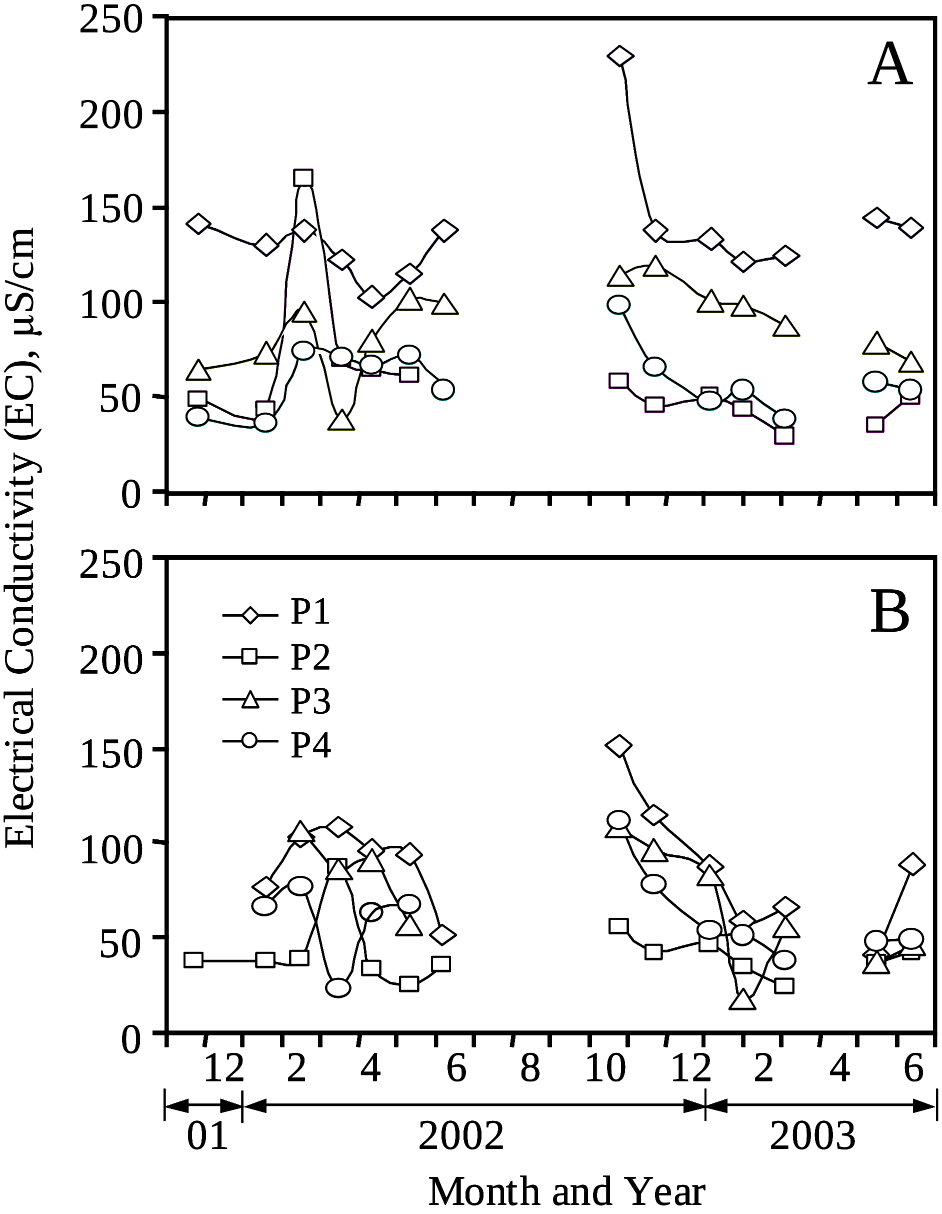

Figure 4B. Electrical conductivity (EC) of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure “A” represents deeper piezometers and “B” represents shallower piezometers. For sampling locations see Fig. 6.

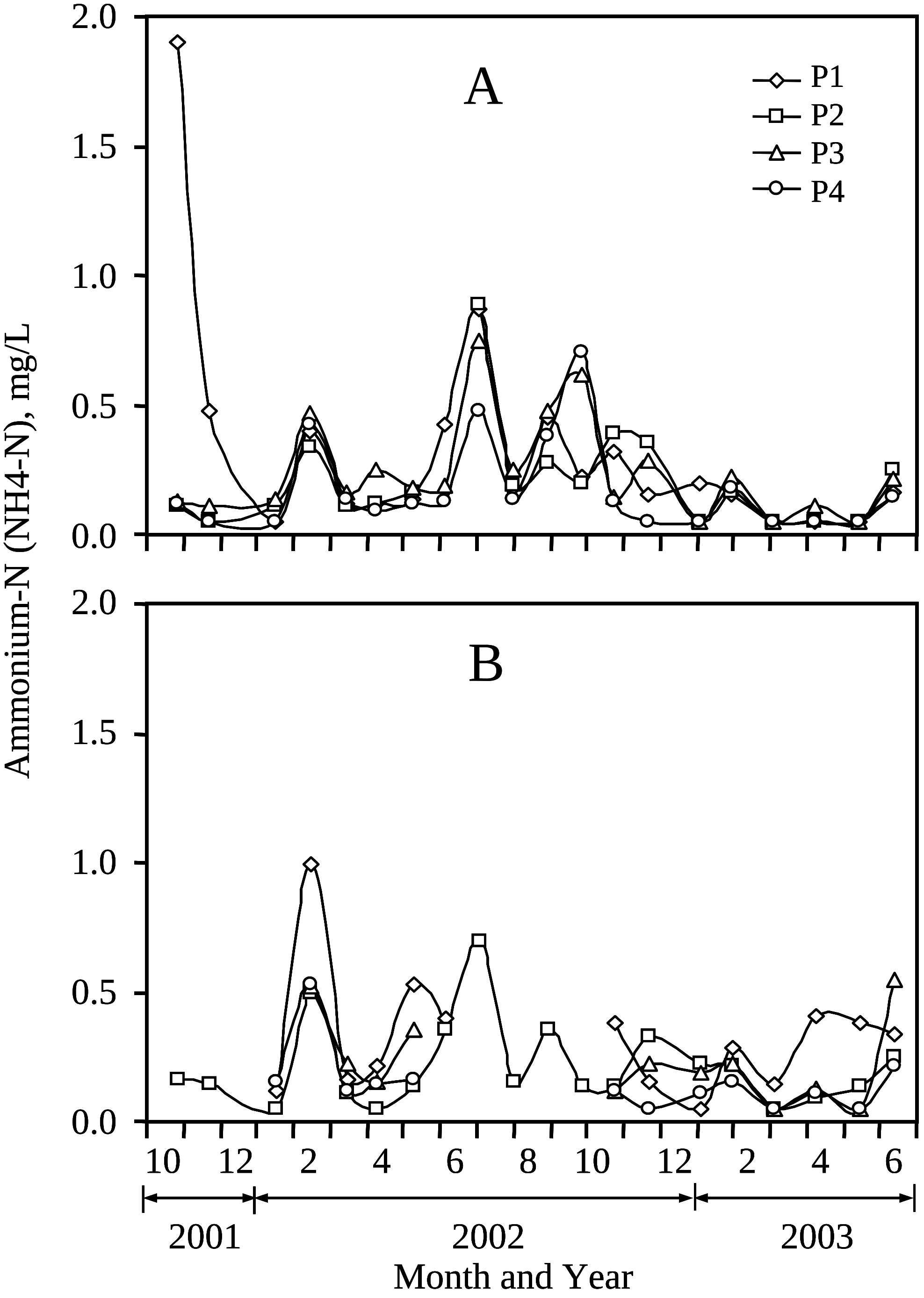

Figure 5B. Ammonium-N (NH_4-N) concentrations of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure “A” represents deeper piezometers and “B” represents shallower piezometers. For sampling locations see Fig. 6.

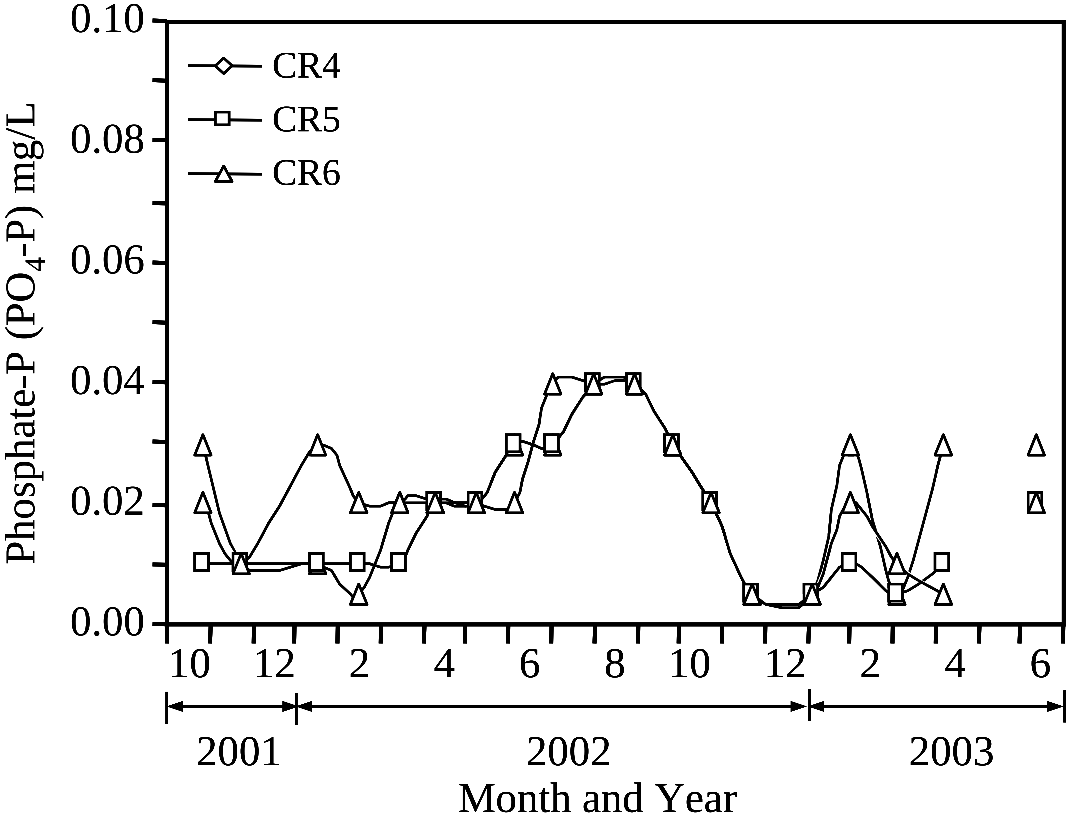

Figure 6B. Phosphate-P (PO_4-P) concentrations in water samples collected at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

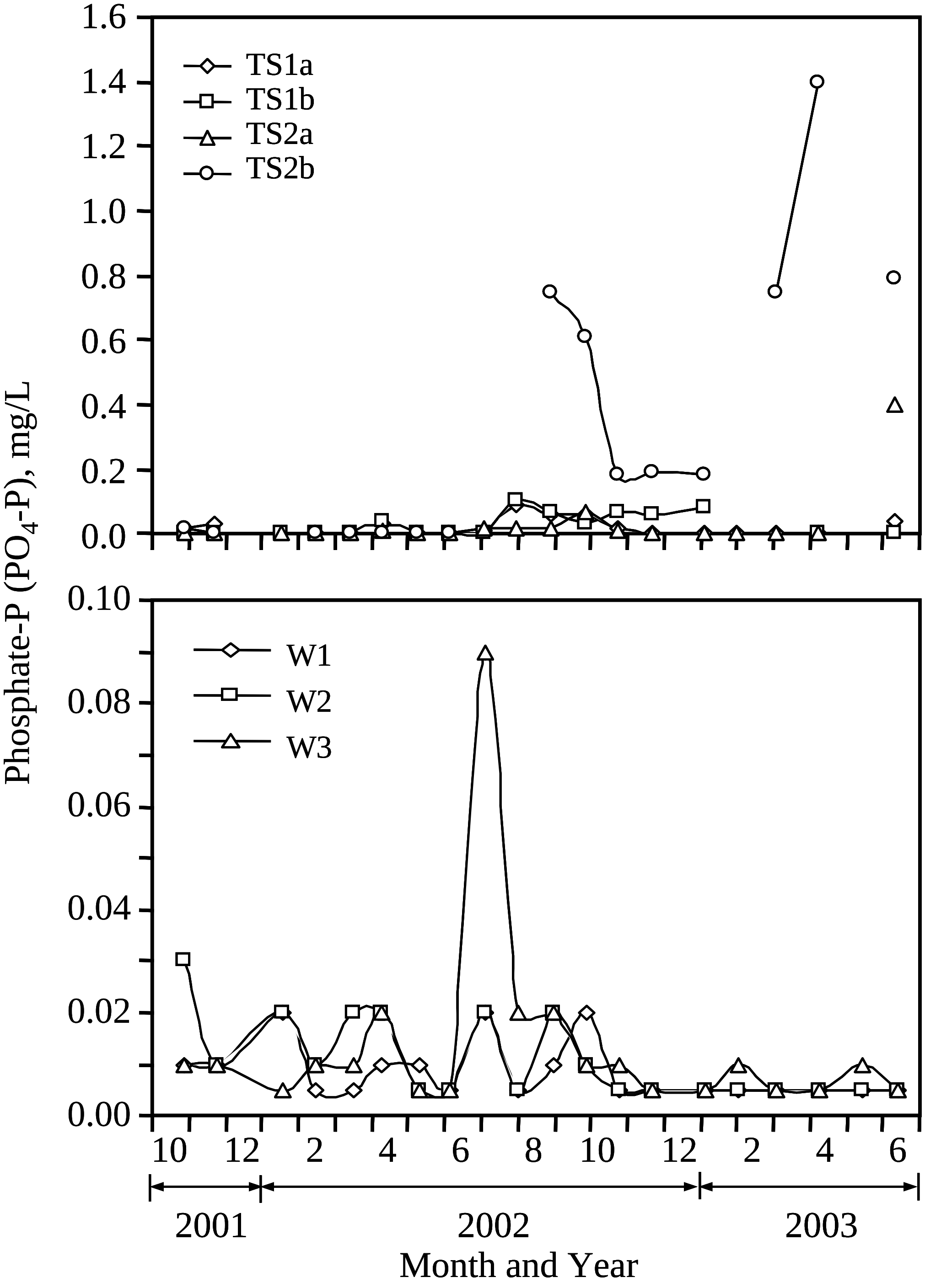

Figure 7B. Phosphate-P (PO$_4$-P) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 2. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

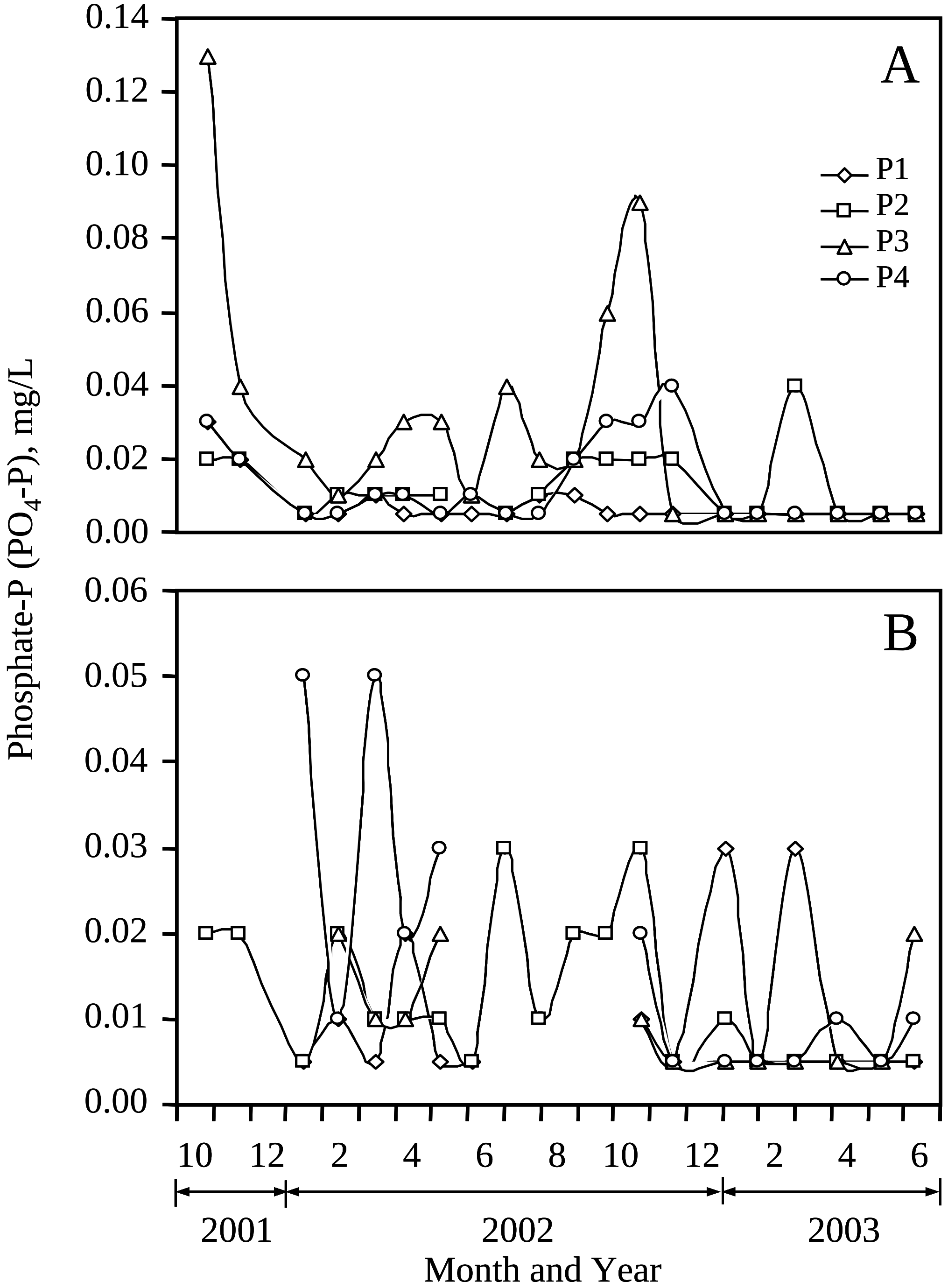

Figure 8B. Phosphate-P (PO_4-P) concentrations of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 6.

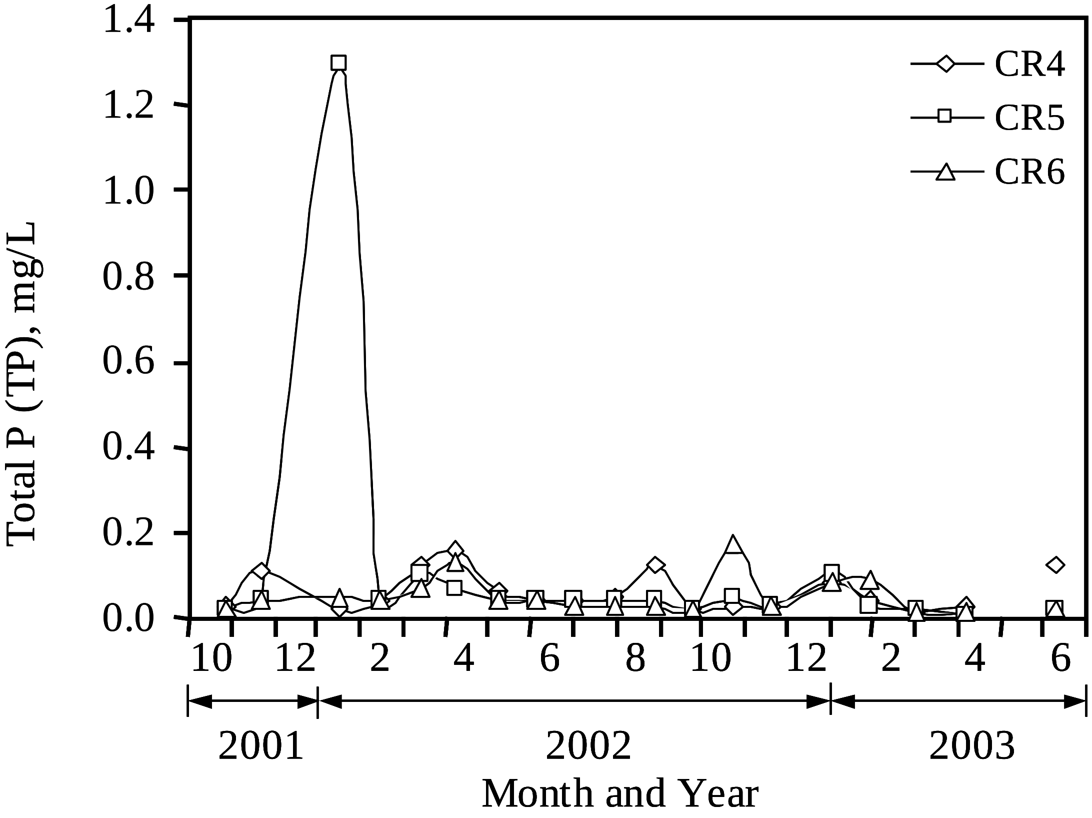

Figure 9B. Total phosphorus (TP) concentrations in water samples collected at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

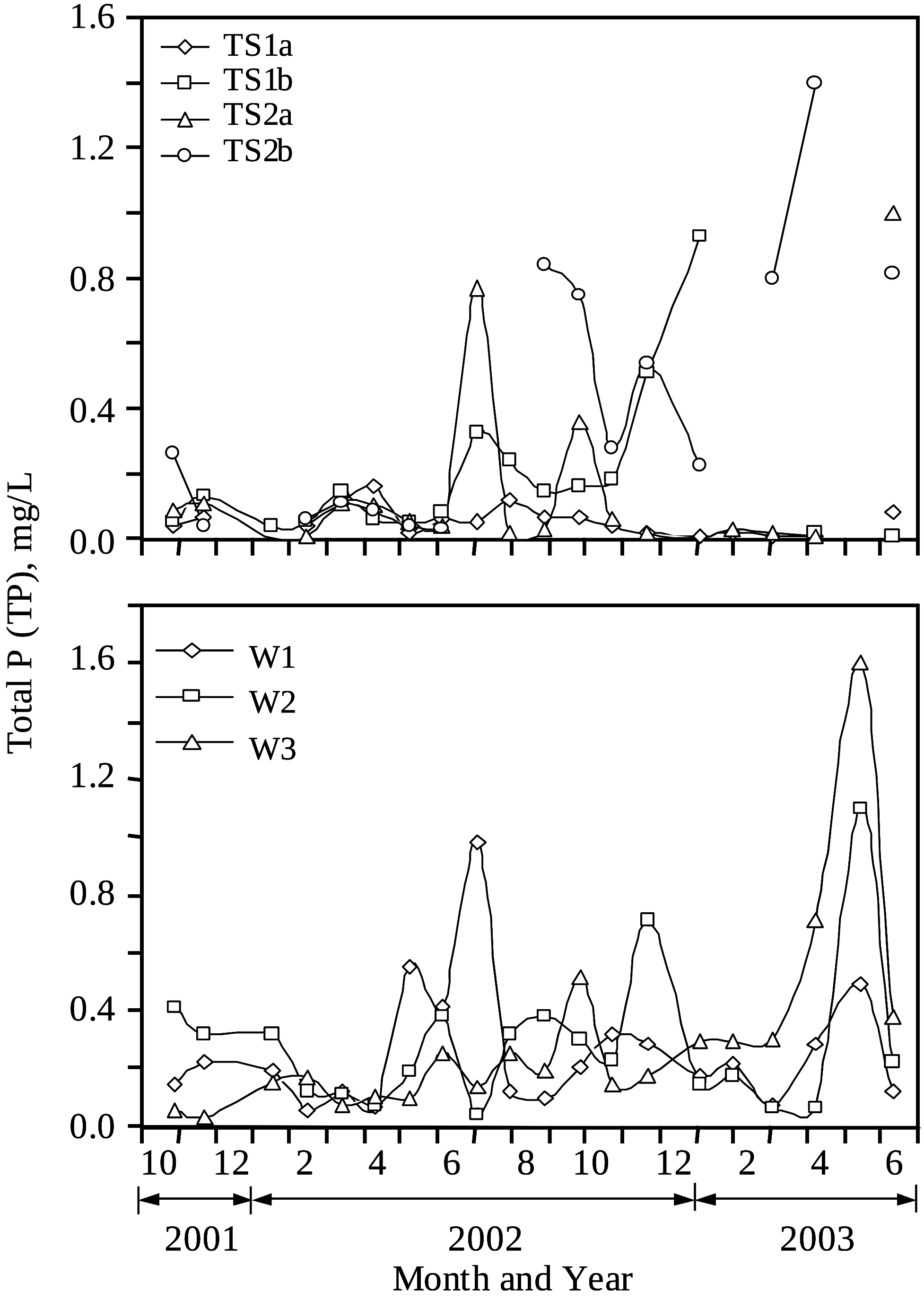

Figure 10B. Total phosphorus (TP) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 2. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

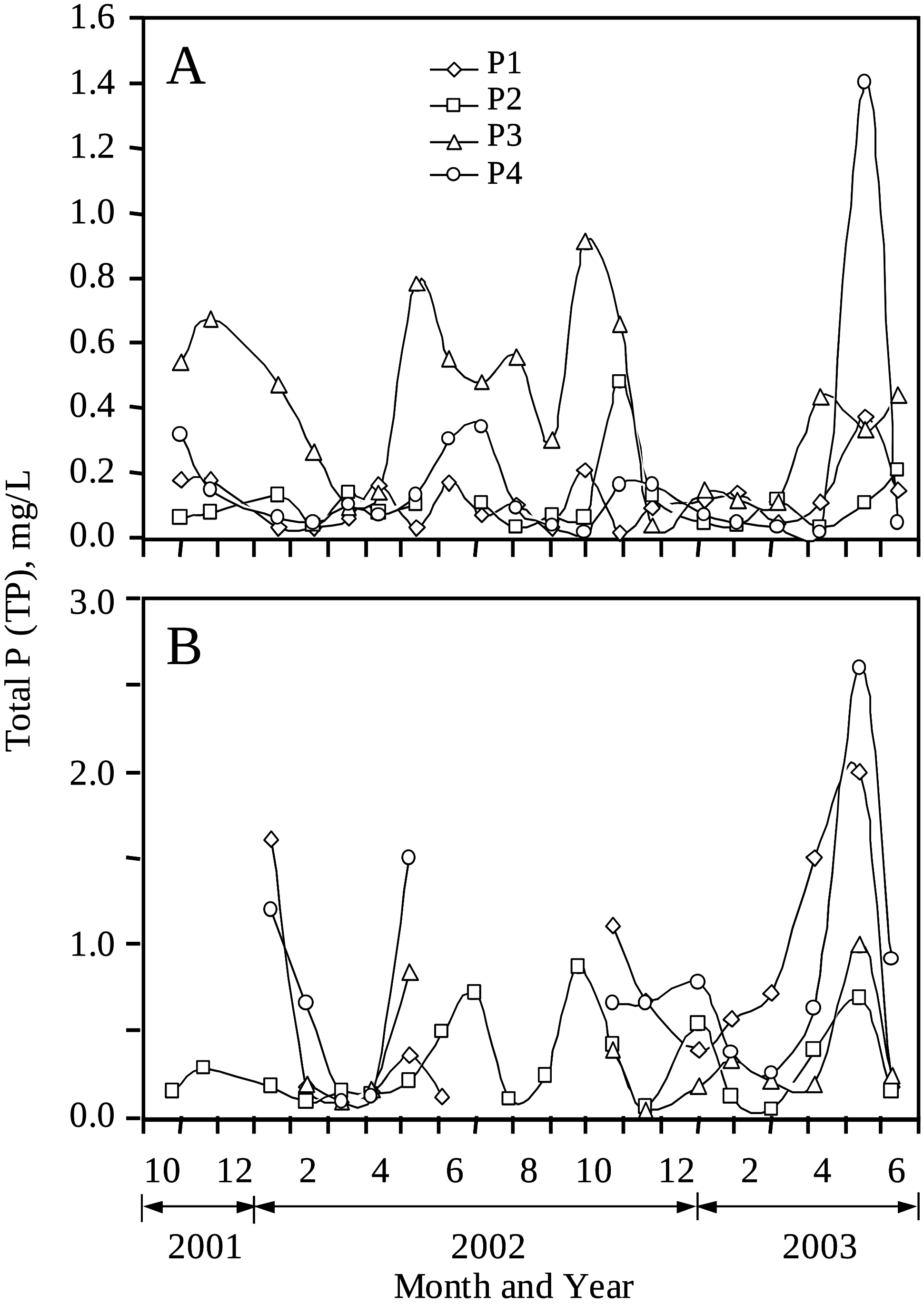

Figure 11B. Total phosphorus (P) concentrations of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure "A" represents deeper piezometers and "B" represents shallower piezometers. For sampling locations see Fig. 6.

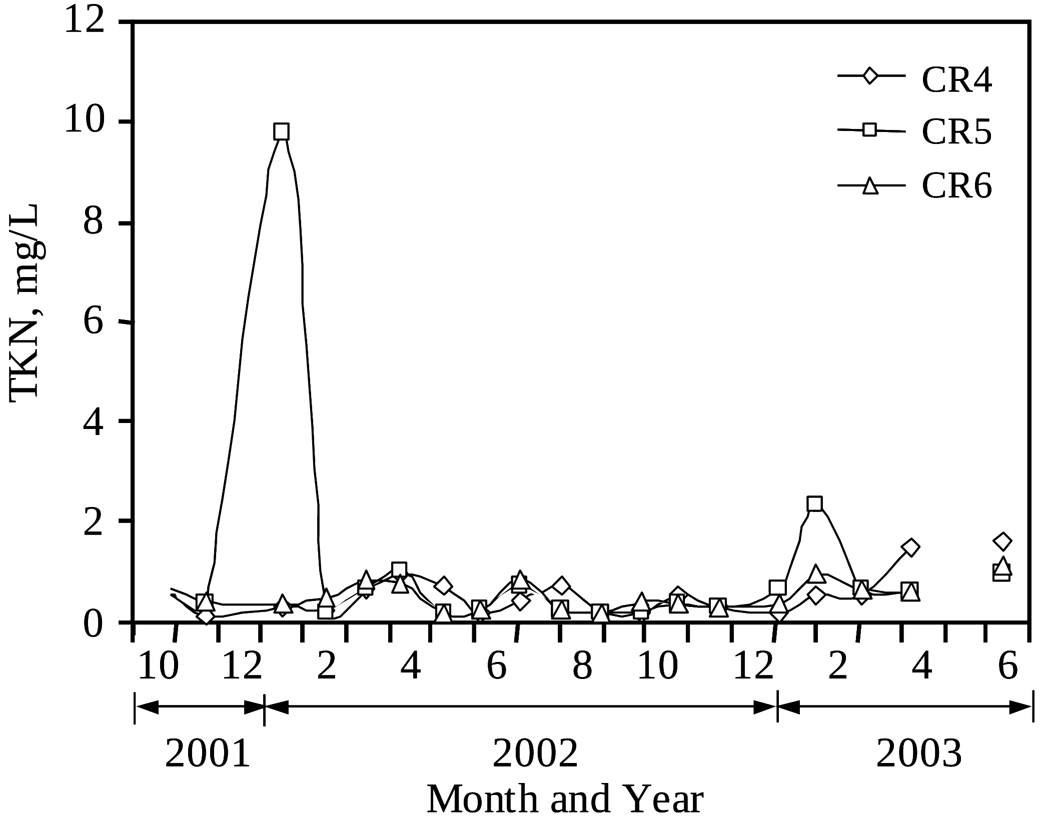

Figure 12B. Total Kjeldahl nitrogen (TKN) concentrations in water samples collected at three locations along the creek adjacent to the drainfield of System 2. For sampling locations see Fig. 6.

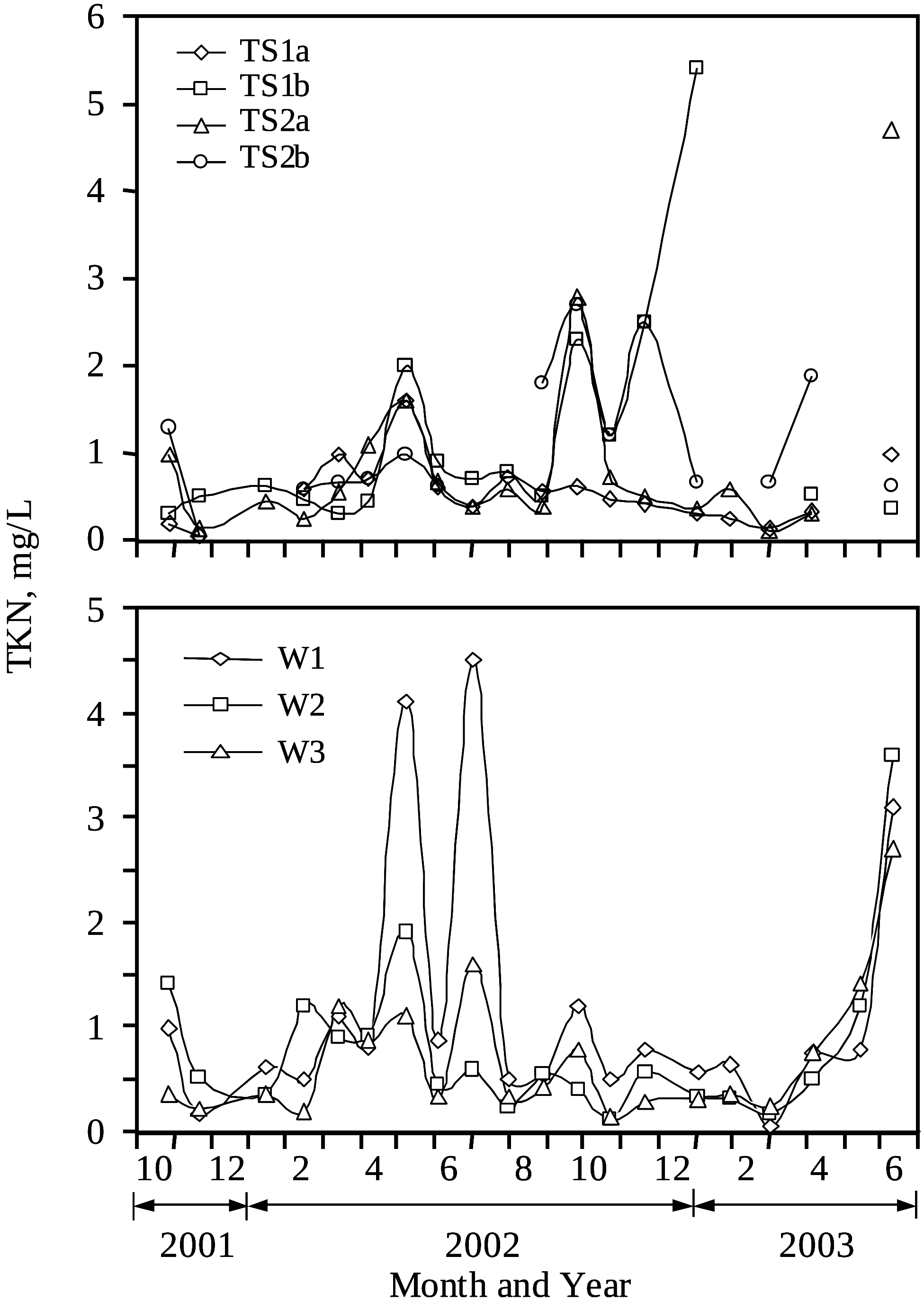

Figure 13B. Total Kjeldahl nitrogen (TKN) concentrations in soil solution collected by tension samplers (TS) and in ground water collected from three sampling wells (W) in the drainfield area of System 2. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 6.

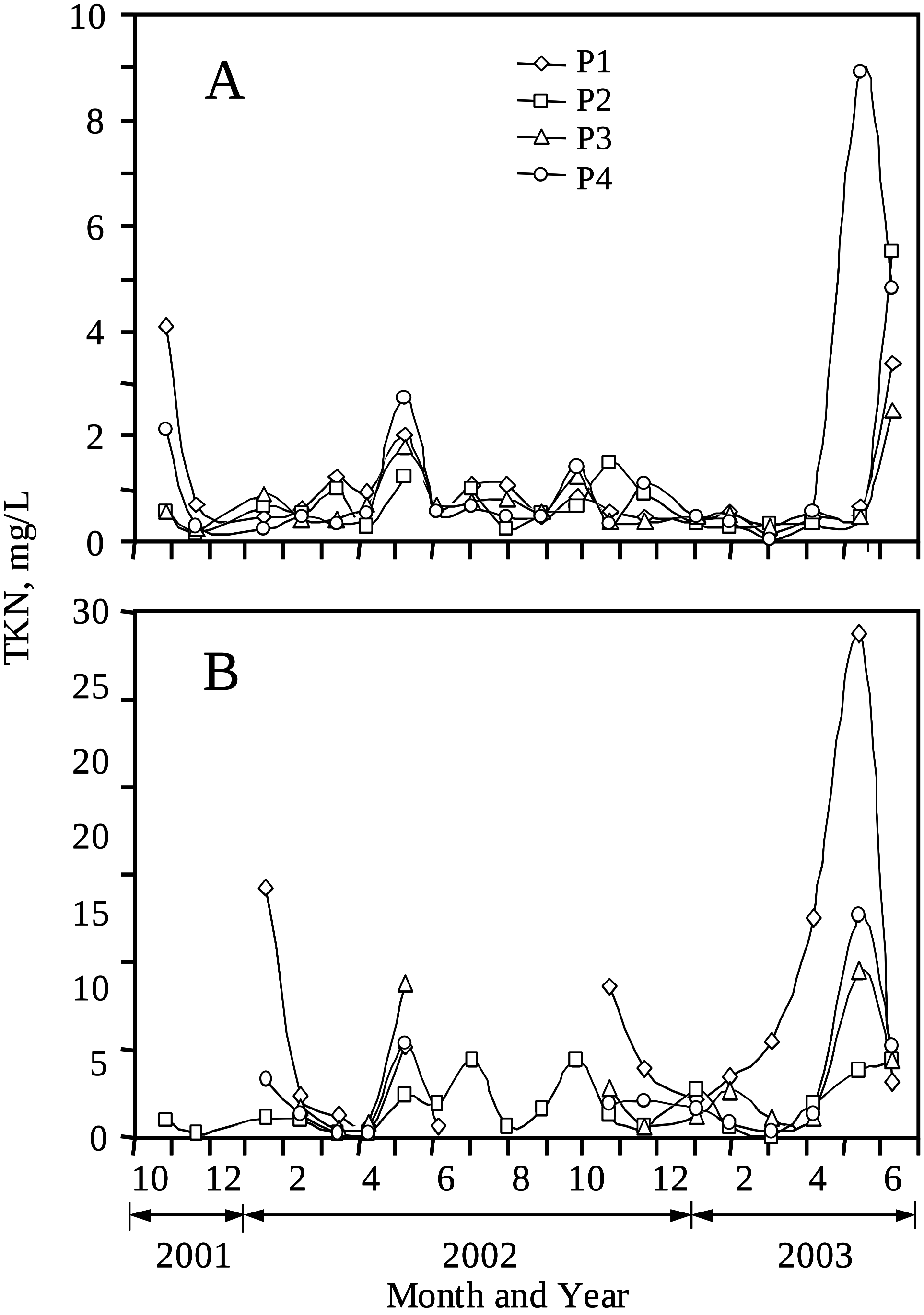

Figure 14B. Total Kjeldahl nitrogen (TKN) concentrations of the ground water collected from two depths at four locations using piezometers installed in the drainfield area of System 2. In this figure “A” represents deeper piezometers and “B” represents shallower piezometers. For sampling locations see Fig. 6.

APPENDIX C

Chemical Characteristics of Surface Water, Ground Water, and Soil Water at Site 3

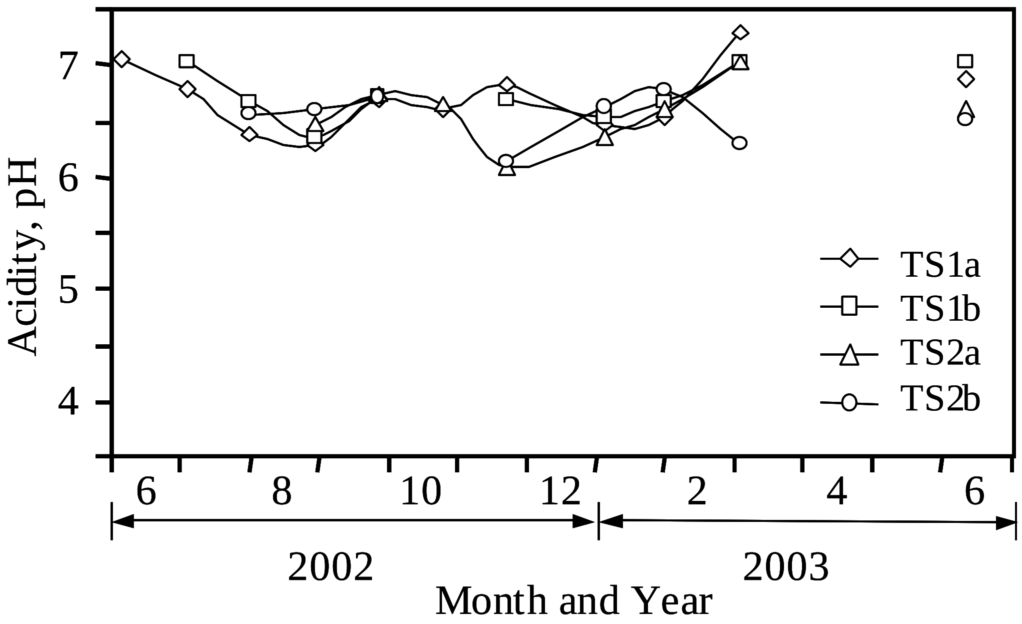

Figure 1C. The acidity (pH) of the soil solution collected by the tension samplers at two locations in the drainfield area of System 3. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

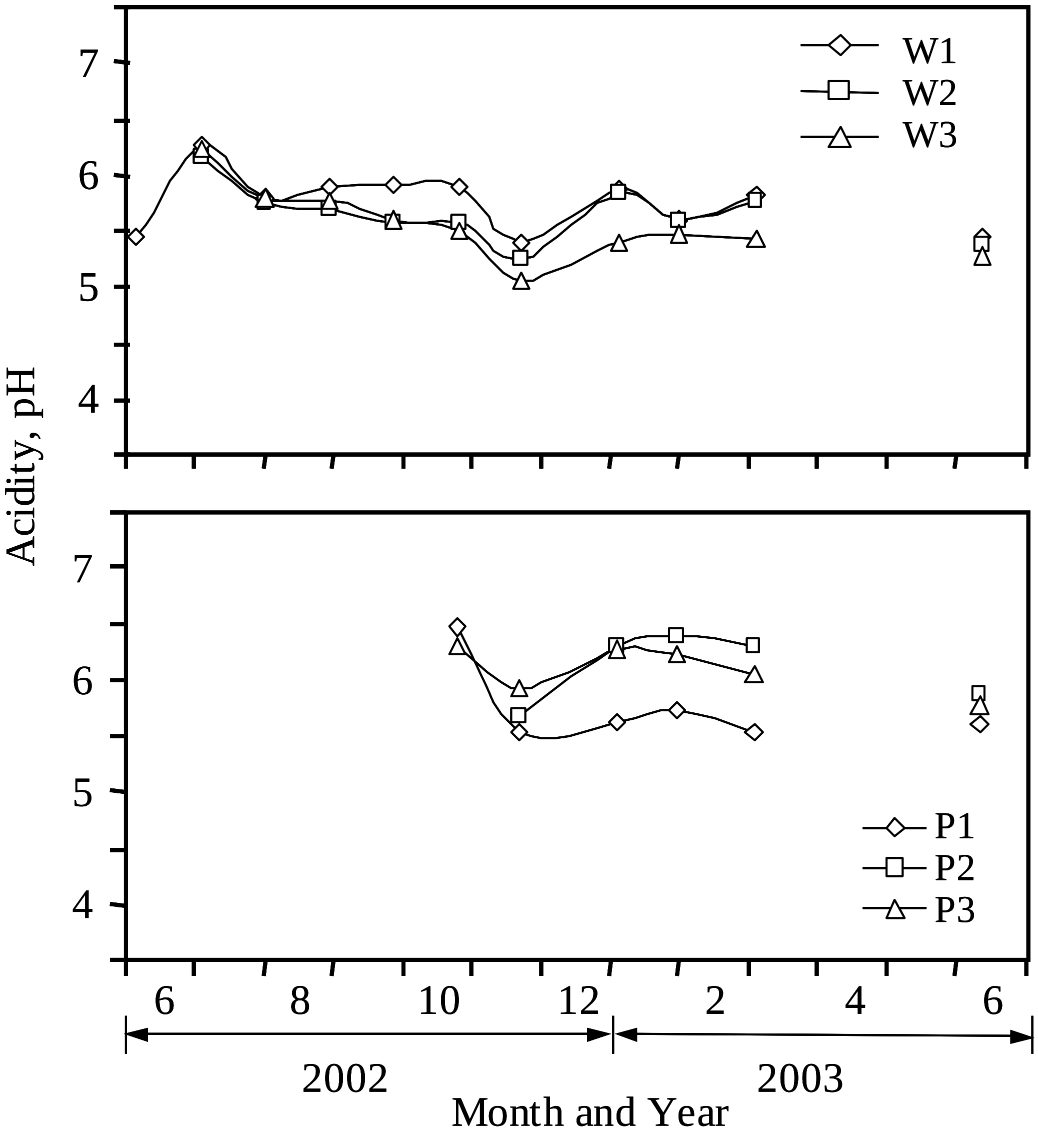

Figure 2C. The acidity (pH) of the ground water collected from wells (W) and piezometers (P) at three locations in the drainfield area of System 3. For sampling locations see Fig. 8.

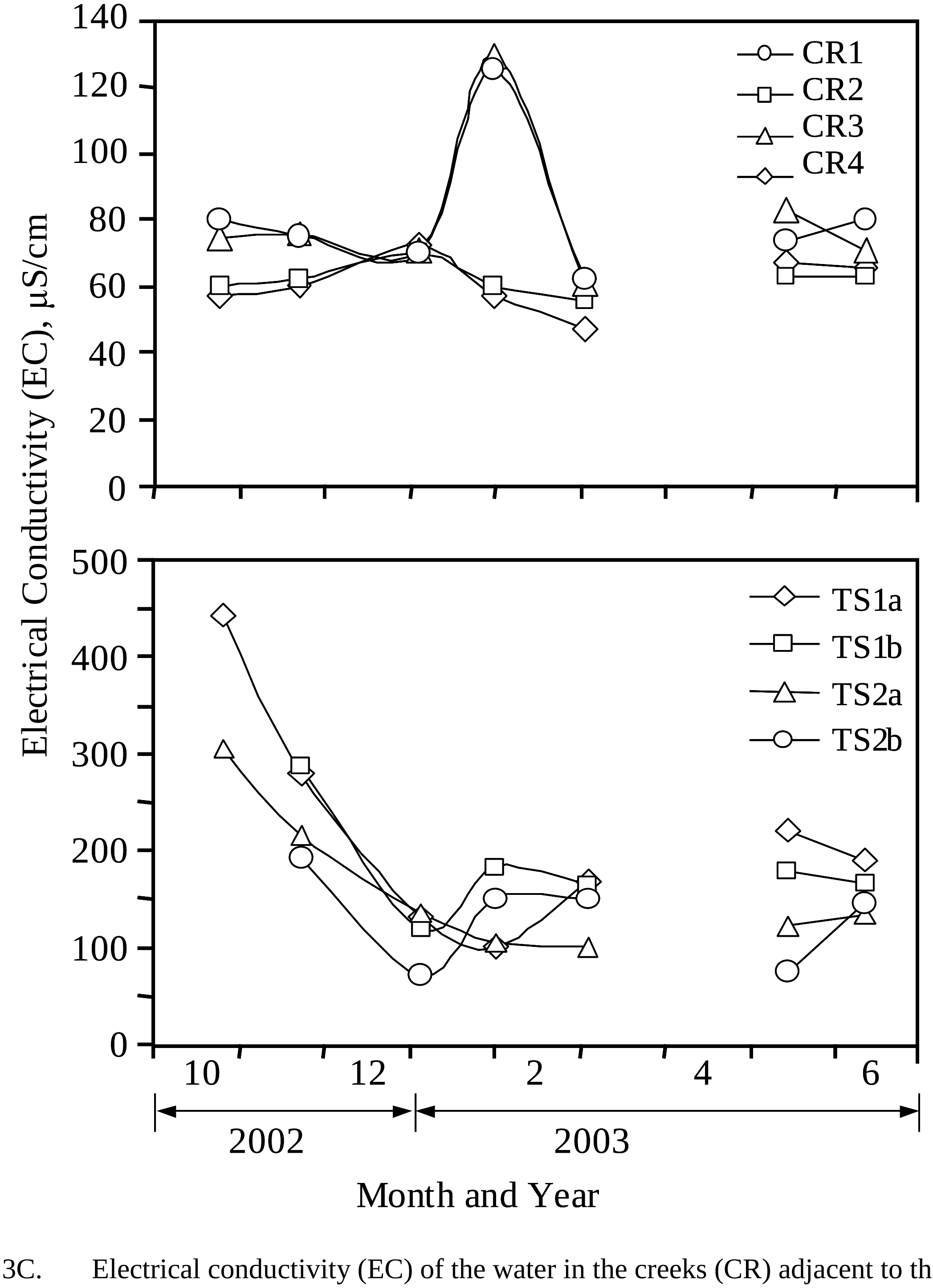

Figure 3C. Electrical conductivity (EC) of the water in the creeks (CR) adjacent to the property and soil solution collected by the tension samplers (TS) at two locations in the drainfield area of System 3. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

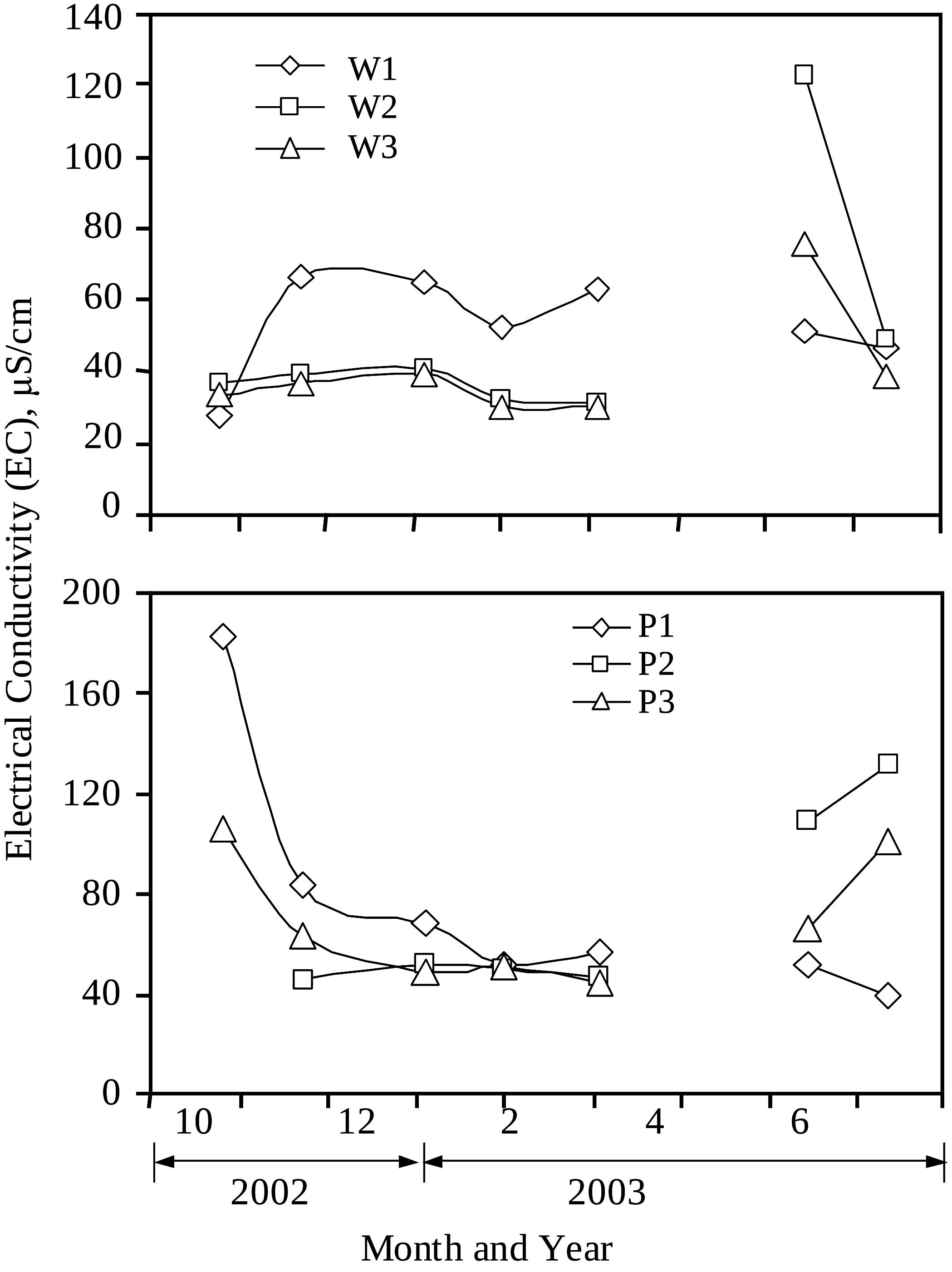

Figure 4C. Electrical conductivity (EC) of the ground water collected from wells (W) and piezometers (P) at three locations in the drainfield area of System 3. For sampling locations see Fig. 8.

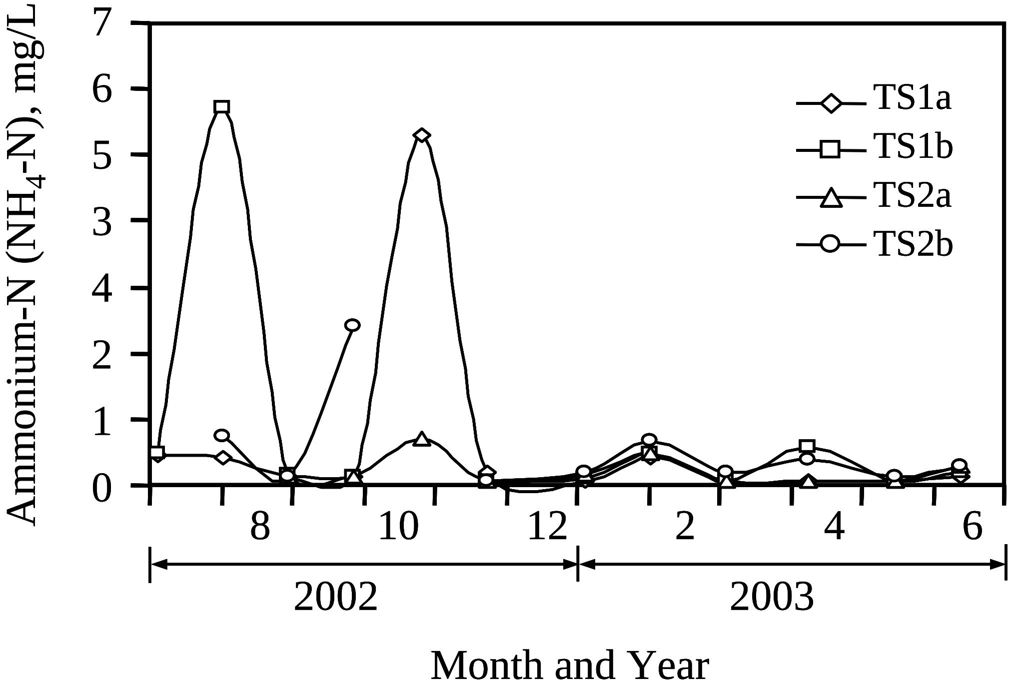

Figure 5C. Ammonium-N (NH_4-N) concentrations of the soil solution collected by the tension samplers at two locations in the drainfield area of System 3. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

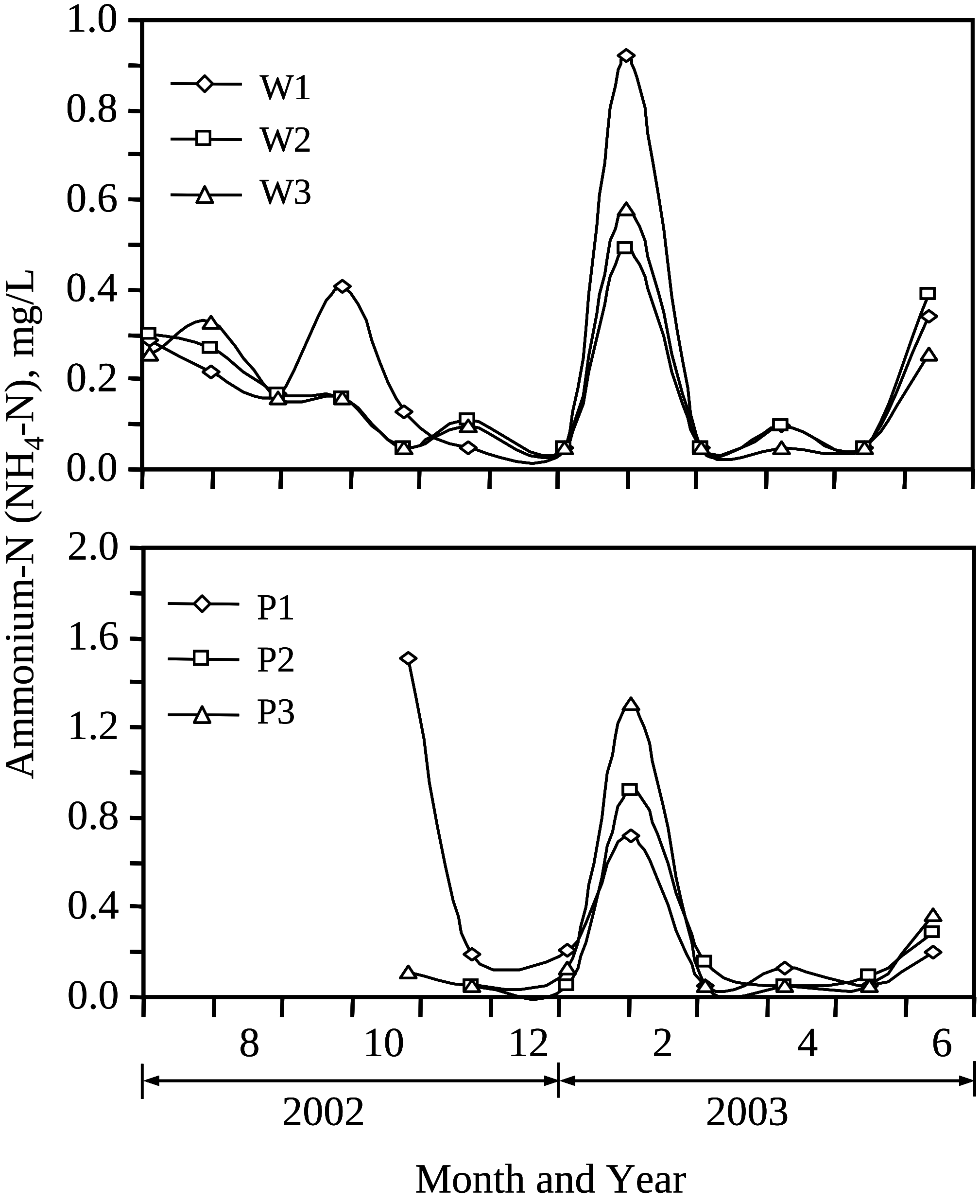

Figure 6C. Ammonium-N (NH_4-N) concentrations of the ground water collected from wells (W) and piezometers (P) at three locations in the drainfield area of System 3. For sampling locations see Fig. 8.

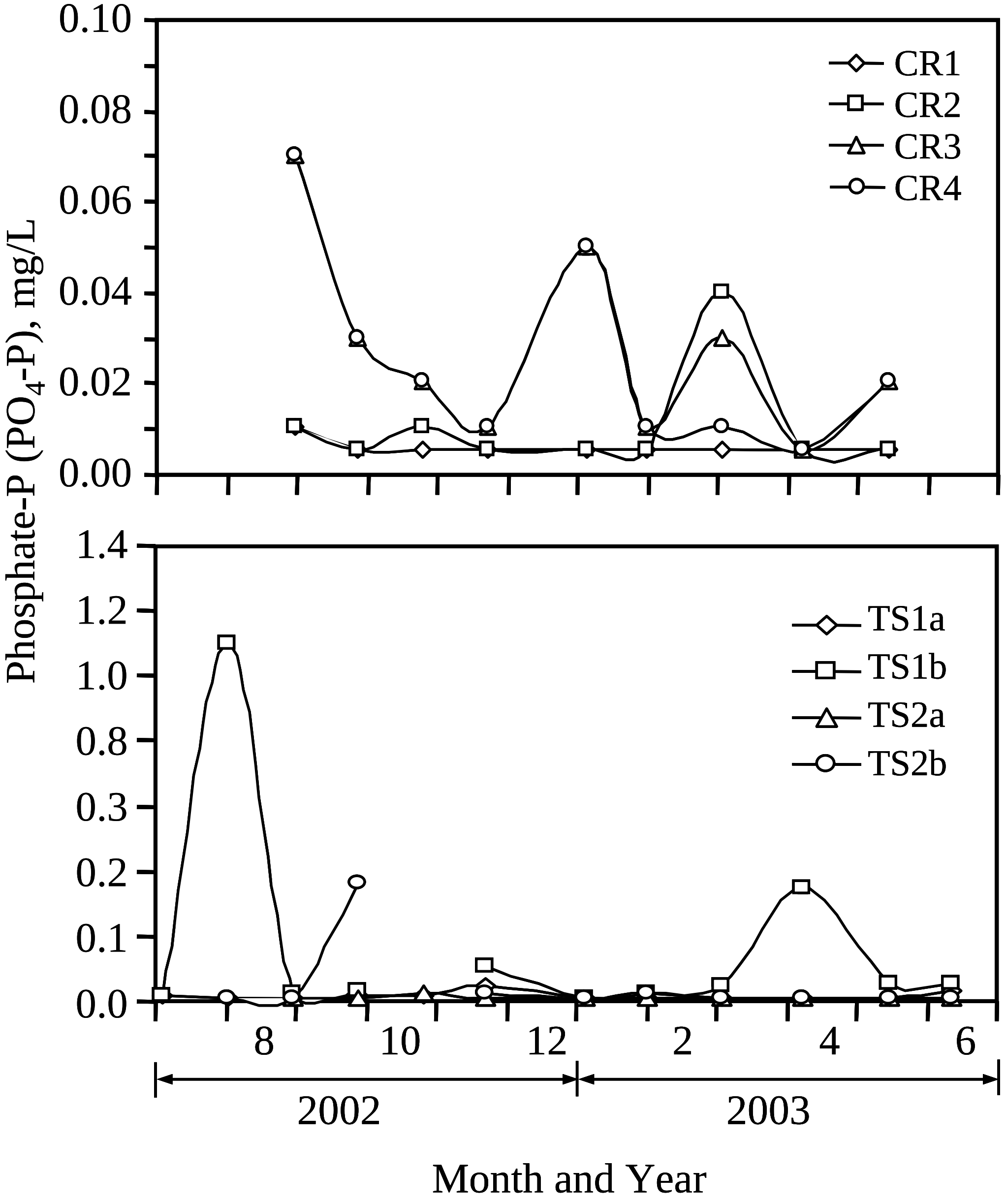

Figure 7C. Phosphate-P (PO_4-P) concentrations of water samples from creeks (CR) and the soil solution collected by the tension samplers (TS) at two locations in the drainfield area of System 3. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

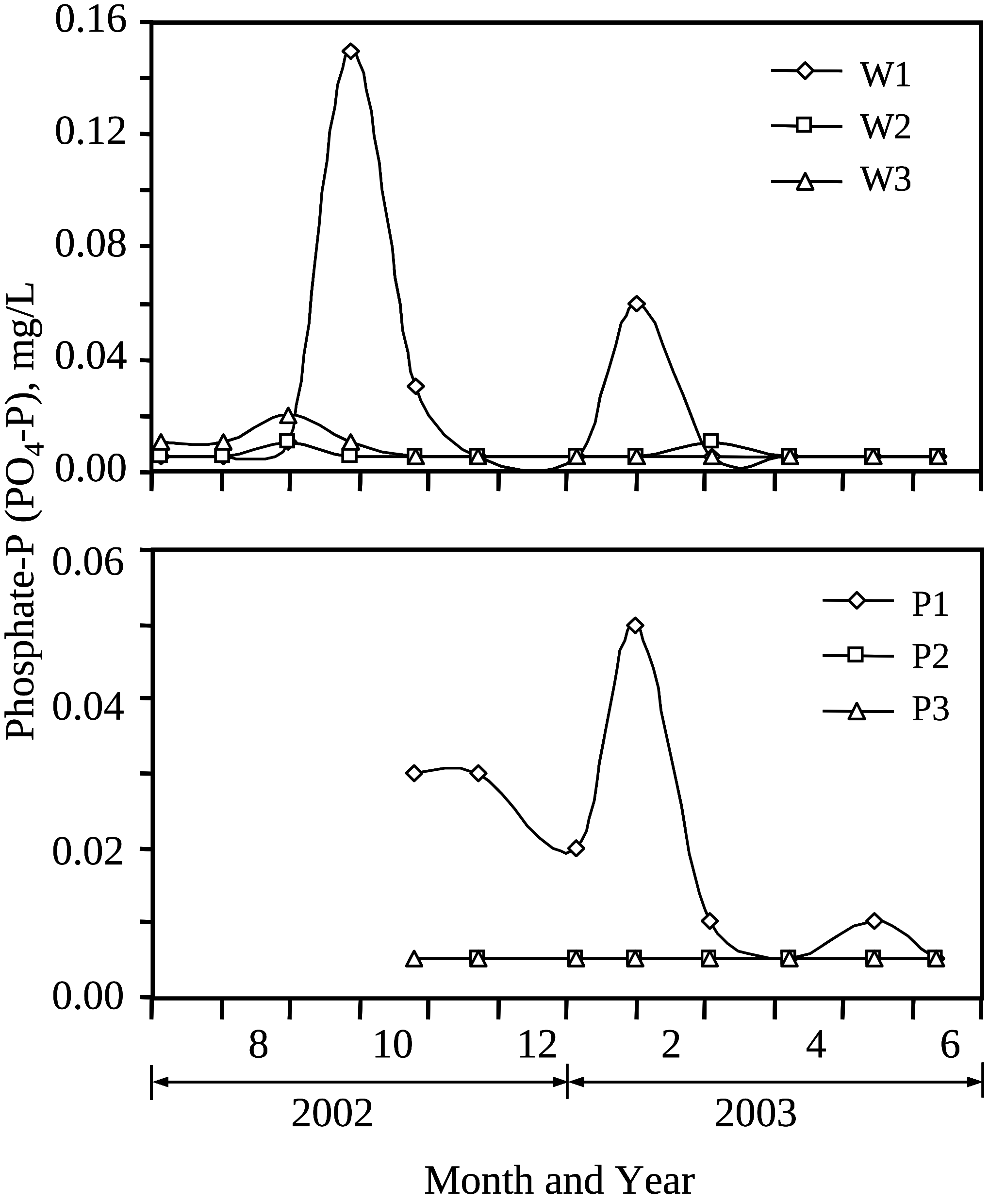

Figure 8C. Phosphate-P (PO_4-P) concentrations of the ground water collected from wells (W) and piezometers (P) at three locations in the drainfield area of System 3. For sampling locations see Fig. 8.

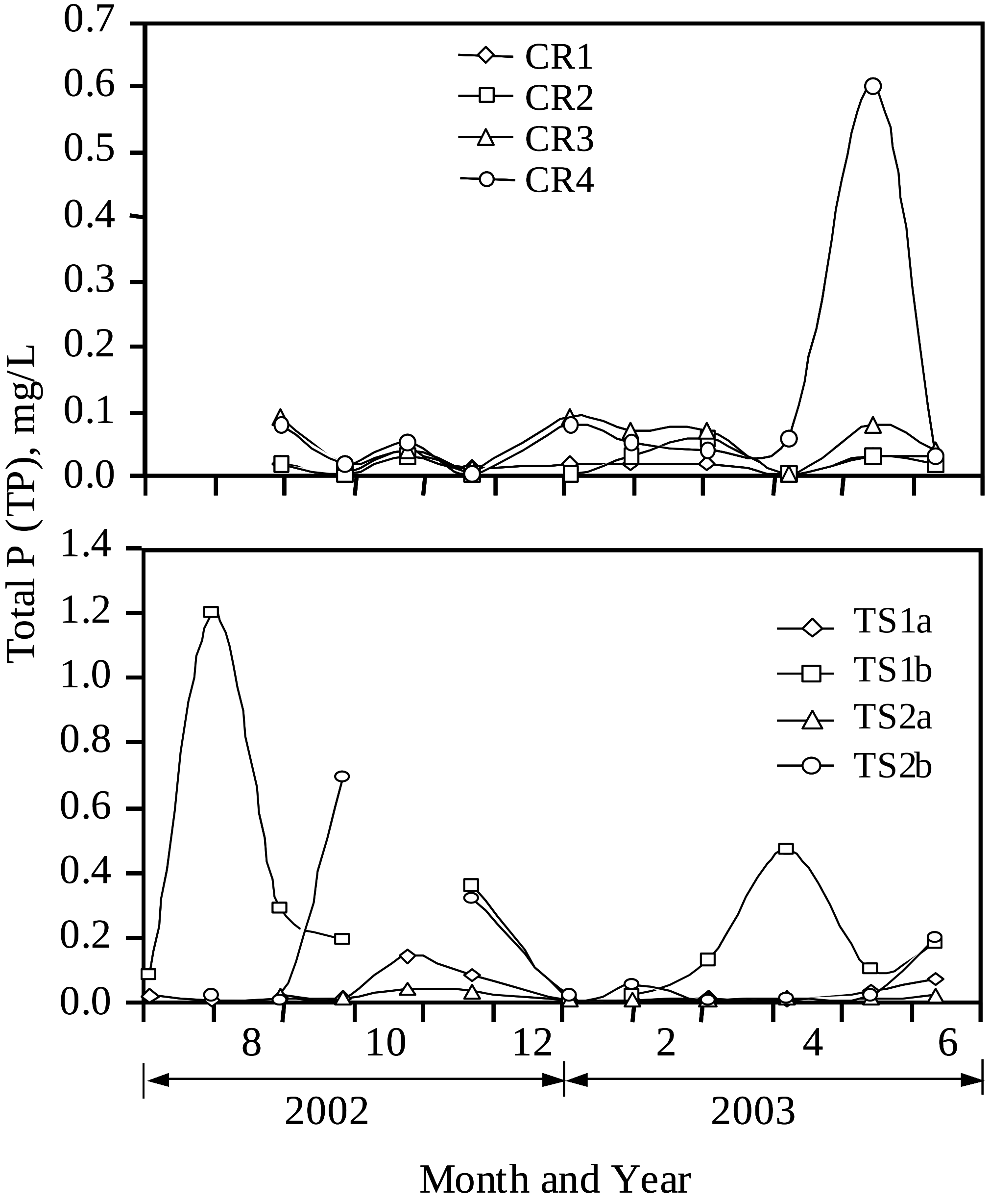

Figure 9C. Total phosphorus (TP) concentrations of water samples from creeks (CR) and the soil solution collected by the tension samplers (TS) at two locations in the drainfield area of System 3. In this figure "a" represents the tension sampler on the side of the trench and "b" represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

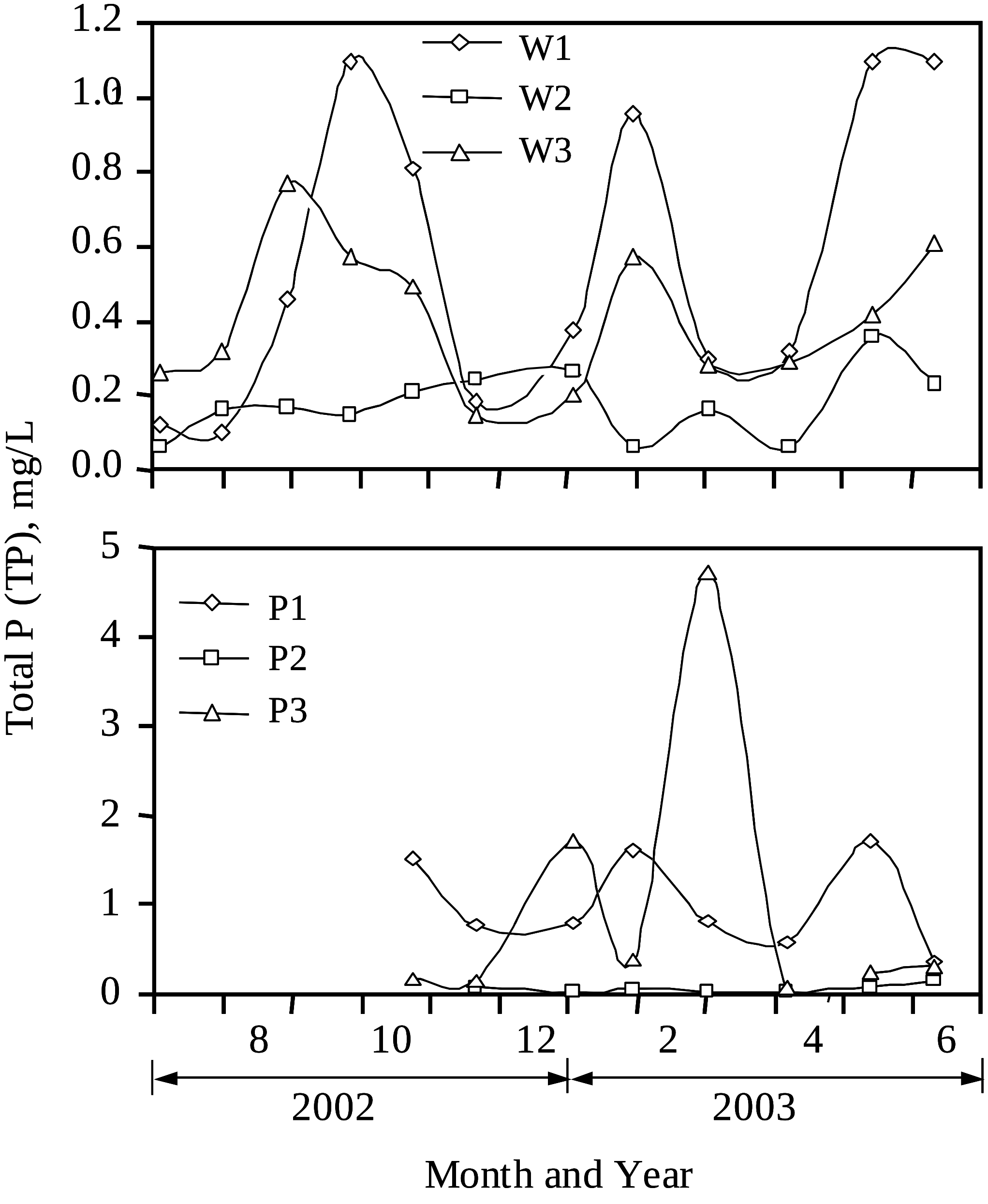

Figure 10C. Total phosphorus (TP) concentrations of the ground water collected from wells (W) and piezometers (P) at three locations in the drainfield area of System 3. For sampling locations see Fig. 8.

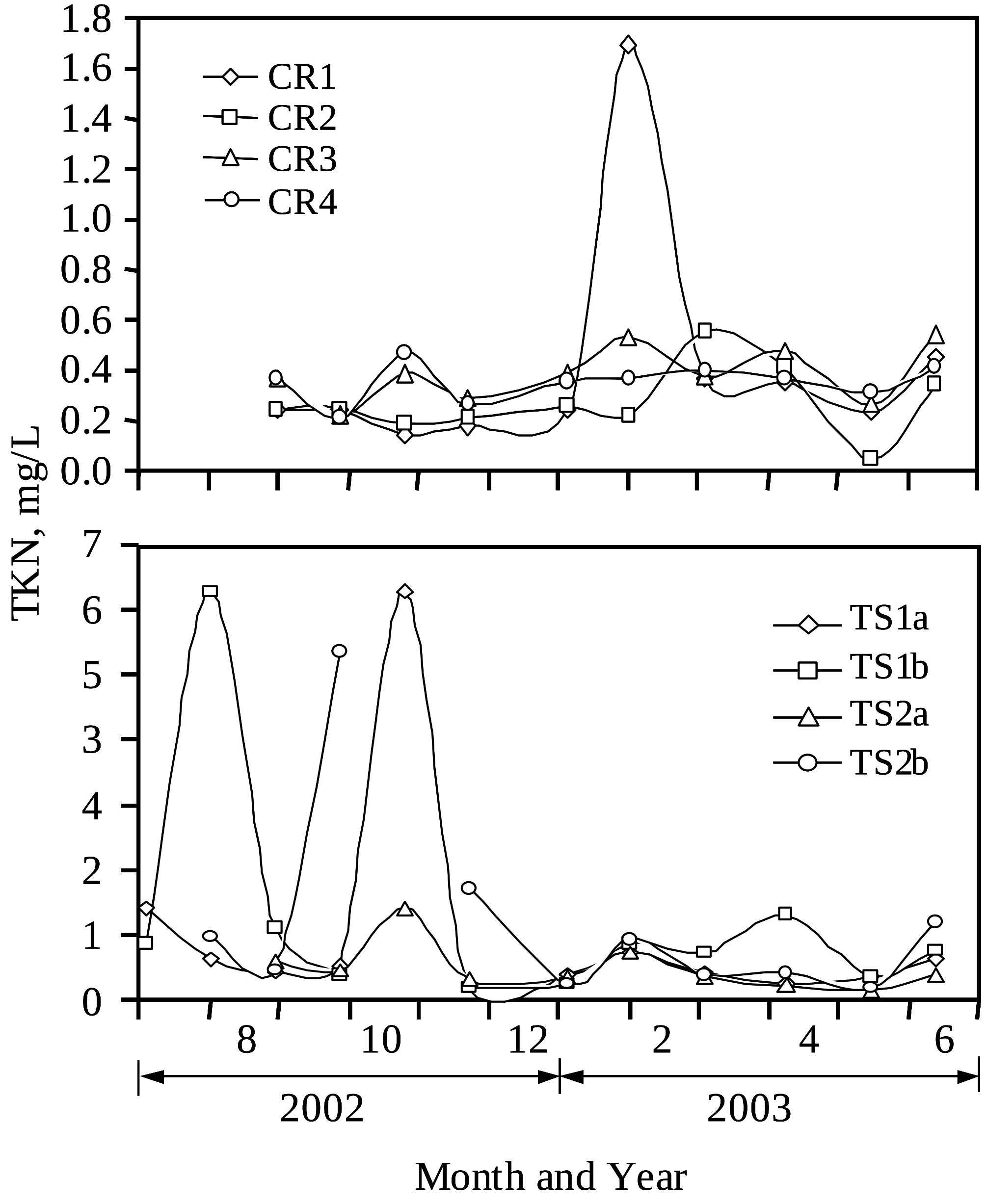

Figure 11C. Total Kjeldahl nitrogen (TKN) concentrations of water samples from creeks (CR) and the soil solution collected by the tension samplers (TS) at two locations in the drainfield area of System 3. In this figure “a” represents the tension sampler on the side of the trench and “b” represents the tension sampler at 20 cm below the bottom of the trench. For sampling locations see Fig. 8.

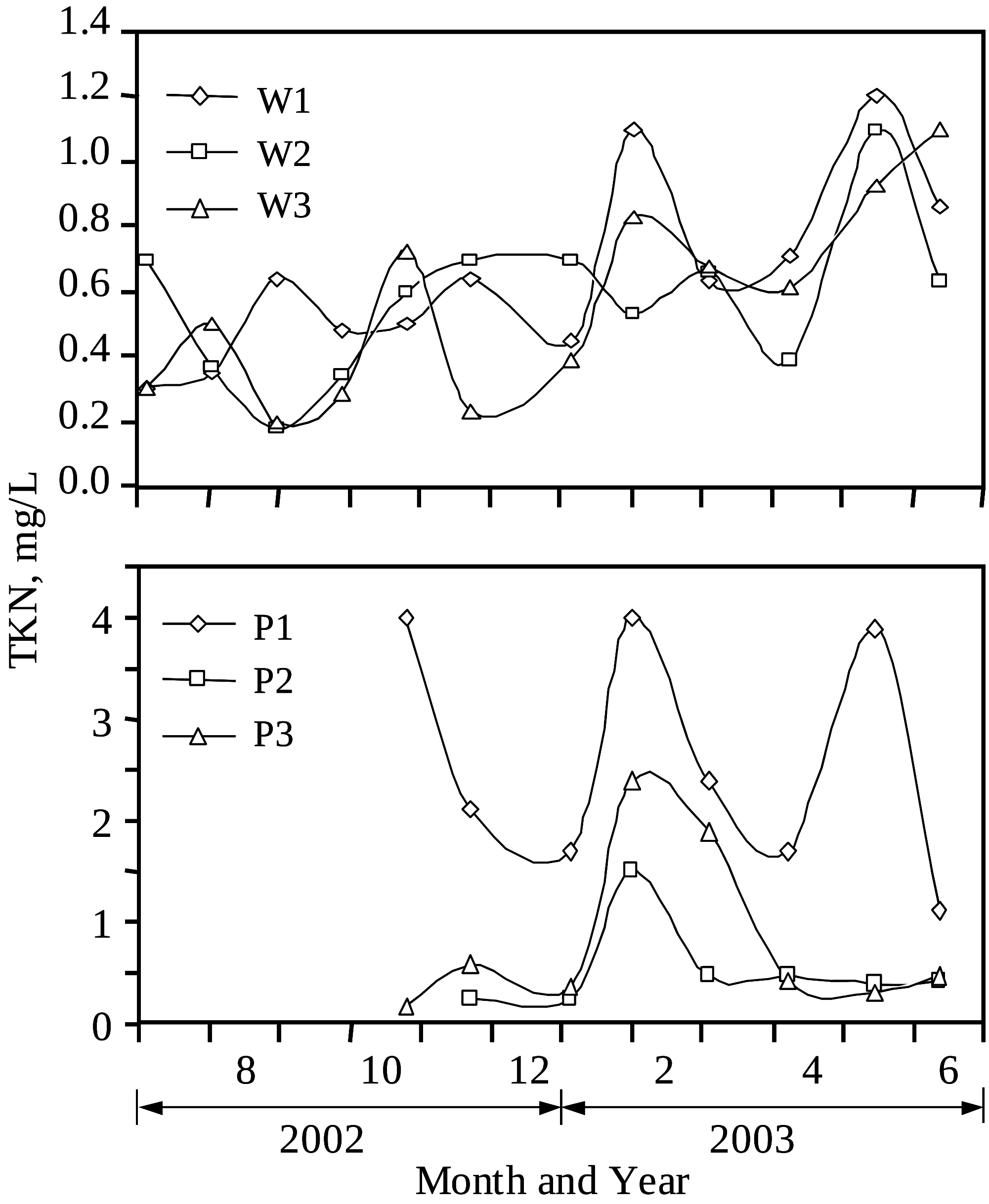

Figure 13C. Total Kjeldahl nitrogen (TKN) concentrations of the ground water collected from wells (W) and piezometers (P) at three locations in the drainfield area of System 3. For sampling locations see Fig. 8.