The

Connecticut

Agricultural

Experiment

Station,

New Haven

Leaching of Metals and Nitrate from Composted Sewage Sludge

BY CHARLES R. FRINK
AND BRIJ L. SAWHNEY

Bulletin 923

August 1994

Summary

Experiments to determine the leaching of metals and NO3-N from soil to ground water from the storage and use of composted sewage sludge produced by the Metropolitan District Commission (MDC) in Hartford were conducted by The Connecticut Agricultural Experiment Station (CAES). The study was requested by the MDC as described in Connecticut Department of Environmental Protection (DEP) Consent Order WC 4988 of January 10, 1991.

Both lysimeter and field studies were performed at the CAES Valley Laboratory in Windsor, CT. Here, a very sandy soil is underlain by an impermeable silt and clay layer at a depth of 2.4 to 3.7 m (8 to 12 ft) that creates a permanently perched water table allowing direct sampling of the ground water with shallow wells. Because ground water normally contains NO3-N and metals from a variety of sources, both the turf plot and stockpile studies utilized upgradient wells as controls. Five cm (2 in) of compost was applied to the lysimeters and turf plots corresponding to the maximum topsoil blending rate in the MDC management plan.

Analyses for heavy metals (As, Be, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn) in the leachate from lysimeters, turf plot wells and stockpile wells indicated that leaching of heavy metals is not likely to cause contamination of ground water. The concentrations observed were generally much lower than drinking water standards. The frequency of detection of metals in upgradient wells did not differ from that in downgradient wells.

The compost contained more available nitrogen than anticipated, with the movement of significant amounts to ground water at the turf plots. The heavy rain in August 1991 from Hurricane Bob increased infiltration considerably and also caused the NO3-N concentrations in the upgradient wells to increase. On average, the net NO3-N contribution from the compost was 5.1 mg l^{-1} (ppm) during the 18 month period, with three excursions over the standard of 10 mg l^{-1} (ppm). Leachate from the stockpile contributed 4.9 mg l^{-1} (ppm). The temporary pulse of nitrate from the storage and one time use of composted sewage sludge at topsoil blending rates does not appear to pose any persistent threat to ground water.

Introduction

The regional in-vessel sewage sludge composting facility owned and operated by the Metropolitan District Commission (MDC) in Hartford is one of the largest producers of compost in Connecticut. The composting plant began operation in 1990. By early 1991, about 7,650 m^3 (10,000 yd^3) were stockpiled at the MDC. The plant nutrients present in sludge make it useful as a fertilizer, while the organic matter improves soil tilth. Application of excessive amounts of composted sewage sludge, however, may result in unwanted leaching of metals and NO3-N to ground water. This report presents the results of experiments to determine the potential for leaching of metals and NO3-N from soil to ground water from the storage and use of this composted sludge. The study was conducted by The Connecticut Agricultural Experiment Station (CAES) at the request of the MDC as described in Connecticut Department of Environmental Protection (DEP) Consent Order WC 4988 of January 10, 1991.

The study had four major objectives. The first was the chemical characterization of the compost to determine the forms of nitrogen present and to measure both total metal content (As, Be, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn) and the amounts that could be extracted by the Toxicity Characteristic Leaching Procedure (TCLP). Because compost may vary in composition, a number of samples were collected to assess this variability.

The second objective was to measure leaching of metals and NO3-N in lysimeters under controlled conditions. Lysimeters are cylindrical tanks containing soil and compost that are placed in the field with provisions for collecting the leachate that passes through them. In our studies, the lysimeters were covered to exclude rain. A known volume of water was added periodically to the top of the lysimeters and the leachate that drained from the bottom was collected. The absence of vegetative cover and the creation of saturated flow results in the worst case potential for excessive leaching of both metals and NO3-N.

The third objective was to evaluate the extent of leaching of metals and NO3-N when compost is used in topsoil blending. This would likely be practiced at construction sites and other areas where the thin layer of topsoil would be greatly benefited from a one time application of a substantial amount of compost. The amount applied for this purpose would be about 5 cm (2 in). In addition, we tested the effect of adding additional fertilizer nitrogen during the first year, as might be practiced by some homeowners and landscapers when establishing a lawn.

The fourth objective was to determine the extent of leaching of metals and NO3-N from a stockpile that might be temporarily established during the process of topsoil blending or landscaping. This represents a higher loading rate of compost per unit area of land, but infiltration of rain into such a pile is probably limited.

The field studies were conducted at the CAES Valley Laboratory in Windsor, CT where a very sandy soil is underlain by an impermeable silt and clay layer at a depth of about 2.4 m to 3.7 m (8 to 12 ft). This layer creates a permanently perched water table with the surface of the water only 1.5 m to 2.4 m (5 to 8 ft) below the surface of the soil. Thus, this study combines the worst case scenario of a high loading rate of compost on a very porous soil with the water table only a few feet below the surface.

Because ground water normally contains metals and NO3-N from a variety of sources, both the turf plot and stockpile studies utilized upgradient wells as controls. We calculated the differences in concentration between the upgradient and downgradient wells to obtain the net NO3-N or metals contributed by the compost. Initial exploratory wells were installed to aid in locating the turf plots as nearly as possible in a direction perpendicular to the ground water gradient. The stockpile was ringed with six wells: Three served as upgradient controls and three were downgradient.

During these experiments, the U.S. Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 1993) published its long-awaited "Standards for the Use or Disposal of Sewage Sludge," generally known as the "503 Regs." The earlier versions of these regulations focused on establishing the concentrations of metals that would be acceptable for unrestricted uses at high loading rates, i.e. the "safe sludge" concept as developed by the W-170 Peer Review Committee. The final rule also contains guidance on agronomic rates of application based on the nitrogen requirements of the crop. With particular reference to topsoil blending, the EPA preamble states in part: "The final Part 503 rule allows the permitting authority to grant nitrogen application in excess of crop and vegetative requirements on a site-specific basis as long as the sewage sludge application rate is designed to minimize the amount of nitrogen that passes below the root zone of a crop or vegetation grown on the site to the ground water. Although this may cause a temporary pulse of nitrogen to occur in ground water or surface water near the site the Agency believes that any minor excursion granted by the permitting authority will cause no persistent harmful effects to human health or the environment. Any slight potential for adverse impacts from a temporary nitrogen pulse will be more than offset by the beneficial effects of land reclamation such as decreased acid run-off, erosion control, attenuation of inorganic and organic pollutants, and increased soil nutrient levels."

The experiments commenced in May 1991 and were completed in December 1992. The results and an interpretive report were provided to the DEP and MDC.

Literature Review

Metals

Pioneering studies of the application of digested sewage sludge to soil were conducted at CAES by Lunt (1959). Since then, many others have examined the use of sewage sludge as a soil amendment for plant growth and the uptake of heavy metals by different crops, including work in Connecticut by Sawhney and Norvell (1980). On the basis of these and other studies, criteria and recommendations for land application of sewage sludge in the Northeast were published by the Technical Committee of Northeastern Regional Research Coordinating Project, NEC-28 (NEC, 1985).

Most of this work focused on plant uptake of metals. Where soils have been analyzed, a large portion of the sludge applied metal has been found to be concentrated in the surface few cm. Sanders et al. (1986) analyzed three different soils 5 years after the last application of sludge and found that Cu, Ni, Cd, and Zn persisted in the top 20 cm in forms that were available to plants and could be extracted by chelating reagents and neutral salt solutions. Berrow and Burridge (1990) analyzed soils treated 17 years earlier with a highly contaminated sludge at the rate of 125,000 kg ha^{-1}. They found that soil metals persisted in extractable and plant available forms for many years. A recent study by Cabrera et al. (1989) showed that three additions of urban compost (14,000 kg ha^{-1} yr^{-1}) increased the heavy metal content of surface soils, but no significant increases occurred in the subsoil. However, Xiu and Taylor (1989) reported that the heavy metals Cd, Cr, Cu, Ni, and Zn had migrated into the subsoil in a cultivated soil that had received an application of 20,000 kg ha^{-1} yr^{-1} of sewage sludge for 5 years. This is one of the few reports that indicates potential downward movement of heavy metals from sewage sludge applied to agricultural soils, although no details of the experiment are available.

Immobilization of sludge applied metals in soil and composted sewage sludge is generally attributed to precipitation or complexation in relatively stable forms. Sposito et al. (1982) observed an increase in the heavy metals Ni, Cu, Zn, Cd, and Pb in organic and carbonate fractions in arid-zone soils that had received sewage sludge for 4 years. Humic acids in such soils have also been found to adsorb metals strongly (Senesi et al., 1989), but they may also act as chelating agents and enhance migration. Other factors that have been found to influence the attenuation of heavy metals in soils include soil pH (Harter, 1983; Tackett et al., 1986), sorption onto clays, CEC, hydrous oxides (Boyle and Fuller 1987; Kotuby-Amacher et al., 1988) and organic matter (McBride et al., 1981; Eighmy et al., 1987).

Similar results have been observed in soil columns in the laboratory. Emmerich et al. (1982) mixed sewage sludge into the top 15 cm of 120 cm long soil columns and leached them with water for 25 months. Essentially all metals remained in the sludge-soil layer and were assumed to be converted to residual stable forms. Chang et al. (1984) found over 90% of the applied metals in the top 15 cm of two soils that had received annual applications of composted sludge for 6 years. Mass balance calculations, however, revealed that recovery of the metals by extraction with 4 M HNO_3 was low. In a similar study, Welch and Lund (1987) found that Ni moved below the sludge layer to a depth of 15 cm in saturated columns and 45 cm in unsaturated columns. Saturated columns were irrigated for 7 months while the unsaturated columns were irrigated every 12 days for 13 months.

Bugbee et al. (1991) measured the concentrations of Cd, Cr, Cu, Mn, Ni, Pb, and Zn in leachate from potting media containing composted leaves, sewage sludge and street sand. All concentrations of Pb and Cd were below the federal primary drinking water standards of 0.05 mg l^{-1} for Pb and 0.01 mg l^{-1} for Cd. Concentrations of Cr and Cu were near or below the standard of 0.05 mg l^{-1} for Cr and 1.0 mg l^{-1} for Cu. No primary standards exist for Mn, Ni or Zn.

These results (Bugbee et al., 1991) are consistent with the assumptions stated by EPA (U.S. Environmental Protection Agency, 1989) that metal concentrations in leachate are generally defined by solubility constraints. An example from Bugbee et al. (1991) with samples containing 10% and 100% compost illustrates this point: In no case did the 10-fold increase in concentration of compost cause a 10-fold increase in metal concentrations in the leachate.

The concentrations of six metals, Cd, Cr, Cu, Ni, Pb, and Zn were measured in laboratory column studies with compost from Fairfield and from Greenwich (Sawhney et al., 1992). The pH of the leachates remained near neutral throughout the experiment. The concentration of metals in the leachate decreased rapidly, followed by leaching at a decreased rate, tending towards a continuous steady slow rate of release. The concentrations of the heavy metals in leachates from both composts were generally lower than the interim primary drinking water standards established by the EPA (U.S. Environmental Protection Agency, 1990).

These results indicate that removal of metals after the initial leaching is likely controlled by the solubility of solid phases. Similar conclusions were reached in a recent investigation (Fruchter et al., 1990) where leachates collected under natural rainfall from a large fly ash field lysimeter were analyzed.

In developing the "503" standards for use and disposal of sewage sludge, the EPA (U.S. Environmental Protection Agency, 1989) modeled the transport of metals to ground water in the worst case scenario of an unlined sewage sludge monofill located immediately over a Class I aquifer. Using the drinking water standards of $0.05\ mg\ l^{-1}$ for Pb and $0.01\ mg\ l^{-1}$ for Cd, they estimated that these concentrations would not be exceeded unless the sludge contained more than $1600\ mg\ kg^{-1}$ Pb and $380\ mg\ kg^{-1}$ Cd.

Availability of Nitrogen

Frink (1990) reviewed the availability of nitrogen from compost and the potential for NO3-N leaching at the request of the MDC and the DEP.

The availability to plants of nitrogen (N) from composted sewage sludge is controlled primarily by the rate of microbial conversion of organic forms of N to inorganic ammonium nitrogen (NH4-N) and its subsequent microbial oxidation to NO3-N. Inorganic NH4-N present is readily converted to NO3-N and is also available to plants during the first year of application. The rate of release or mineralization of N from composted sewage sludge should follow the pattern reported for digested sewage sludge (Barbarika et al., 1985) with two exceptions. First, finished compost generally contains less inorganic N than sludge and hence less N is available during the first year. Second, the higher C/N ratio of compost when compared with non-composted materials suggests a slower rate of mineralization.

The conversion of NH4-N to NO3-N is microbially mediated; hence, the rate is a function of soil moisture and temperature. The usual pattern is an increase in NO3-N production in the spring as the soil warms and a decrease as the soil cools in the fall. Extremes of wet or dry soil also slow the process. Organic nitrogen fertilizers, such as composted sewage sludge, are considered "slow-release" fertilizers that provide for release of NO3-N as crop needs increase during the growing season. Utilization of compost as a soil amendment could reduce the need for commercial nitrogen fertilizers and reduce the possibility of contamination of ground water with NO3-N. However, even slow release fertilizers need to be applied at rates consistent with crop needs (Rathier and Frink, 1986).

The rate of mineralization of N from composted sewage sludge was estimated from the limited information in the literature. Unfortunately, most studies dealt with digested sewage sludge that has a highly variable rate of availability during the first year. This is due to the varying amounts of NH4-N normally present in sludge (Pratt et al., 1973; Keeney et al., 1975; Somers and Nelson, 1976). If the data from these studies for the second and subsequent years are plotted, the inferred rate of mineralization in the first year is about 6% to 7% (Frink, 1990). Magdoff and Amadon (1980) studied aerobic liquid sludge (1.02% solids) containing large amounts of NH4-N and reported a mineralization rate of 24% for the second year. Keeling et al. (1977) observed a rate of 10-15% in the second year for an anaerobic liquid sludge (2.99% solids) with 36% NH4-N. Both of these liquid sludges contain far more readily available NH4-N than most digested sludges.

Less information is available on the availability of N from composted sewage sludge. In laboratory incubation studies, Epstein et al. (1978) reported rates of mineralization of 3.8% to 4.7% for composted raw sludge and 7.0% to 9.3% for composted digested sludge. In similar laboratory studies, Tester et al. (1977) reported 6% mineralization of N from composted sewage sludge applied to a loamy sand and less than 1% for compost applied to a silt loam. In subsequent greenhouse studies, Tester et al. (1982) found that about 10% of the total N in composted sewage sludge applied to the loamy sand was available for the growth of fescue, with lower amounts available in the silt loam. Additional N fertilizer produced a yield response in both soils.

These studies led to the conclusion that about 10% of the total N in compost made from raw sludge and wood chips by the Beltsville Aerated-Pile Method and passed through a 1.27 cm (0.5 in) mesh screen (Willson et al., 1980) is available for plant uptake during the first year of application (Hornick et al., 1979). This estimate includes any inorganic N initially present in the compost (Hornick et al., 1984). An estimate of 10% for the first year is also contained in a review of N availability from composted sewage sludge by Fox and Axley (1985).

The data cited above for composted sewage sludge in the first year of application as well as the data for digested sewage sludge in the second and subsequent years suggest that, within the accuracy of the data, an estimate of 5% to 10% is reasonable.

Frink (1990) suggested a rate of 5% based on the expectation that unscreened MDC compost used for topsoil blending will contain more sawdust and wood chips than the screened compost from the Beltsville process. Moreover, this ratio can be controlled more precisely during in-vessel composting.

Leaching Potential

The potential for NO3-N contamination of ground water can be estimated by a nutrient budget that compares total inputs of N with the amounts removed by the crop. The balance is assumed to be available for conversion to NO3-N and loss by leaching. The concept of a nutrient budget is useful in estimating the potential for ground water contamination (Frink, 1969), but estimates of the various sources and sinks for N are uncertain.

Some N is fixed in soil by microbial processes and some is released to the atmosphere by volatilization of ammonia. Microbes also convert NO3-N to nitrogen oxides and nitrogen gas that are lost to the atmosphere by denitrification.

Additional inputs of N are the amounts released by native soil organic matter and small but significant amounts in rainfall. Not all these processes can be measured directly; hence losses must be obtained by difference between the sum of measured inputs in fertilizer and amounts removed by the crop. The early difficulties encountered in such experiments were aptly summarized by Allison (1955) as the "enigma of soil nitrogen balance sheets." In a more recent review, Legg and Meisinger (1982) conclude that the nitrogen budget approach has shown that the major mechanisms for N removal from soil are crop uptake, leaching, and gaseous losses.

Ultimately, predicted losses by leaching must be compared with direct measurements of NO3-N leaching through soil or present in ground water. Early studies of leaching through soil were conducted in lysimeters such as those at Windsor described by Morgan et al. (1942). Lysimeters have been criticized because leaching is artificial, particularly for fine-textured soils where much water moves by capillary action. These anomalies are less in sandy soils. Indeed, the Windsor Lysimeter Studies are a classic cited by Allison (1955) as most likely to resemble leaching in undisturbed field soils.

Where possible, measurements in test wells installed for the specific purpose are desirable. In many locations, the depth to the water table and the complex hydrology of the site makes this an expensive and somewhat uncertain technique (Mullaney et al., 1991). Fortunately, the shallow perched water table at the Valley Laboratory in Windsor provides ready access to ground water at a site with relatively straightforward hydrology.

A number of computer models have been developed to mimic the N cycle in soil (Tanji, 1982), and new ones are constantly being devised. Numerous others are available to predict water movement through soil (Frink, 1989). Then, the two must be coupled with a ground water model to predict whether leaching of NO3-N from native soil and applied fertilizer will cause concentrations to exceed the drinking water standard of 10 mg l^{-1} at some specified site. One model that is well suited to the present site where depths to ground water are only a few feet is LEACHM by Hutson and Wagenet (1992). However, experiments at the Valley Laboratory have shown that water and solutes can move through such soils in fingers of flow (Starr et al., 1978; Starr, Parlange and Frink, 1986), a process that is not readily modeled.

Frink (1969) suggested that a simple rainfall-dilution equation proposed by Stout and Burau (1967) could be used on an annual basis. The average rainfall in the upper Connecticut River basin is 112 cm yr^{-1} with about half or 56 cm lost by evapotranspiration (Ryder et al., 1981). The difference, or 56 cm, is available for runoff and ground water recharge. If all 56 cm percolates through a hectare of soil, the amount of N required to produce 10 mg l^{-1} in the ground water can be readily estimated. The total volume of water would be 560×10^6 cm^3 and would weigh 560×10^6 g. Hence, 10 mg l^{-1} is equivalent to a loss of 56.0 kg ha^{-1} of N. Because both nitrogen availability and ground water recharge are seasonal phenomena, this is a considerable oversimplification. Nonetheless, these calculations provide a useful rule of thumb: Losses of N in excess of 56.0 kg ha^{-1} have the potential to produce NO3-N concentrations in excess of 10 mg l^{-1} in the ground water on an average annual basis.

Topsoil Blending

A major use for compost is expected to be in topsoil blending, where about 5 cm (2 in) would be blended with poor soils typical of construction sites. The sites would then be seeded or sodded. In this application the organic matter in the compost would have a major beneficial effect on the physical properties of the soil including aeration and moisture holding capacity.

In studies of turf establishment using modest amounts of nitrogen, DeRoo (1980) measured NO3-N concentrations in the ground water upgradient and under turf plots at the Valley Laboratory. The plots were established by direct seeding in August and fertilized at the rate of 73 kg ha^{-1} of N. Following establishment, the plots were fertilized annually with a slow release urea formaldehyde fertilizer at the rate of 196 kg ha^{-1} of N. Half was applied in April-May and the other half in September-October. In one portion of the experiment, the clippings were removed from half the plots.

The results of analyses of the test wells by DeRoo (1980) are summarized here. The means for the upgradient well of 0.88 mg l^{-1} can be compared with 2.01 mg l^{-1} under plots where clippings were returned and 1.86 mg l^{-1} where they were removed. This limited leaching of N from turf has since been confirmed in other studies where leaching losses generally were far less than 10% of the applied N (Petrovic, 1990). Much of the applied N is recycled fairly rapidly through the clippings as shown by Starr and DeRoo (1981) using nitrogen fertilizer labeled with the heavy isotope N^{15}.

Their results indicate that 3 years after application, the cumulative nitrogen in the clippings alone was about 157 kg ha^{-1} when fertilizer was applied at the rate of 196 kg ha^{-1} of N (DeRoo and Starr 1979). In a recent review of the fate of N fertilizers applied to turf grass, Petrovic (1990) showed that substantial amounts of nitrogen can accumulate in soil over time, but not all of it is available for leaching.

With particular reference to topsoil blending, the EPA (U.S. Environmental Protection Agency, 1993) preamble to the sewage sludge regulations states in part: "Although this (rate of application) may cause a temporary pulse of nitrogen to occur in ground water or surface water near the site the Agency believes that any minor excursion granted by the permitting authority will cause no persistent harmful effects to human health or the environment. Any slight potential for adverse impacts from a temporary nitrogen pulse will be more than offset by the beneficial effects of land reclamation such as decreased acid run-off, erosion control, attenuation of inorganic and organic pollutants, and increased soil nutrient levels."

Summary of Literature

A review of the available literature indicates that the heavy metal concentrations present in composted sewage sludge used in Connecticut under proposed DEP regulations are not likely to pose a threat to ground water.

About 5% of the total organic nitrogen present in the MDC compost is expected to be mineralized and hence become available to plants during the first year of application. The rates of availability should slow with time.

The potential for leaching was evaluated by nutrient budgets that compare total inputs of N with amounts removed by crops. The balance was assumed to be available for leaching, with no allowance for losses to the atmosphere. Direct measurements of NO3-N in ground water under turf plots were used to supplement the nutrient budget approach. A simple rainfall dilution equation was used to quantify leaching losses. These calculations show that losses of N in excess of 56 kg ha^{-1} have the potential to produce concentrations in excess of 10 mg l^{-1} in the ground water on an annual basis. Turf fertilized at the rate of 196 kg ha^{-1} of N contained as much as 157 kg ha^{-1} of N in the clippings. Test wells showed an increase in NO3-N of about 1 mg l^{-1} beneath these plots.

The proposed maximum rates of application of N for topsoil blending for turf would provide about 134 kg ha^{-1} during the first year of application based on the assumption that about 5% of the N in compost containing 1.5% total N will be available for plant growth. This rate of application would not be expected to add a net amount of NO3-N to ground water in excess of the standard of 10 mg l^{-1}.

Procedures

Chemical Analyses

In the early spring of 1991, about 7,650 m^3 (10,000 yd^3) of composted sewage sludge were stockpiled at the MDC. A subsample of 76 m^3 (100 yd^3) was isolated for use in these experiments and turned regularly to ensure homogeneity.

Chemical analyses for heavy metals for the characterization, lysimeter, turf plot and stockpile experiments were performed through June 1992 under contract between the MDC and Phoenix Environmental Laboratories, Inc. (PEL). Subsequently, the contract analyses were performed by Analytical Consulting Technology, Inc. (ACT), including appropriate quality control assurance.

About 10% of the samples of ground water were split with the CAES for metal analysis using ICP and AA (U.S. Environmental Protection Agency, 1986a). The CAES also examined samples of ground water and determined that filtration was necessary prior to acidification of the samples to prevent dissolution of small amounts of metals in suspended sediment. Chemical analyses for NO3-N in ground water were performed by CAES, with about 10% of the samples split with PEL and ACT for quality control. Specific methods and detection limits for metals in ground water are shown in Appendix Table 1.

Total heavy metals (As, Be, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn) in six composite samples of the compost were determined by PEL using a mixture of HNO_3 and H_2O_2 recommended in EPA Method 3050 for evaluating solid wastes (USEPA, 1986a). Solids, total N, ammonia N, nitrate N, total P, ortho P, and total K were also determined by PEL laboratories.

To determine potential heavy metal leachability from the wastes, the Toxicity Characteristic Leaching Procedure (TCLP) was performed on the same six composite samples. The TCLP (Federal Register, March 29, 1990) has replaced the previous EPA extraction test (EP) (U.S. Environmental Protection Agency, 1986b). This procedure employs 0.1 M sodium acetate buffered at pH 5 for extracting heavy metals from wastes. Analyses for metals in the TCLP extract were completed by PEL. There are only a few published reports where the predictive value of this procedure has been evaluated (Sawhney and Frink, 1991) and it needs to be tested both for a variety of wastes as well as compared with observations in the field.

Leaching in Lysimeters

The Station installed a set of lysimeters at the Valley Laboratory in Windsor in 1929 to study the movement of fertilizers through soils. The lysimeters consist of cylindrical open-top metal tanks 23, 46, and 69 cm deep and 51 cm in diameter, with tin-lined metal pipes at the bottom that lead to the interior of a collection chamber underground. Polyethylene garbage pails were placed in the lysimeters and Tygon tubing was installed through the metal pipes to prevent contamination of the leachate with metals.

We refurbished eight lysimeters and filled them with Merrimac sandy loam (Entic haplorthod) in the following sequence of horizons. Two lysimeters had only the C horizon, two had the C and B horizons and two had C, B and A horizons. This sequence of soil horizons was chosen to represent what may occur if topsoil is removed from construction sites and not replaced. We applied 5 cm (2 in) and 10 cm (4 in) of compost on top of soils in six lysimeters and also to two lysimeters with no soil. The lysimeters were protected from rainfall. Leaching experiments were conducted monthly by adding approximately 2.5 cm of water to obtain saturated flow. The leachates (approximately 10 l) were collected in acid-washed glass or plastic bottles by CAES staff and analyzed for pH and NO3-N by CAES and heavy metals by PEL/ACT. The lysimeter experiments were suspended during freezing weather in the winter of 1991 and were resumed in late spring of 1992.

Leaching in Turf Plots

Composted sewage sludge from the stockpile at the MDC was applied to a 15 m x 43 m (50 ft x 140 ft) test plot at the Valley Laboratory on May 23, 1991. The soil at the site is a Merrimac sandy loam, a moderately coarse-textured soil developed over coarse sand and gravel, which occurs at a depth of about 0.6 m. The soil is underlain by impervious varved silt and clay layers at a depth of about 2.4 to 3.7 m (8 to 12 ft), while the surface of the perched water table fluctuates between 1.5 and 2.4 m (5 to 8 ft).

The compost was spread by hand at the rate of 293 Mg ha^{-1} (6,000 lbs/1,000 ft^2) and harrowed into the top 10 to 15 cm of soil. This corresponds to the maximum rate of application of 5 cm (2 in) in the MDC Management Plan for topsoil blending. The plot was then sodded with bluegrass from a commercial grower.

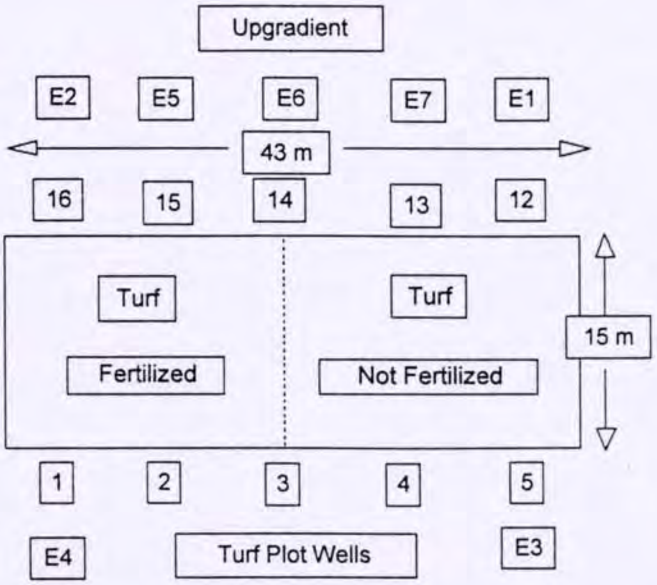

Figure 1. Turf plot design.

A sketch of the plot is shown in Figure 1. The numbered boxes indicate test wells. Prior to laying out the plot, exploratory wells E1 and E2 had been installed about 6 m (20 ft) upgradient and E3 and E4 about 6 m (20 ft) downgradient to verify the direction of the ground water gradient. Wells E5 through E7 were installed in 1992 to provide further information on the quality of water upgradient from the plot. The plot is oriented so that the ground water gradient is perpendicular to the long dimension of the rectangular plot. Wells 12 through 16 are the upgradient control wells and wells 5 through 1 are the corresponding downgradient wells in that numerical sequence. The spacing between these wells is 7.6 m (25 ft). The long dimension of the plot extends about 6 m (20 ft) beyond the wells as shown in Figure 1 in order to minimize edge effects.

Half the plot received no fertilizer and half received 50 kg ha^{-1} of N (1 lb of N per 1000 ft^2) three times during the 1991 growing season (on August 8, September 24, and December 12). In 1992 fertilizer was applied to the same half of the plot at the same rate on May 28, September 10, and November 20. In addition, in 1992, both plots were treated with Dacthal 75W at 16 kg ha^{-1} on April 29 for crabgrass control, with Chipco 26019 at 6 kg ha^{-1} on May 5 for Helminthosporium control, with the fungicides Daconil 2787 at 6.2 kg ha^{-1} and Subdue 2E at 6 kg ha^{-1} on August 19, and with Diazinon AG 500 at 9 kg ha^{-1} on September 2 for grub control. Supplemental irrigation was used to provide about 2.5 cm of water per week during the growing season. A weather station is located near the turf plots and a complete record of rainfall and irrigation is in Appendix Table 8. The three center test wells upgradient (15, 14, 13) and three downgradient (2, 3, 4) from the plot were sampled monthly and analyzed for pH and NO3 by CAES and heavy metals by PEL/ACT. The additional two wells upgradient (16, 12) and two wells downgradient (1, 5) were analyzed by CAES for pH and NO3 only.

The upgradient wells and the exploratory wells are 5 cm perforated PVC pipe installed as described by DeRoo (1980). The downgradient wells were installed and purged by Welti Associates in accordance with DEP monitoring well guidelines (February, 1990). Well logs are on file at CAES. Samples were collected monthly with dedicated bailers by lowering a 76 cm PVC tube (3 cm ID), fitted with a floating valve, into the ground water and withdrawing it when filled. Three sampler volumes were taken from each well before collecting the sample for analysis. The samples were placed in acid-washed glass or plastic bottles and refrigerated until analyzed. The elevation of water in the wells was measured at each sampling period by lowering a weighted tape into the well. The elevation of the wells was determined from a common reference datum.

Leaching in Stockpiles

A stockpile of 38 m^3 (50 yds^3) was established on May 16, 1991 at the Valley Laboratory in Windsor as shown in Figure 2. The stockpile was a pyramid about 9 m (30 ft) in diameter and 1.8 m (6 ft) high in the center, with a circumference of about 28 m (92 ft).

Six test wells spaced about 4.5 m (15 ft) apart were installed around the perimeter of the pile in accordance with DEP monitoring well guidelines. The elevation of water in these wells was also determined monthly from a common reference datum. Samples were collected monthly from the upgradient (11, 6, 7) and downgradient (10, 9, 8) wells. Metals were analyzed by PEL/ACT and pH and NO3-N by CAES. Supplemental irrigation was available but not used.

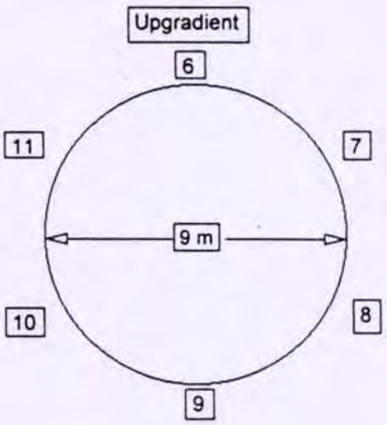

Figure 2. Stockpile design.

Results

Chemical analysis

The analysis of the compost prior to its use is shown in Appendix Table 2. The TCLP results (Appendix Table 2, Top) revealed that none of the extractable metals exceeded the regulatory standards shown in the last column (i.e. 100 times the drinking water standard). Similarly, none of the total metals in the compost (Appendix Table 2, Middle) exceeded DEP approved concentration limits for MDC sludge compost shown in the last column.

The total nitrogen analyses (Appendix Table 2, Bottom) indicate that this particular compost sample contained about 2.0% N, as well as some ammonia and NO3-N. The mean pH of the compost was 7.5. The application rates were based on a projected N content of 1.5% with little or no available ammonia. The actual loading rate may have been greater as noted subsequently.

Leaching in Lysimeters

Analyses of metals in lysimeter leachate are shown in Appendix Tables 3-1 to 3-5. The concentrations of metals clearly decrease with time as would be expected from the column experiments reported by Sawhney et al. (1992). The concentrations also tend to decrease in the lysimeters containing increasing amounts of soil (Appendix Table 3-5) as would also be expected. It is instructive to compare the concentrations of metals observed in the lysimeters with those observed in the earlier column studies (Sawhney et al. 1992). In general, the concentrations observed in leachate from MDC compost in lysimeters 1 and 5 (Appendix Table 3-5) are intermediate between those in the Fairfield compost and those in the Greenwich compost.

The results of the analyses for NO3-N are shown at the bottom of the summary (Appendix Table 3-5) and confirm the availability of NO3-N for leaching in the absence of plant growth. They also demonstrate the strong acidification accompanying the biological mineralization of organic nitrogen and its conversion to NO3-N. The increased acidity produced in the lysimeters with increasing amounts of soil is attributed to incubation effects between leaching episodes.

To determine the forms of heavy metals present in wastes, their concentrations in leachates from the laboratory columns (Sawhney et al. 1992) and lysimeters were compared with mathematical predictions from a metal speciation equilibrium model (PRODEF/MINTEQ, 1988) for surface and ground water. The model is designed to calculate equilibrium aqueous speciation, adsorption, gas phase partitioning, solid phase saturation states, and precipitation-dissolution of metals. Preliminary analysis of the data indicates that the observed concentrations of Pb and Cd are lower than those expected from known insoluble forms of Pb and Cd. This is not unusual in such complex models and indicates that more needs to be learned before they can be used for predictive purposes.

Leaching in Turf Plots

The analyses of the turf plot wells for metals are shown in Appendix Tables 4-1 to 4-4 and summarized in Figures 3, 4 and 5. The elevation of the ground water in the wells is shown in Figure 6. The NO3-N concentrations are shown in Appendix Table 5-1 and summarized in Figures 7 through 13. The mean pH of the ground water was 7.4. Unlike the lysimeters, the buffering capacity of the soil prevented any acidification of ground water and there were no apparent differences due to treatment.

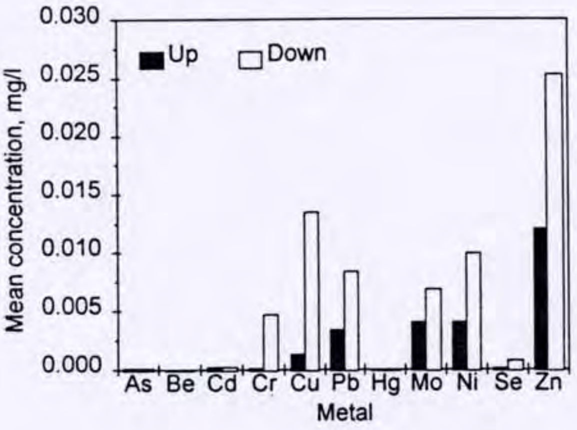

Figure 3. Mean metal concentrations in turf plot wells.

Our principal concern with the analyses of ground water was to determine whether there were significant differences between the concentrations of metals and of NO3-N in upgradient and downgradient wells. Because the concentrations of many of the metals are near or below detection limits, statistical analysis of these data is difficult. The common practice of fabricating data by arbitrarily substituting zero, the detection limit, or some fraction of the detection limit is generally not defensible and can lead to serious errors in subsequent analyses and conclusions (Helsel, 1990).

In addition, water quality data are usually not normally distributed, with a large number of low values and a few high values. Hence, the usual statistics of means and standard deviations are not always appropriate. Some type of transformation such as conversion to logarithms will often provide a more nearly normal distribution. We also found that the concentrations may change with time and the significance of these changes must also be examined. It is necessary to provide the reader with some summary statistics, however, and the data were analyzed with these constraints in mind.

The metal concentration data in Figure 3 were calculated for illustrative purposes by setting all the "non-detects" equal to zero. This method was chosen to provide the most sensitivity in illustrating the differences in concentration between upgradient and downgradient wells. If all the "non-detects" are set equal to the detection limit, the differences between the means would generally disappear. A third method is to try to infer something about the frequency distribution of the data below the detection limit. Lacking any other information, the best estimate may be one half the detection limit, although not all would agree (Helsel, 1990). Hence, we chose to illustrate the results as in Figure 3.

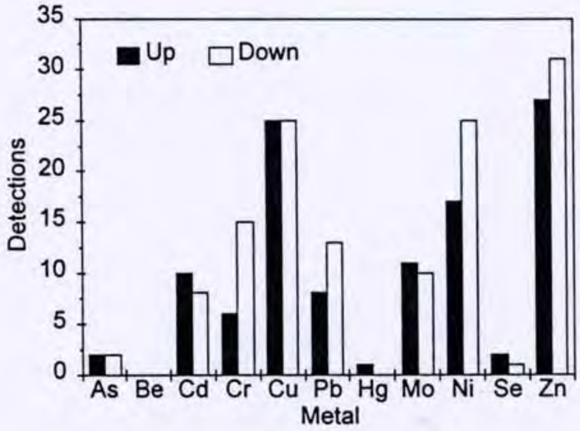

Figure 4. Frequency of metal detections in turf plot wells.

The frequency of detection of the metals also provides some useful information. The data in Figure 4 show the total number of detections of each metal in 54 analyses of samples from upgradient wells and another 54 samples from downgradient wells. The significance of the differences in the number of detections can be tested in a simple 2 x 2 contingency table as described by Fisher and Yates (1948). This is a robust method that does not require that the data fit a particular frequency distribution. The number of detections upgradient and downgradient are compared in Table 1.

As can be seen from the last column in the table, only the difference in the number of detections of Cr upgradient and downgradient exceeded that expected due to chance alone. This analysis suggests that leaching of metals from the turf plots had little or no significant impact on ground water quality.

Table 1. A 2 x 2 contingency test for metals in turf plot wells.

Metal	Detections			Chi	Sig.
	Up	Down	Total	Square	p=
As	2	2	4	0.000	ns
Be	0	0	0	0.000	ns
Cd	10	8	18	0.067	ns
Cr	6	15	21	3.783	0.05
Cu	24	25	49	0.000	ns
Pb	8	13	21	0.946	ns
Hg	1	0	1	0.000	ns
Mo	11	10	21	0.000	ns
Ni	17	25	42	1.909	ns
Se	2	1	3	0.000	ns
Zn	27	31	58	0.335	ns

We also need to inquire if the number of detections of metals increased with time. Figure 5 shows the total number of detections per month.

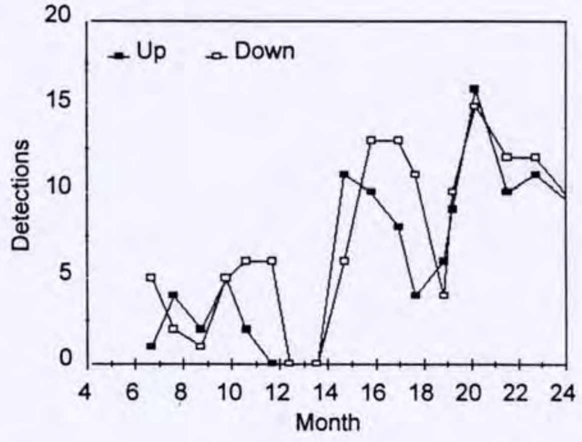

Figure 5. Monthly detections of metals in turf plot wells.

The answer must consider the change of laboratories in June 1992 (month 18.9). Since the numbers of detections in upgradient and downgradient wells were not significantly different (with the exception of Cr), the data were pooled and then separated into two groups as analyzed by the two laboratories before and after month 18.9. An analysis of variance showed that the number of detections was significantly higher when the samples were analyzed by ACT. Because ACT had lower detection limits than PEL, we attribute the increase in detections to the increased sensitivity of the analytical methods.

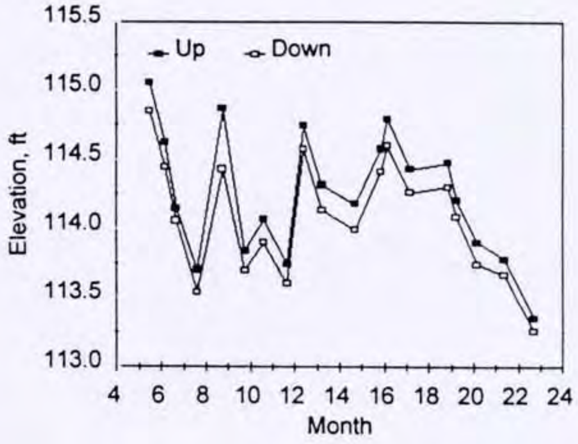

Figure 6. Elevation of ground water in wells upgradient and downgradient of turf plots.

The average hydraulic gradient between the two sets of turf plot wells for 1991-1992 as shown in Figure 6 was 0.052 m in 15 m (0.171 feet in 50 feet), or 0.00347 m m^{-1}.

Measurements of hydraulic conductivity from samples collected at a depth of 100 cm gave a value for K=0.039 cm sec^{-1} and a porosity of 0.4 (Starr, et al. 1978, 1986). Thus, the average ground water velocity is about 0.29 m per day or 105 m per year. The velocity varied from a low of 0.15 m per day (month 6.7) to a high of 0.72 m per day (month 8.7) following Hurricane Bob.

The results of the NO3-N analyses for the turf plot and stockpile wells are shown in Appendix Tables 5-1 and 5-2 and discussed in detail below.

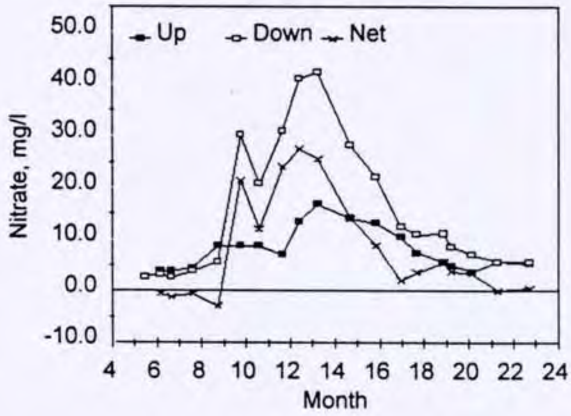

Figure 7. Concentration of NO3-N in wells upgradient and downgradient of turf plots.

The compost apparently contained more available N than anticipated, with the movement of significant amounts to ground water beneath the turf plots (Figure 7). We attribute much of this leaching to the heavy rain in August that increased infiltration considerably (month 8.7, Figure 6) and also caused the NO3-N concentrations in the upgradient wells to increase. It is important to realize that this represents the worst possible case of leaching since the 25 cm (10 in) of rainfall in August exceeded 100 years of record in most of New England (Appendix Table 8 and Figure 21). On average, the net NO3-N, i.e. the difference between the concentrations in the upgradient and downgradient wells, was 7.4 mg l^{-1} (Appendix Table 5-1).

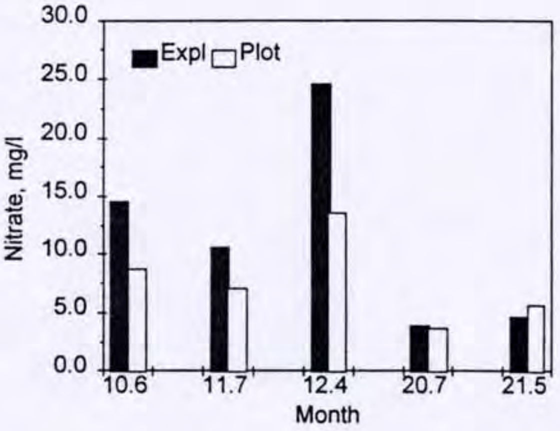

Figure 8. Concentration of NO3-N in upgradient exploratory and turf plot wells.

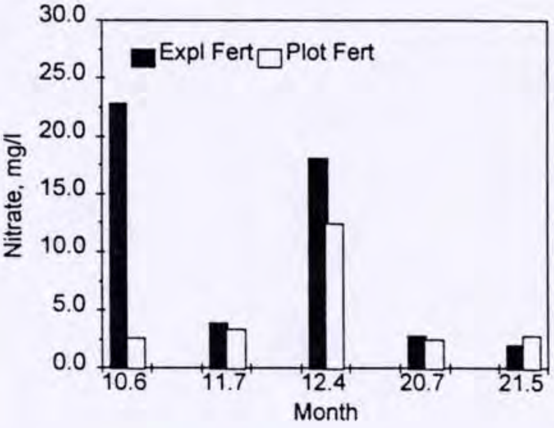

Figure 9a. Concentration of NO3-N in upgradient (Plot) and exploratory (Expl) wells on the fertilized half of the plot.

The appearance of NO3-N in the upgradient wells raised some concerns that NO3-N enriched leachate had moved upgradient. Given the rate of movement of ground water at that time of 0.72 m per day this seems unlikely. Fortunately, the two "exploratory" wells about 6 m (20 ft) upgradient of the plots (E1 and E2, Figure 1) are in the direct path of flow towards the fertilized and non-fertilized halves of the plot. The data in Figure 8 show that NO3-N concentrations in these wells exceeded the concentrations in the upgradient turf wells in the fall of 1991, confirming an upgradient source of NO3-N.

Three additional "exploratory" wells were installed in late summer of 1992 (E5, E6, E7, Figure 1). Thus, each upgradient turf plot well (Plot) had a companion exploratory well (Expl) upgradient from the fertilized and non-fertilized halves of the plot.

The data in Figures 8 and 9a and 9b show that the concentrations in the two sets of wells were nearly identical in the fall of 1992 in the absence of any major leaching events. These data indicate that contamination of the upgradient wells by the plot itself is unlikely.

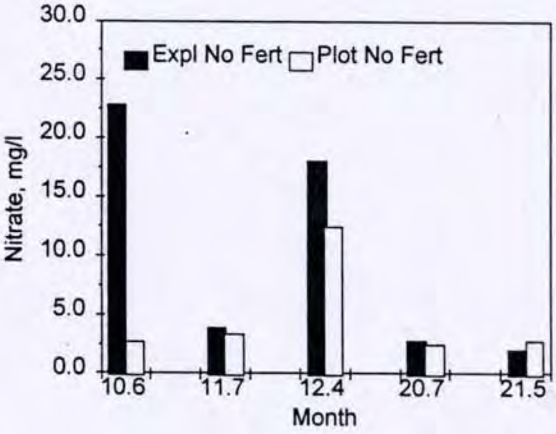

Figure 9b. Concentration of NO3-N in upgradient (Plot) and exploratory (Expl) wells on the non-fertilized half of the plot.

The net NO3-N concentrations in the wells in the fertilized and non-fertilized halves of the plot are shown in Figure 10. This test was designed to determine the fate of additional fertilizer applied during the first year of turf establishment. The mean net concentration of NO3-N added from the fertilized plot was 8.7 mg l^{-1} while the mean concentration from the non-fertilized half was 5.1 mg l^{-1} (Appendix Table 5-1). In order to determine if these differences in concentration were significant, the data were subjected to appropriate statistical analyses.

The frequency distribution of NO3-N concentrations in all the turf plot wells is shown in Figure 11. The smooth curve shows the expected frequency if the distribution followed the normal bell-shaped curve. Like most water quality data, the frequency distribution is highly skewed, with many samples with low concentrations and a few with high concentrations. As noted earlier, a transformation of the concentrations to logarithms often produces a better fit.

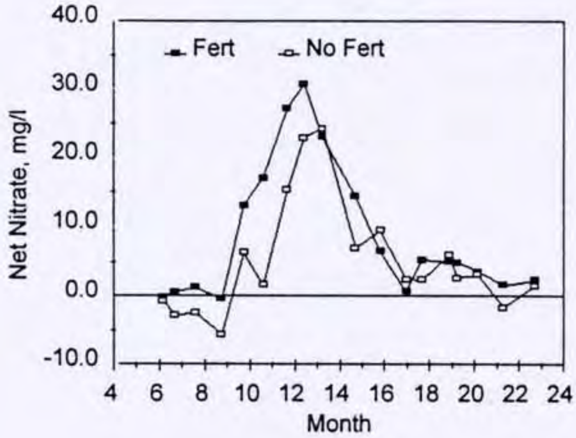

Figure 10. Net concentration of NO3-N in wells upgradient and downgradient of fertilized and non-fertilized halves of the turf plots.

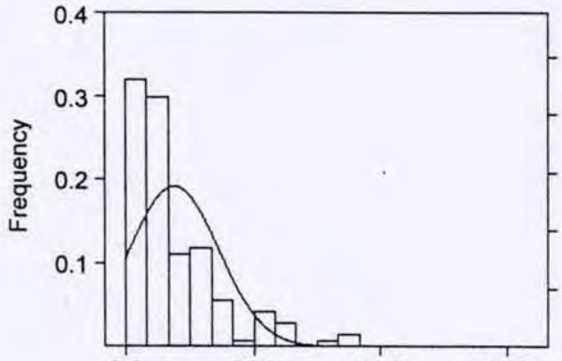

Figure 11. Frequency distribution of NO3-N concentrations in turf plot wells.

The transformed data are shown in Figure 12 and are a much better fit to the normal bell-shaped curve. The transformed data were then analyzed by a conventional parametric analysis of variance.

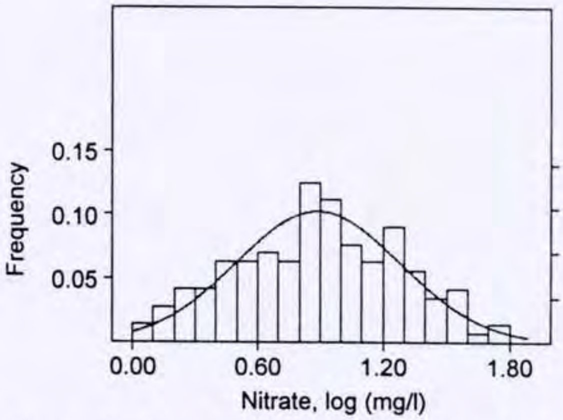

Figure 12. Frequency distribution of the logarithms of NO3-N concentrations in turf plot wells.

The results showed that the net NO3-N concentration of 5.1 mg l^{-1} from the unfertilized half of the plot was significantly less than the net NO3-N concentration of 8.7 mg l^{-1} from the fertilized half. This difference had largely disappeared in the second year, suggesting greater uptake (or less leaching) of the supplemental fertilizer. Indeed, if the data set is divided into two halves: 1991 (month 6.2 to 13.2) and 1992 (month 14.7 to 22.7), only the differences in 1991 are statistically significant. This suggests that supplemental fertilizer is not needed during the first year when turf is established by topsoil blending. It also shows that the actual contribution of NO3-N from the compost to the ground water was on average only 5.1 mg l^{-1}.

As noted earlier, water moves beneath the plot at an average rate of about 0.29 m per day. It is necessary to take this travel time into account when calculating the net difference in NO3-N concentrations between upgradient and downgradient wells. As a first approximation, travel time was assumed to be approximately 1 month (the interval between sampling periods). The net NO3-N data in Figure 13 were obtained by subtracting the concentrations in the downgradient wells from the concentrations observed in the previous month in the upgradient wells. The resulting calculated mean net NO3-N concentration from the unfertilized plot was 5.4 mg l^{-1} and 8.9 mg l^{-1} from the fertilized half. The graph also shows only two excursions over the 10 mg l^{-1} standard from the plot treated with compost only. These results do not appear to change our conclusions concerning leaching of NO3-N.

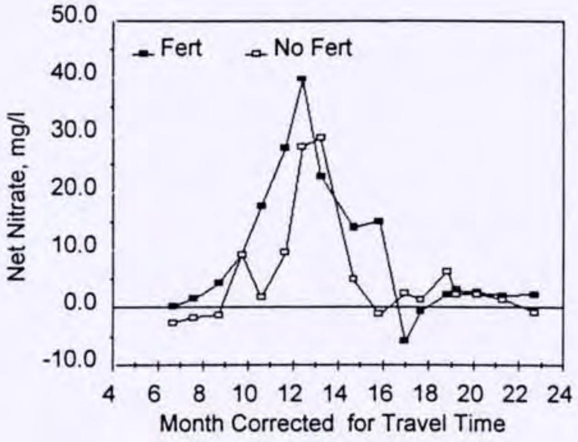

Figure 13. Net concentration of NO3-N in turf plot wells corrected for travel time.

Leaching in Stockpiles

The analyses of the stockpile wells for metals are shown in Appendix Tables 6-1 to 6-4. Wells 6, 7, and 11 are upgradient of wells 8, 9, and 10. The results of the analyses of metals are shown in Figures 14 to 16. The elevation of the ground water in the wells is shown in Figure 17. The NO3-N concentrations are shown in Appendix Table 5-2 and summarized in Figure 18. The mean pH of the ground water was 7.4 as observed in the turf plot wells.

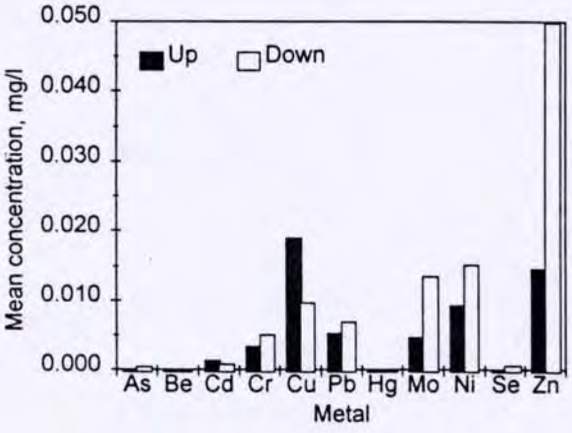

Figure 14. Mean metal concentrations in stockpile wells.

The metal data from the stockpile wells were analyzed as with the turf plot wells. The means in Figure 14 were calculated by setting all the "non-detects" to zero with the same caveats that apply to the turf plot data. The mean concentrations are similar to those observed in the turf plot wells, but this cannot be tested statistically as discussed earlier.

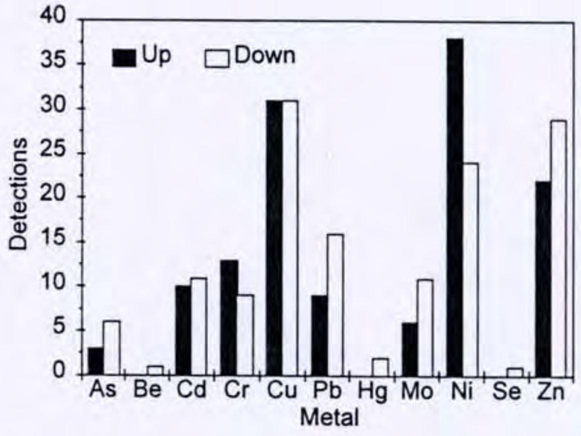

Figure 15. Frequency of metal detections in stockpile wells.

The data in Figure 15 show the total number of detections of each metal in 54 analyses of upgradient wells and another 54 analyses of downgradient wells. In order to determine if the number of detections differed significantly in the upgradient and downgradient wells, the data were tested in a 2 x 2 contingency table as shown in Table 2.

Only the differences in Ni detections were significant, but note that the number of detections was higher upgradient

Table 2. A 2 x 2 contingency test for metals in stockpile wells.

Metal	Detections			Chi	Sig.
	Up	Down	Total	Square	p=
As	3	6	9	0.485	ns
Be	0	1	1	0.000	ns
Cd	10	11	21	0.000	ns
Cr	13	9	22	0.514	ns
Cu	31	31	62	0.038	ns
Pb	9	16	25	1.874	ns
Hg	0	2	2	0.000	ns
Mo	6	11	17	1.117	ns
Ni	38	24	62	6.400	0.01
Se	0	1	1	0.000	ns
Zn	22	29	51	1.337	ns

than downgradient. Thus, leaching of metals from the stockpile does not appear to be adversely affecting ground water.

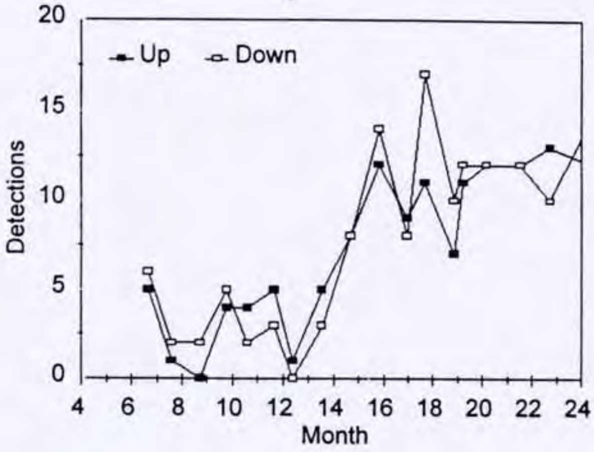

Figure 16. Monthly detections of metals in stockpile wells.

The total number of detections per month is shown in Figure 16. Statistical analysis of the data showed that the number of detections was significantly higher after changing laboratories in June 1992 (month 18.9). As with the turf plots we attribute this to the more sensitive analysis afforded by the lower detections limits for ACT.

It is also instructive to compare the total number of detections of metals in the turf plot wells with those observed in the stockpile wells at the higher loading rates of compost. A 2 x 2 contingency test is appropriate for this comparison as shown in Table 3.

Table 3. A 2 x 2 contingency test for metals in all wells.

Metal	Detections			Chi	Sig.
	Turf	Stock	Total	Square	p=
As	4	9	13	1.310	ns
Be	0	1	1	0.000	ns
Cd	18	21	39	0.125	ns
Cr	21	22	43	0.000	ns
Cu	49	62	111	2.669	ns
Pb	21	25	46	0.249	ns
Hg	1	2	3	0.000	ns
Mo	21	17	38	0.287	ns
Ni	42	62	104	6.694	0.01
Se	3	1	4	0.255	ns
Zn	58	51	109	0.667	ns

Only in the case of Ni was the number of detections significantly different, but recall that the number of detections of Ni in the upgradient stockpile wells was higher that in the downgradient wells. Thus, we conclude that leaching of metals from the storage and use of compost will have no adverse effects on ground water quality.

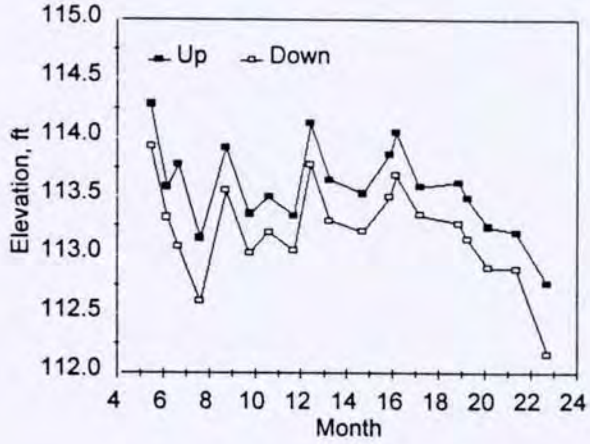

Figure 17. Elevation of ground water in wells upgradient and downgradient of the stockpile.

The average hydraulic gradient between the two sets of stockpile wells for 1991-1992 as shown in Figure 17 was 0.114 m in 9.2 m (0.374 feet in 30 feet), or 0.0124 m m^{-1}. Thus, the average ground water velocity at this site is about 1.0 m per day or 380 m per year. Because the wells are located in a circle, the distinction between upgradient and downgradient wells is not as obvious as with the turf plots. However, after examining the ground water contours at the stockpile, we consider the mean concentration for wells 8, 9 and 10 as representative of the plume of water and solutes moving downgradient from the well. The higher ground water velocity at this site is due to its closer proximity to the zone of discharge of ground water downgradient from the Valley Laboratory.

During Aug. 19-21, 14.2 cm (5.6 in) of rain fell as a part of Hurricane Bob. The elevation of the water table increased by about 30 cm (12 in) as shown in Figure 17 (month 8.7), with significant infiltration through the soil.

However, even under these drastic conditions, little leaching was observed until elevated levels of NO3-N were observed in stockpile well 9 on December 12, 1991 (month 12.4). Observations of compost stored at the MDC indicate only limited wetting of the interior of stockpiles.

The NO3-N concentrations in the stockpile wells are tabulated in Appendix Table 5-2 and summarized in Figure

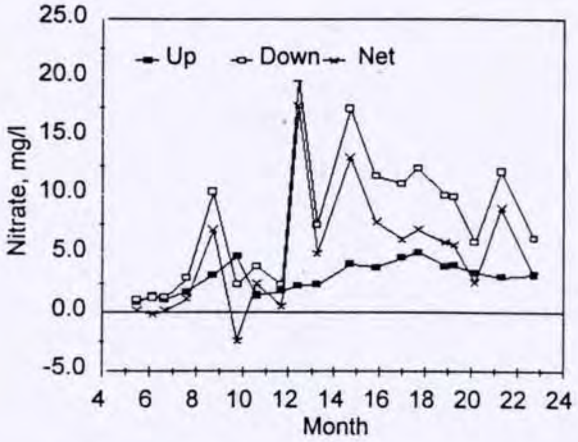

Figure 18. NO3-N concentrations in stockpile wells.

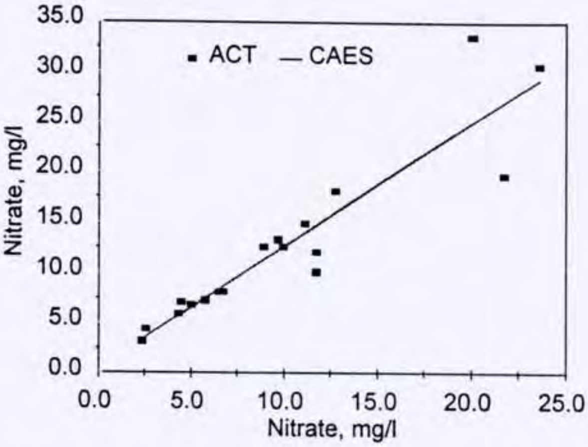

Figure 19. Inter-laboratory comparison of NO3-N analyses.

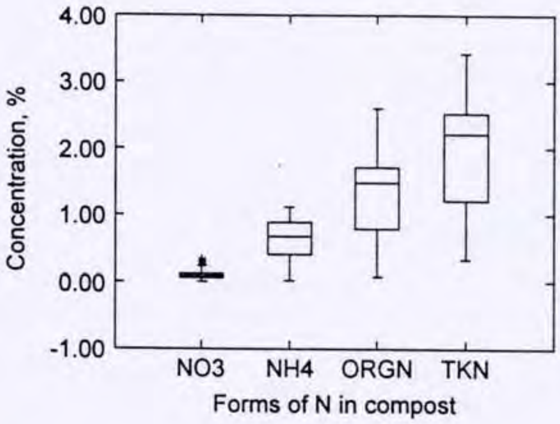

Figure 20. Forms of nitrogen in compost on a dry weight basis.

18. The average net contribution of NO3-N was 4.9 mg l^{-1}. The concentrations of NO3-N in downgradient well 9 are considerably higher than in adjacent wells 8 and 10. However, we believe that the mean of the three wells is a reasonable estimate of the downgradient movement of NO3-N. It is also important to note that essentially no leaching of NO3-N occurred under the stockpile for the first 8 months despite the higher loading rates.

Laboratory Comparisons

In addition to the internal quality control and quality assurance procedures used by PEL and ACT, a number of samples were split with CAES for interlaboratory comparisons of NO3-N and metals. Also, some other comparative laboratory analyses were performed as described below.

Fifteen sets of seven standard NO3-N samples were analyzed during a period of 7 months at CAES. The coefficient of variation (the standard deviation divided by the mean) was 7.65%, which is satisfactory. Eighteen well water samples were exchanged with ACT during a 2-month period with the results summarized in Figure 19. The regression line through the data accounts for 86% of the variability (r^2=0.86) which is considered acceptable. As noted earlier, CAES data for NO3-N were used throughout the study.

During the startup phase of composting and continuing throughout 1992, 64 samples of compost were analyzed by ACT for NO3-N, ammonia (NH4), organic nitrogen (ORGN) and total Kjeldahl nitrogen (TKN) with the results shown in the box plot in Figure 20. Total Kjeldahl nitrogen (TKN) refers to the analytical method used and is the sum of ammonia (NH4) and organic N (ORGN).

Eighteen samples of compost analyzed by ACT from May 28, 1990 through June 4, 1991 contained 0.05% NO3, 0.34% NH4, 0.65% ORGN and 0.99% TKN. We expected the TKN to increase to about 1.5% as the compost plant continued to come on line. Frink (1990) estimated that 5% of this total N would become available as noted earlier.

Analyses by PEL of six samples collected from the stockpile set aside in early 1991 for this experiment indicated a TKN content of about 0.23%. A second analysis was requested, with the TKN reported to be 0.34%. We suspected that the differences might be due in part to the use of EPA methods for water, waste water and sewage sludge that are not well suited to compost because of its physically heterogeneous nature.

Following a visit to PEL laboratories and changes in their sample preparation techniques, the TKN was reported to be 2.07% (Appendix Table 1) with about 0.08% NH4. By this time, the compost samples had been stored in the laboratory for many months and we suspect that the actual concentrations were closer to the median values in Figure 20.

Thus, some uncertainty exists in the actual N loading rates. Using the analyses by PEL, the total N content of 2.08% and an availability of 5% during the first year corresponds to 184 kg ha^{-1} of N. Second, if the ammonia N is considered readily available, this plus the small amounts of NO3-N reported by PEL corresponds to an additional 153 kg ha^{-1} of N. The initial loading rate would then be about 336 kg ha^{-1} of N which is higher than the anticipated rate of 132 kg ha^{-1}.

One of the virtues of compost is its ability to immobilize N in the soil and slow its leaching as we have observed with other composts at the Valley Laboratory (Maynard, 1989, 1991, 1993). Although the ammonia N in uncomposted organic fertilizers and animal manures is generally considered immediately available, this assumption may be incorrect for composted sewage sludge. A more accurate estimate of N availability may be that based on the USDA recommendation that 10% of the total N in composted sewage sludge is available for uptake during the first year. This includes any inorganic N initially present in the compost (Hornick et al., 1984), because incubation experiments have shown that ammonia is rapidly converted to organic forms in soils amended with compost (Tester et al., 1977). Using those figures for the present case, the loading rate would have been 368 kg ha^{-1} which is consistent with the calculations above.

The results of inter-laboratory comparisons of metals in turf plot wells are shown in Appendix Tables 7-1 and 7-2, and for stockpile wells in Appendix Tables 7-3 and 7-4. A direct comparison between the two laboratories is complicated by the large number of "non-detects." This is similar to the problem of comparing concentrations in upgradient and downgradient wells as discussed earlier. The inter-laboratory comparisons are also complicated by the different detection limits reported by the three laboratories. Helsel (1990) suggests that the most appropriate method is to censor all data at the highest reporting limit.

Using this method, the comparisons in Appendix Tables 7-1 to 7-4 were quantified by counting the number of analyses where one laboratory (i.e. CAES) did not detect the metal in a sample where the other laboratory (i.e. PEL/ACT) reported a value above the detection limit of the first laboratory (i.e. CAES). A similar count was made for detections by PEL/ACT versus CAES. The 2 x 2 contingency test in Table 4 shows that the numbers of detections were not significantly different for Cr and Ni. The differences for Cd and Zn can be attributed to differences in detection limits. The differences between laboratories were significant for Cu and Pb as discussed below. Copper is an essential plant nutrient normally present in trace amounts in soil and was detected with equal frequency in upgradient and downgradient turf and stockpile wells. The drinking water standard for Cu is 1.0 mg l^{-1}. The observed mean concentrations were about 0.01 to 0.02 mg l^{-1} so that Cu does not seem to be of further concern.

Table 4. A 2 x 2 contingency test of inter-laboratory analyses for metals.

	Det limit		Detections			Statistic	
Metal	CAES	PEL	CAES	PEL	Total	Chi sq	p=
Cd	<0.0001	<0.01	51	2	53	57.61	0.01
Cr	<0.002	<0.01	38	28	66	1.77	ns
Cu	<0.01	<0.01	23	53	76	17.07	0.01
Pb	<0.005	<0.01	0	33	33	36.63	0.01
Ni	<0.01	<0.01	45	49	94	0.17	ns
Zn	<0.05	<0.01	17	61	78	17.40	0.01

The difference in the ability of the laboratories to detect lead warrants further comment in view of potential changes in the present standard of 0.05 mg l^{-1}. Because the concentrations reported by PEL are much higher that those reported by CAES, additional laboratory comparisons were performed. Twenty-nine samples collected during three sampling periods in the spring of 1992 were retrieved from storage at PEL and submitted to ACT for reanalysis for lead. ACT detected lead in only four samples (>0.01 mg l^{-1}) while PEL detected lead in 16. Three known (spiked) samples were also submitted by the MDC (data on file), with PEL again reporting unacceptably high concentrations for all three. We conclude that the lead concentrations in the ground water are intermediate between the CAES detection limit of <.005 mg l^{-1} and the ACT limit of <0.001 mg l^{-1}.

Summary of Results

Chemical analysis

The analysis of the compost showed that none of the total metals in the compost exceeded DEP approved concentration limits for MDC sludge compost. The TCLP results showed that none of the extractable metals exceeded present regulatory standards. The total nitrogen analyses revealed that this particular compost contained about 2.0% N, as well as some ammonia and NO3-N. The application rates were based on a projected N content of 1.5% with little or no available ammonia so that the actual loading rate was higher than anticipated.

Leaching in Lysimeters

The concentrations of metals in leachate from the lysimeters decreased with time as would be expected from earlier column experiments (Sawhney et al., 1992). The concentrations also tended to decrease in the lysimeters containing increasing amounts of soil as would also be expected. The concentrations of NO3-N were high and confirm the availability of NO3-N for leaching in the absence of plant growth.

To determine the forms of heavy metals present in wastes, their concentrations in leachates from the lysimeters were compared with mathematical predictions from a metal speciation equilibrium model that is used by the EPA (PRODEF/MINTEQ, 1988) for surface and ground water. Preliminary analysis of the data indicates that the observed concentrations of Pb and Cd are lower than those expected from known insoluble forms of Pb and Cd. Further analysis is needed before these models can be used for predictive purposes.

Leaching in Turf Plots

The total number of detections of each metal in 54 analyses of samples from upgradient wells and another 54 samples from downgradient wells and the significance of the differences in the number of detections was tested with a simple 2 x 2 contingency table. Only the number of detections of Cr exceeded those expected due to chance alone.

We also inquired if the number of detections of metals increased with time. The answer must consider the change of laboratories in June 1992 (month 18.9). Since the numbers of detections in upgradient and downgradient wells were not significantly different (with the exception of Cr), the data were pooled and then separated into two groups as analyzed by the two laboratories before and after month 18.9. An analysis of variance showed that the number of detections was significantly higher when the samples were analyzed by ACT. Because ACT had lower detection limits than PEL, we attribute the increase in detections to the increased sensitivity of their analytical methods. Thus, we conclude that leaching of metals from the turf plots does not have a significant impact on ground water quality.

The compost apparently contained more available N than anticipated, with the movement of significant amounts to ground water at the turf plots. During August 19-21, 14.2 cm (5.6 in) of rain fell as a part of Hurricane Bob. The heavy rain increased infiltration considerably and also caused the NO3-N concentrations in the upgradient wells to increase. On average, however, the net NO3-N contribution from the entire plot was 7.4 mg l^{-1}.

The concentrations of NO3-N in the wells in the fertilized and non-fertilized halves of the plot were significantly different. The mean net concentration of NO3-N added from the plot treated with compost alone was 5.1 mg l^{-1}, while the mean concentration from the compost plus fertilizer was 8.7 mg l^{-1}. This difference had largely disappeared in the second year, suggesting greater uptake (or less leaching) of the supplemental fertilizer. Indeed, if the data set is divided into the 2 years, only the differences in 1991 are statistically significant. This suggests that supplemental fertilizer is not needed during the first year when turf is established by topsoil blending.

Thus, the mean contribution of NO3-N to the ground water from the compost alone was 5.1 mg l^{-1} during the 18 month period, with three excursions over the standard of 10 mg l^{-1}. It is important to realize that this represents the worst possible case of leaching since the 25 cm (10 in) of rainfall in August exceeded 100 years of record in most of New England. This also seems consistent with the expectations by EPA concerning temporary pulses of NO3-N from topsoil blending.

Leaching in Stockpiles

The total number of detections of each metal in 54 analyses of upgradient wells and another 54 analyses of downgradient wells was tested in a 2 x 2 contingency table as with the turf plots. Only the differences in Ni detections were significant, but in this case the numbers of detections were higher upgradient than downgradient. As with the turf plots, the number of detections increased when the samples were analyzed by ACT.

Hurricane Bob increased the elevation of the water table under the stockpile by about 30 cm (12 in), with significant infiltration through the soil. Less apparently moved through the stockpile because only limited leaching was observed for the first 8 months until elevated levels of NO3-N appeared in downgradient stockpile well 9 on December 12, 1991.

On average, the mean concentrations of NO3-N in the upgradient and downgradient wells differed by 4.9 mg l^{-1}. The concentrations of NO3-N in downgradient well 9 are considerably higher than in adjacent wells 8 and 10. However, we believe that the mean of these three downgradient wells is a reasonable estimate of the movement of NO3-N.

Conclusions

The analyses for heavy metals in the lysimeters, turf plot wells and stockpile wells indicate that leaching of heavy metals is not likely to cause contamination of ground water. Elevated levels of lead were reported by Phoenix Environmental Laboratories, Inc. (PEL), but laboratory comparisons with the Experiment Station and Analytical Consulting Technology, Inc. (ACT) indicated that analyses for lead by PEL were erroneously high. The frequency of detection of metals in upgradient wells did not differ from that in downgradient wells. Similarly, the frequency of detection of metals in the turf plot wells did not differ from that in the stockpile wells despite the higher loading rates under the stockpile.

The compost apparently contained more available N than anticipated, with the movement of significant amounts to ground water at the turf plots. The heavy rain from Hurricane Bob in August 1991 increased infiltration considerably and also caused the NO3-N concentrations in the upgradient wells to increase. On average, however, the net NO3-N contribution from the entire plot was 7.4 mg l^{-1}. It is important to realize that this represents the worst possible case of leaching since the 25 cm (10 in) of rainfall in August exceeded 100 years of record in most of New England.

The concentrations of NO3-N in the wells in the fertilized and non-fertilized halves of the plot were significantly different. The mean net concentration of NO3-N added from the plot treated with compost alone was 5.1 mg l^{-1}, while the mean concentration from the compost plus fertilizer was 8.7 mg l^{-1}. This difference had largely disappeared in the second year, suggesting greater uptake (or less leaching) of the supplemental fertilizer. This indicates that additional fertilizer is not needed during the first year when turf is established by topsoil blending.

Thus, the mean contribution of NO3-N to the ground water from the compost alone was 5.1 mg l^{-1} during the 18 month period, with three excursions over the standard of 10 mg l^{-1}.

Hurricane Bob increased the elevation of the water table under the stockpile by about 30 cm (12 in), with significant infiltration through the soil. Less apparently moved through the stockpile because only limited leaching was observed for the first 8 months until elevated levels of NO3-N appeared in downgradient stockpile well 9 on December 12, 1991. On average, the difference in the mean concentrations of NO3-N in upgradient and downgradient stockpile wells was 4.9 mg l^{-1}.

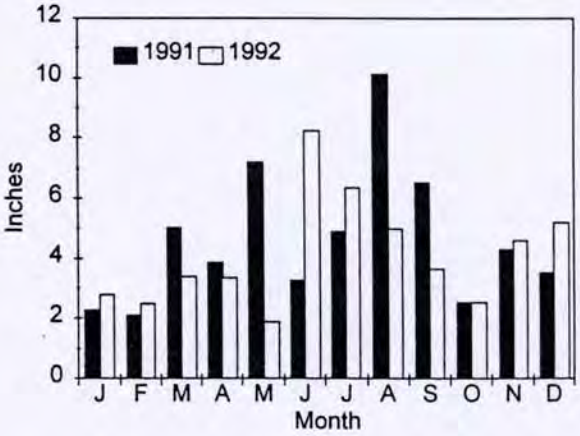

Figure 21. Rainfall plus irrigation at Windsor.

The leaching of NO3-N from the turf plots and stockpile needs to be viewed from the context of the EPA (U.S. Environmental Protection Agency 1993) preamble to its newly issued "Standards for the Use and Disposal of Sewage Sludge." They state that "The final Part 503 rule allows the permitting authority to grant nitrogen application in excess of crop and vegetative requirements on a site-specific basis as long as the sewage sludge application rate is designed to minimize the amount of nitrogen that passes below the root zone of a crop or vegetation grown on the site to the ground water. Although this may cause a temporary pulse of nitrogen to occur in ground water or surface water near the site the Agency believes that any minor excursion granted by the permitting authority will cause no persistent harmful effects to human health or the environment. Any slight potential for adverse impacts from a temporary nitrogen pulse will be more than offset by the beneficial effects of land reclamation such as decreased acid run-off, erosion control, attenuation of inorganic and organic pollutants, and increased soil nutrient levels."

The difficulties of detecting trace quantities of lead and uncertainties in the N loading rate led to the proposal that portions of this experiment be repeated. This is currently under the direction of DEP. The rainfall at Windsor during 1991-1992 is shown below as a reminder that this is an important variable that is not under our control.

Acknowledgments

We thank the MDC for defraying the cost of the installation and chemical analyses of wells, as well as for helpful support and encouragement by Paul Gilbert and James Chase during the study. Several people at CAES also provided assistance, but we thank Richard Horvath in particular for faithfully maintaining the plots at the Valley Laboratory. We also thank Tom A. Pedersen of Camp, Dresser and McKee for helpful review comments. The conclusions, however, are the responsibility of the authors.

References

Allison, F.E. 1955. The enigma of soil nitrogen balance sheets. *In* A.G. Norman (Ed.) Advances in Agronomy, VII, Academic Press, NY.

Barbarika, A., L.J. Sikora and D. Colacicco. 1985. Factors affecting the mineralization of nitrogen in sewage sludge applied to soils. Soil Sci. Soc. Am. J. 49:1403-1406.

Berrow, M.L. and J.C. Burridge. 1990. Persistence of metal residues in sewage sludge treated soils over seventeen years. Intern. J. Environ. Anal. Chem. 39:173-177.

Boyle, M. and W.H. Fuller. 1987. Effect of municipal solid waste leachate composition on zinc migration through soils. J. Environ. Qual. 16: 357-360.

Bugbee, G.J., C.R. Frink, and D. Migneault. 1991. Composted leaves, sewage sludge, and street sand: Growth of perennial flowers and leaching of heavy metals. J. Environ. Hort. 9:47-50.

Cabrera, F., E. Diaz, and L. Madrid. 1989. Effect of using urban compost as manure on soil contents of some nutrients and heavy metals. J. Sci. Food Agr. 47:159-169.

Chang, A.C., J.E. Warneke, A.L. Page, and L.J. Lund. 1984. Accumulation of heavy metals in sewage sludge-treated soils (cadmium, chromium, copper, nickel, lead, zinc). J. Environ. Qual. 13:87-91.

DeRoo, H.C. and J.L. Starr. 1979. Recycling of clippings from lawns will save energy from nitrogen fertilizer. Frontiers Plant Sci. 32(1):4-5.

DeRoo, H.C. 1980. Nitrate fluctuations in ground water as influenced by use of fertilizer. Conn. Agr. Exp. Sta. Bull 779.

Eighmy, T.T., M.A. Guay, S.A. McHugh, P.H. Thompson, N.E. Kinner, and T.P. Ballestero. 1987. Codisposal of municipal solid waste bottom ash and wastewater sludges. Proc. International Workshop on Municipal Waste Incineration, Montreal, Quebec. Environment Canada, pp. 349-379.

Emmerich, W.E., L.J. Lund, A.L. Page and A.C. Chang. 1982. Solid phase forms of heavy metals in sewage sludge-treated soils (cadmium, copper nickel, zinc). J. Environ. Qual. 11:178-181.

Epstein, E., D.B. Keane, J.S. Meisinger and J.O. Legg. 1978. Mineralization of nitrogen from sewage sludge and sludge compost. J. Environ. Qual. 7:217-221.

Fisher, R.A. and F. Yates. 1948. Statistical tables for biological, agricultural and medical research. Hafner Pub. Co., NY

Fox, R.H. and J.H. Axley. 1985. Nitrogen release from sewage sludge. *In* Criteria and Recommendations for Land Application of Sludges in the Northeast. Penn. Agr. Exp. Sta. Bull. 851.

Frink, C.R. 1969. Water pollution potential estimated from farm nutrient budgets. Agron. J. 61:550-553

Frink, C.R. (Ed.). 1989. Ground water in the Northeast. Conn. Agr. Exp. Sta. Bull. 876, 75 pp.

Frink, C.R. 1990. Composted sewage sludge as a nitrogen fertilizer. Report to MDC and DEP, September 17, 1990.

Fruchter, J.S., D. Rai and J.M. Zachara. 1990. Identification of solubility-controlling solid phases in a large fly ash field lysimeter. Environ. Sci. Technol. 24:1173-1179.

Harter, R.D. 1983. Effect of soil pH on adsorption of lead, copper, zinc, and nickel. Soil Sci. Soc. Am. J. 47: 47-51.

Helsel, D.R. 1990. Less than obvious: Statistical treatment of data below the detection limit. Environ. Sci. Technol. 24: 1766-1774.

Hornick, S.B., J.J. Murray, R.L. Chaney, L.J. Sikora, J.F. Parr, W.D. Burge, G.B. Willson and C.F. Tester. 1979. Use of sewage sludge compost for soil improvement and plant growth. US. Dept. Agriculture, Science and Education Admin., Agric. Rev. and Manuals, ARM-NE-6, 10pp.

Hornick, S.B., L.J. Sikora, S.B. Sterrett, J.J. Murray, P.D. Millner, D. Burge, D. Colacicco, J.F. Parr, R.L. Chaney and G.B. Willson. 1984. Utilization of sewage sludge compost as a soil conditioner and fertilizer for plant growth. USDA/ARS Agriculture Information Bulletin No. 464, 32 pp.

Hutson, J.L. and R.J. Wagenet. 1992. LEACHM. Leaching Estimation and Chemistry Model. Research Series No. 92-3, Department of Soil, Crop and Atmospheric Sciences, Cornell University, Ithaca, NY 14853.

Keeney, D.R., K.W. Lee, and L.M. Walsh. 1975. Guidelines for the application of wastewater sludge to agricultural land in Wisconsin. Dept. Nat. Res. Tech. Bull. 88, 30 pp.

Keeling, K.A., L.M. Walsh, D.R. Keeney, J.A. Ryan and A.E. Peterson. 1977. A field study of the agricultural use of sewage sludge: II. Effect on soil N and P. J. Environ. Qual. 6:345-352.

Kotuby-Amacher, J. and R.P. Gambrell. 1988. Factors affecting trace metal mobility in subsurface soils. EPA/600/52-88/306, Robert S. Kerr Environmental Research Laboratory, Ada, OK, pp. 1-7.

Legg, J.O. and J.J. Meisinger. 1982. Soil Nitrogen Budgets. *In* F.J. Stevenson (Ed.) Nitrogen in Agricultural Soils, Agronomy Monograph 22, American Society of Agronomy, Madison, WI.

Lunt, H.A. 1959. Digested sewage sludge for soil improvement. Conn. Agr. Exp. Sta. Bull. 622.

Magdoff, F.R. and J.F. Amadon. 1980. Nitrogen availability from sewage sludge. J. Environ. Qual. 9:451-455.

Maynard, A.A. 1989. Agricultural composts as amendments reduce nitrate leaching from soil. Frontiers Plant Sci. 42(1):2-3.

Maynard, A.A. 1991. Intensive vegetable production using composted animal manures. Conn. Agr. Exp. Sta. Bull. 894, 13 p.

Maynard, A.A. 1993. Nitrate leaching from compost-amended soils. Compost Sci. Util. 1(2):65-72.

McBride, M.B., L.D. Tyler, and D.A. Horde. 1981. Cadmium adsorption by soils and uptake by plants as affected by soil chemical properties. Soil Sci. Soc. Am. J. 45:739-744.

Mullaney, J.R., R.C. Melvin, J.T. Adamik, B.R. Robinson, and C.R. Frink. 1991. Pesticides in ground water, soil and unsaturated-zone sediments at selected sites in Connecticut. Conn. Water Res. Bull. No. 42, Connecticut Department of Environmental Protection, Hartford, CT.

Morgan, M.F., H.G.M. Jacobson and S.B. LeCompte, Jr. 1942. Drainage water losses from a sandy soil as affected by cropping and cover crops. Windsor Lysimeter Series G. Conn. Agr. Exp. Sta. Bull. 466.

NEC. 1985. Criteria and recommendations for land application of sludges in the Northeast. Bull. 851, Penn. State Univ., University Park, PA.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turf grass. J. Environ. Qual. 19:1-14.

Pratt, P.F., F.E. Broadbent and J.P. Martin. 1973. Using organic wastes as nitrogen fertilizers. Calif. Agric. 27(6):10-13.

PRODEF/MINTEQ. 1988. Metal speciation equilibrium model for surface and ground water (MINTEQ). U.S. EPA, Environmental Research Laboratory, Athens, GA.

Rathier, T.M. and C.R. Frink. 1986. Efficiency of nitrogen fertilizer use by shade tobacco improved by timed applications. Agron. J. 78:459-464.

Ryder, R.B., M.P. Thomas and L.A. Weiss. 1981. Water Resources Inventory of Connecticut, Part 7. Upper Connecticut River Basin. Conn. Water Res. Bull. 24, U.S. Geological Survey, Hartford, CT.

Sanders, J.R., T.M. Adams, and B.T. Christensen. 1986. Extractability and bioavailability of zinc, nickel, cadmium and copper in three Danish soils sampled 5 years after application of sewage sludge. J. Sci. Food Agric. 37:1155-1164.

Sawhney, B.L. and C.R. Frink. 1991. Heavy metals and their leachability in incinerator ash. Water Air Soil Poll. 57-58:289-296.

Sawhney, B.L., G.J. Bugbee, and D.E. Stilwell. 1992. Heavy metals leachability from municipal compost. *In* K. B. Hoddinott and T. A. O'Shay (Eds.) Application of agricultural analysis in environmental studies. ASTM, Philadelphia, PA

Sawhney, B.L., and W.A. Norvell. 1980. Sewage sludge for plant growth: Benefits and potential hazards. Conn. Agr. Exp. Sta. Bull. 788.

Senesi, N., G. Sposito, K.M. Holtzslaw and G.R. Bradford. 1989. Chemical properties of metal-humic acid fractions of a sewage sludge-amended aridisol. J. Environ. Qual. 18:186-194.

Sommers, L.E. and D.W. Nelson. 1976. Analyses and their interpretation for sludge application. *In* Application of Sludges and Wastewaters on Agricultural Lands, B.D. Knezek and R.H. Miller (Eds.), Ohio Agr. Res. & Dev. Ctr. Res. Bull. 1090, pp. 2.1-2.7.

Sposito, G., L.J. Lund and A.C. Chang. 1982. Trace metal chemistry in arid zone field soils amended with sewage sludge. I. Fractionation of Ni, Cu, Zn, Cd and Pb. Soil Sci. Soc. Am. J. 46:260-264.

Starr, J.L. and H.C. DeRoo. 1981. The fate of nitrogen fertilizer applied to turfgrass. Crop Sci. 21:531-536.

Starr, J.L., H.C. DeRoo, C.R. Frink and J.-Y. Parlange. 1978. Leaching characteristics of a layered field soil. Soil Sci. Soc. Am. J. 42:386-391.

Starr, J.L., J.-Y. Parlange and C.R. Frink. 1986. Water and chloride movement through a layered field soil. Soil Sci. Soc. Am. J. 50:1384-1390.

Stout, P.R. and R.G. Burau. 1967. The extent and significance of fertilizer buildup in soils as revealed by vertical distributions of nitrogenous matter between soils and underlying water reservoirs. *In* N.C. Brady (Ed.) Agriculture and the Quality of Our Environment. Amer. Assoc. Adv. Sci. Publ. 85, Washington, DC.

Tackett, S.L., E.R. Winter and M.J. Puz. 1986. Leaching of heavy metals from composted sewage sludge as a function of pH. Canadian J. Soil Sci. 66:763-765.

Tanji, K.K. 1982. Modeling of the soil nitrogen cycle. *In* F.J. Stevenson (Ed.) Nitrogen in Agricultural Soils, Agronomy Monograph 22, American Society of Agronomy, Madison, WI.

Tester, C.F., L.J. Sikora, J.M. Taylor and J.F. Parr. 1977. Decomposition of sewage sludge compost in soil: 1. Carbon and nitrogen transformations. J. Environ. Qual.6:459-463.

Tester, C.F., L.J. Sikora, J.M. Taylor and J.F. Parr. 1982. Nitrogen utilization by tall fescue from sewage sludge compost amended soils. Agron. J. 74:1013-1018.

United States Environmental Protection Agency. 1986a. Method 3050, Acid Digestion of Sediments, Sludges and Soils. *In*: SW 846 Test Methods for Evaluating Solid Wastes, U. S. Govt. Print. Off., Washington, DC.

United States Environmental Protection Agency. 1986b. Method 1310, Extraction Procedure (EP) Toxicity Test Method and Structural Integrity Test. *In*: SW 846 Test Methods for Evaluating Solid Wastes, U. S. Govt. Print. Off., Washington, DC.

United States Environmental Protection Agency. 1989. Technical support document. Surface disposal of sewage sludge. Office of Water Regulations and Standards, Washington, DC 20460.

United States Environmental Protection Agency. 1990. EPA Interim Primary Drinking Water Standards. *In*: Title 40 - Protection of Environment, 40 CFR 265.1, U. S. Govt. Print. Off., Washington, DC.

United States Environmental Protection Agency. 1993. Standards for the Use or Disposal of Sewage Sludge. 40 CFR Parts 257, 403 and 503. Federal Register 58(32):9248-9415.

Welch, J.E., and L.J. Lund. 1987. Soil properties, irrigation water quality, and soil moisture level influence the movement of nickel in sewage sludge-treated soils. J. Environ. Qual. 16:403-410.

Willson, G.B., J.F. Parr, E. Epstein, P.B. Marsh, R.L. Chaney, D. Colacicco, W.D. Burge, L.J. Sikora, C.F. Tester and S. Hornick. 1980. Manual for composting sewage sludge by the Beltsville aerated-pile method. U.S. Environmental Protection Agency, Cincinnati, OH. 61 pp.

Xiu, H., and R.W. Taylor. 1989. Heavy metal movement in sewage treated plots: A residual study. Agron. Abstr., p. 48.

Appendix Tables

Table 1. Analytical methods and detection limits in mg/l for metals.

Laboratory	PEL		ACT		CAES	
Metal	Method	Det. limit	Method	Det. limit	Method	Det. limit
Arsenic	SW846-7061	<0.01	SW846-7060	<0.001	-------------------	---------
Barium	----------------	-------	SW846-7080	<0.1	-------------------	---------
Beryllium	6010/E200.7	<0.01	SW846-7090	<0.001	-------------------	---------
Cadmium	6010/E200.7	<0.01	SW846-7130	<0.001	USEPA (1986a)	<.0001
Chromium	6010/E200.7	<0.01	SW846-7196	<0.001	USEPA (1986a)	<0.002
Copper	6010/E200.7	<0.01	SW846-7210	<0.001	USEPA (1986a)	<0.01
Lead	SW846-7420	<0.01	SW846-7421	<0.001	USEPA (1986a)	<0.005
Mercury	SW846-7471	<0.002	SW846-7471	<0.001	-------------------	---------
Molybdenum	6010/E200.7	<0.05	SW846-7480	<0.001	-------------------	---------
Nickel	6010/E200.7	<0.01	SW846-7520	<0.001	USEPA (1986a)	<0.01
Selenium	SW846-7741	<0.01	SW846-7740	<0.001	-------------------	---------
Zinc	6010/E200.7	<0.01	SW846-7950	<0.001	USEPA (1986a)	<0.05

Table 2. Summary of analyses of MDC compost by PEL.

Source	Compost Pile		Compost PLot		Lysimeter/Lab				
Sample No.	1	2	3	4	5	6			
Date	5/16/91	5/16/91	5/16/91	5/16/91	7/30/91	7/30/91	Means	CV, %	Limit
Analyte					TCLP Metals, mg/l				
Arsenic	0.03	0.03	0.02	<.01	0.03	0.01	0.02	65.0%	5.0
Barium	3.10	1.30	2.50	3.70	3.00	0.29	2.32	55.2%	100.0
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	---	1.0
Chromium	0.03	0.03	0.02	0.02	0.02	0.04	0.03	29.6%	5.0
Lead	0.05	0.13	0.06	0.07	0.06	0.14	0.09	45.9%	5.0
Mercury	<.005	<.005	<.005	<.005	<.005	<.005	<.005	---	0.2
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	---	1.0
Silver	0.02	<.01	0.02	0.01	0.02	0.04	0.02	72.2%	5.0
					Total metals, mg/kg dry wt				
Arsenic	27.5	14.5	14.0	20.1	18.2	17.1	18.6	26.6%	--
Beryllium	<.1	<.1	<.1	<.1	0.2	<.1	<.1	---	--
Cadmium	5.3	5.3	0.5	5.0	5.1	6.8	4.6	45.8%	40
Chromium	54.9	51.0	46.6	48.2	52.8	64.9	52.6	12.3%	1000
Copper	372.5	408.2	368.9	401.6	391.4	49.4	343.4	42.0%	1200
Lead	145.1	140.2	145.6	138.6	148.7	171.4	147.4	8.0%	400
Mercury	7.6	4.5	5.8	5.6	5.5	4.4	5.6	21.4%	10
Molybdenum	20.6	20.4	18.1	20.1	19.0	21.6	19.9	6.2%	--
Nickel	43.1	42.9	40.8	42.2	43.1	51.9	43.7	9.0%	200
Selenium	<.1	<.1	<.1	<.1	<.1	<.1	<.1	---	--
Zinc	509.8	510.2	466.0	518.1	528.4	623.4	521.8	9.9%	1250
					Total nutrients, % dry wt				
Total-N	1.98%	2.04%	2.49%	2.04%	2.00%	1.86%	2.07%	10.90%	--
NH4-N	0.09%	0.10%	0.06%	0.17%	0.04%	0.04%	0.08%	60.50%	--
NO3-N	0.01%	0.02%	0.00%	0.01%	0.05%	0.06%	0.03%	88.90%	--
PO4-P	0.06%	0.20%	0.05%	0.04%	0.12%	0.08%	0.09%	68.10%	--
Total P	0.85%	1.00%	0.37%	1.04%	1.02%	1.30%	0.93%	33.40%	--
Total K	0.22%	0.22%	0.23%	0.24%	0.19%	0.29%	0.23%	14.30%	--
% Solids	51.0%	49.0%	51.5%	49.8%	51.1%	38.5%	48.5%	10.3%	--

Table 3-1. Analyses of lysimeter leachate for metals.

Lysimeter 1, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	0.03	0.04	0.02	0.03	0.01	0.01	0.04	0.005	0.004	0.003	0.008	0.008	0.017
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Cadmium	<.01	<.01	0.02	<.01	<.01	<.01	<.01	<0.001	0.002	0.001	<0.001	<0.001	0.002
Chromium	0.02	0.02	<.01	<.01	<.01	<.01	<.01	0.001	0.002	<0.001	0.002	<0.001	0.004
Copper	0.19	0.20	0.09	0.12	0.07	0.08	0.12	0.009	0.111	0.063	0.102	0.072	0.102
Lead	0.09	<.01	0.08	0.07	0.02	0.01	<.01	0.001	0.004	0.004	<0.001	0.002	0.023
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	0.08	0.06	<.05	<.05	<.05	<.05	0.04	0.002	0.003	<0.001	<0.005	<0.001	0.015
Nickel	<.01	0.04	0.05	0.02	0.02	0.03	0.04	0.009	0.015	0.011	0.010	0.010	0.021
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.74	0.27	<.01	0.28	0.13	0.15	0.23	0.100	0.113	0.074	0.072	0.103	0.189

Lysimeter 2, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.002	<0.001	<0.001	<0.001	<0.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	0.001	<0.001	<0.001	<0.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.002	0.005	0.003	<0.001	0.002	0.001
Chromium	0.06	0.01	<.01	<.01	<.01	<.01	<.01	<0.001	0.002	<0.001	<0.001	<0.001	0.006
Copper	0.05	<.01	<.01	0.01	0.01	<.01	<.01	0.008	0.007	0.007	<0.001	0.080	0.014
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	0.012	<0.001	<0.001	0.002	0.001
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.01	0.001	0.002	<0.001	<0.005	<0.001	0.000
Nickel	0.05	0.02	0.07	0.02	0.02	0.02	0.03	0.015	0.022	0.023	<0.001	0.015	0.025
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.29	0.08	0.09	0.21	0.26	0.16	0.18	0.175	0.225	0.225	<0.001	0.175	0.173

Table 3-2. Analyses of lysimeter leachate for metals.

Lysimeter 3, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.002	0.002	<0.001	<0.001	0.002	0.001
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	0.001	<0.001	<0.001	<0.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.002	0.004	0.002	<0.001	0.010	0.002
Chromium	0.05	0.13	<.01	<.01	<.01	<.01	<.01	0.003	<0.001	0.018	<0.001	<0.001	0.017
Copper	0.03	<.01	<.01	0.01	<.01	0.01	<.01	0.017	0.011	0.011	0.001	0.010	0.008
Lead	<.01	<.01	<.01	0.1	<.01	<.01	<.01	<0.001	0.002	<0.001	<0.001	0.002	0.009
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	<.05	<.05	<.05	0.07	<.05	<.05	<.01	0.001	0.002	<0.001	<0.005	<0.001	0.006
Nickel	0.03	0.02	0.08	0.02	<.01	0.01	0.03	<0.001	0.016	0.033	<0.001	0.012	0.021
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.17	0.03	0.12	0.22	0.19	0.15	0.14	0.160	0.163	0.138	0.007	0.096	0.132

Lysimeter 4, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.005	0.004	0.005	0.004	0.003	0.002
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	0.001	<0.001	0.001	0.000
Chromium	0.06	0.03	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	0.001	<0.001	0.008
Copper	0.06	0.03	<.01	0.02	<.01	0.02	0.02	0.052	0.067	0.075	0.066	0.055	0.039
Lead	<.01	<.01	0.04	0.01	<.01	<.01	<.01	<0.001	0.008	<0.001	<0.001	<0.001	0.005
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	0.04	0.09	<.05	<.05	<.05	<.05	<.01	0.002	0.003	<0.001	<0.005	<0.001	0.011
Nickel	0.04	0.03	0.07	0.02	0.05	<.01	0.02	0.016	0.026	0.310	0.023	0.020	0.052
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.19	0.17	0.04	0.09	0.08	<.01	0.06	0.050	0.040	0.038	0.050	0.033	0.070

Table 3-3. Analyses of lysimeter leachate for metals.

Lysimeter 5, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	4.0	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	0.05	0.05	0.06	0.12	0.07	0.04	0.05	0.005	0.007	0.015	0.007	0.005	0.040
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Cadmium	<.01	<.01	0.08	<.01	<.01	<.01	<.01	<0.001	0.002	0.001	<0.001	<0.001	0.007
Chromium	0.06	0.08	<.01	0.02	<.01	0.01	<.01	0.002	0.002	0.003	0.006	<0.001	0.015
Copper	0.32	0.25	0.18	0.21	0.11	0.11	0.21	0.150	0.186	0.121	0.112	0.066	0.169
Lead	0.04	0.05	0.26	<.01	0.02	0.01	<.01	<0.001	0.010	<0.001	<0.001	0.002	0.033
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	0.01	0.14	<.05	<.05	<.05	<.05	0.05	0.003	0.004	<0.001	<0.005	<0.001	0.017
Nickel	0.08	0.06	0.11	0.06	<.01	0.04	0.04	0.023	0.025	0.220	0.013	0.010	0.057
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.58	0.47	0.15	0.24	0.15	0.16	0.21	0.138	0.150	0.138	0.150	0.070	0.217

Lysimeter 6, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.003	0.003	0.002	<0.001	0.003	0.001
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	0.001	<0.001	<0.001	<0.001	0.000
Cadmium	0.02	<.01	0.02	<.01	<.01	<.01	<.01	0.003	0.005	0.004	<0.001	0.002	0.005
Chromium	0.05	0.02	<.01	0.01	<.01	<.01	<.01	0.001	0.001	<0.001	<0.001	<0.001	0.007
Copper	0.02	0.01	<.01	0.03	<.01	<.01	<.01	0.014	0.014	0.013	<0.001	0.013	0.010
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	0.012	<0.001	<0.001	0.019	0.003
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	0.05	0.06	0.06	0.1	<.05	<.05	<.01	0.003	0.003	<0.001	<0.005	<0.001	0.023
Nickel	0.08	0.05	0.09	0.06	<.01	0.02	<.01	0.020	0.034	0.380	<0.001	0.022	0.063
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.65	0.28	0.38	0.66	0.48	0.20	0.15	0.500	0.263	0.275	<0.001	0.362	0.350

Table 3-4. Analyses of lysimeter leachate for metals.

Lysimeter 7, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.003	0.002	<0.001	<0.001	0.002	0.001
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	0.001	<0.001	0.000
Cadmium	0.01	<.01	0.02	0.01	<.01	<.01	<.01	0.001	0.003	0.002	0.001	0.002	0.004
Chromium	0.05	0.02	<.01	0.02	<.01	<.01	0.03	0.001	0.001	<0.001	0.002	<0.001	0.010
Copper	0.03	<.01	<.01	0.04	<.01	0.01	<.01	0.020	0.020	0.020	0.024	0.016	0.015
Lead	<.01	0.01	0.08	0.05	<.01	<.01	<.01	<0.001	0.003	<0.001	<0.001	0.001	0.012
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	0.03	0.07	0.11	0.10	<.05	<.05	0.03	0.002	0.002	<0.001	<0.005	<0.001	0.029
Nickel	0.06	0.05	0.09	0.06	<.01	0.02	0.03	0.011	0.018	0.200	0.014	0.017	0.048
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.49	0.36	0.47	0.40	0.21	0.12	0.14	0.138	0.163	0.163	0.125	0.150	0.244

Lysimeter 8, mg/l

Date	07/22	08/26	09/26	10/22	11/20	12/12	05/21	06/30	07/17	08/20	09/16	10/29	Means
Month (fraction)	7.7	8.9	9.9	10.7	11.7	12.4	17.7	19.0	19.6	20.7	21.5	23.0	
Arsenic	<.01	0.04	0.03	0.06	<.01	0.01	0.05	0.020	0.012	0.009	0.007	0.007	0.020
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Cadmium	<.01	0.01	0.03	<.01	<.01	<.01	<.01	0.001	0.003	0.001	0.001	<0.001	0.004
Chromium	0.05	0.05	0.03	0.02	<.01	<.01	<.01	0.006	0.004	0.001	0.005	<0.001	0.014
Copper	0.10	0.25	0.18	0.19	0.16	0.14	0.25	0.199	0.180	0.163	0.187	0.107	0.176
Lead	0.08	0.16	0.39	<.01	0.01	0.01	<.01	0.001	0.018	<0.001	<0.001	0.002	0.056
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Molybdenum	0.10	0.24	0.12	0.85	<.05	<.05	<.01	0.003	0.005	<0.001	<0.005	<0.001	0.110
Nickel	0.05	0.10	0.14	0.09	<.01	0.05	0.09	0.067	0.067	0.520	0.061	0.310	0.129
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<0.001	<0.001	<0.001	<0.001	<0.001	0.000
Zinc	0.35	0.80	0.67	0.34	0.28	0.23	0.36	0.213	0.213	0.163	0.125	0.200	0.329

Table 3-5. Summary of lysimeter leaching experiments.

Treatment	No soil		C horizon		B+C horizon		A+B+C horizon		
Compost	2"	4"	2"	4"	2"	4"	2"	4"	Detection
Lysimeter No.	1	5	4	8	3	7	2	6	Limit
Metal, mg/l	Means	Means	Means	Means	Means	Means	Means	Means	
Arsenic	0.02	0.04	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
Beryllium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	<0.01
Copper	0.10	0.17	0.04	0.18	0.01	0.02	0.01	0.01	<0.01
Lead	0.02	0.03	0.00	0.06	0.01	0.01	0.00	0.00	<0.01
Mercury	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Molybdenum	<0.05	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	<0.05
Nickel	0.02	0.06	0.05	0.13	0.02	0.05	0.03	0.06	<0.01
Zinc	0.19	0.22	0.07	0.33	0.13	0.24	0.17	0.35	<0.01
pH	6.2	6.1	5.2	5.0	4.6	4.5	4.6	4.4	--------
Nitrate, mg/l	9.5	20.0	14.3	43.1	21.2	38.0	16.5	51.0	--------

Table 4-1. Analyses of upgradient turf plot wells for metals.

Upgradient Turf Plot Well 13, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	0.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.002	0.001	<.001	0.001
Chromium	<.01	0.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.001
Copper	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	<.01	0.02	<.01	<.001	0.001	0.002	0.003	0.001	0.002	0.003
Lead	<.01	0.02	<.01	<.01	<.01	<.01	<.01	<.01	0.01	<.005	0.05	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.004
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	0.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	0.06	<.05	<.05	<.05	<.05	<.05	0.08	<.01	<.01	<.001	0.001	<.001	<.001	<.001	<.001	0.008
Nickel	<.01	<.01	<.01	0.03	<.01	<.01	<.01	<.01	0.01	0.03	<.01	<.01	<.001	<.001	0.005	<.001	0.002	<.001	0.004
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	0.08	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.04	0.04	0.01	0.002	0.024	0.021	<.001	0.003	0.013

Upgradient Turf Plot Well 14, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.001	0.001	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	0.001	0.001
Copper	0.03	<.01	<.01	<.01	0.01	<.01	<.01	<.01	0.03	<.01	<.01	<.01	0.005	0.002	0.003	0.003	0.003	0.002	0.005
Lead	<.01	<.01	0.04	<.01	<.01	<.01	<.01	<.01	0.01	<.005	0.03	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.004
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	0.05	0.05	<.05	<.05	<.05	<.05	<.05	0.08	<.01	0.02	0.002	0.001	<.001	<.001	<.001	<.001	0.011
Nickel	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.01	0.02	0.02	0.02	<.01	<.001	<.001	0.006	0.002	0.004	0.002	0.005
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.04	0.09	0.012	0.004	0.022	0.014	0.010	0.004	0.012

Table 4-2. Analyses of upgradient turf plot wells for metals.

Upgradient Turf Plot Well 15, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.001	0.001	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	0.02	<.01	<.01	<.001	<.001	<.001	<.001	<.001	0.001	0.002
Copper	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	0.03	<.01	<.01	<.01	0.003	0.002	0.001	0.004	0.003	0.002	0.003
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	<.005	0.03	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.002
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	0.03	<.05	<.05	<.05	<.05	<.05	0.06	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.005
Nickel	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	0.03	<.01	<.01	<.001	<.001	0.004	<.001	0.001	<.001	0.004
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	0.02	0.07	0.014	0.006	0.019	0.015	0.007	0.012	0.011

Mean Upgradient Turf Plot Wells, mg/l

Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	Means
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.001	0.001	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	0.001	0.000
Copper	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.001	0.001	0.001	0.002	0.001	0.001	0.001
Lead	<.01	<.01	0.01	<.01	<.01	<.01	<.01	<.01	0.01	<.01	0.04	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.003
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	0.07	<.05	<.05	<.001	<.001	<.001	<.001	<.001	<.001	0.004
Nickel	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.01	0.02	0.03	<.01	<.01	<.001	<.001	0.005	0.001	0.002	0.001	0.004
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	<.001	<.001	<.001	0.000
Zinc	<.01	0.03	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.03	0.07	0.012	0.004	0.022	0.017	0.006	0.006	0.012
Detections	1	4	2	5	2	0	0	0	11	10	8	4	6	9	16	10	11	9	6

Table 4-3. Analyses of downgradient turf plot wells for metals.

Downgradient Turf Plot Well 2, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	0.001	0.002	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	0.01	0.01	<.01	<.01	0.04	0.01	0.01	0.04	<.001	<.001	<.001	<.001	<.001	0.002	0.007
Copper	<.01	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	0.01	0.02	0.09	<.001	0.004	0.004	0.002	0.024	0.004	0.009
Lead	0.06	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.02	0.03	0.02	<.001	<.001	0.001	<.001	<.001	<.001	0.008
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	0.04	0.06	0.001	0.008	<.001	<.001	<.001	<.001	0.006
Nickel	<.01	<.01	0.01	0.02	0.02	0.25	<.01	<.01	<.01	0.03	0.03	0.03	<.001	<.001	0.003	0.001	0.002	0.001	0.022
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.04	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.002
Zinc	<.01	0.1	<.01	<.01	<.01	0.04	<.01	<.01	<.01	0.02	0.09	0.26	<.001	0.003	0.042	0.002	0.024	0.045	0.035

Downgradient Turf Plot Well 3, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.002	0.001	<.001	0.000
Chromium	<.01	<.01	<.01	0.01	0.01	0.01	<.01	<.01	0.03	0.03	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.005
Copper	<.01	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.02	<.01	0.03	<.01	<.001	0.004	0.003	0.006	0.007	0.034	0.007
Lead	0.03	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.13	0.02	0.04	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.012
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	0.06	0.05	<.05	<.05	<.05	<.05	<.05	0.03	0.05	<.001	<.001	<.001	<.001	<.001	<.001	0.011
Nickel	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.01	<.01	0.05	<.01	<.01	0.001	0.002	0.002	0.003	0.004	<.001	0.005
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	0.03	0.03	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.04	0.08	0.06	<.001	0.003	0.02	0.01	0.006	0.030	0.017

Table 4-4. Analyses of downgradient turf plot wells for metals.

Downgradient Turf Plot Well 4, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.002	<.001	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.02	<.001	<.001	<.001	<.001	0.005	<.001	0.003
Copper	0.02	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.002	0.003	0.004	0.006	0.375	0.003	0.024
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.01	0.05	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.004
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.01	0.05	<.001	0.021	<.001	<.001	<.001	<.001	0.004
Nickel	<.01	<.01	<.01	0.02	<.01	<.01	<.01	<.01	<.01	0.02	<.01	<.01	<.001	0.002	0.001	0.003	0.011	0.002	0.003
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	0.03	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	0.03	0.04	0.04	0.003	0.002	0.037	0.010	0.200	0.030	0.024

Mean Downgradient Turf Plot Wells, mg/l

Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	Means
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.002	0.001	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	0.01	0.01	0.02	<.001	<.001	<.001	<.001	0.002	0.001	0.004
Copper	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	<.01	<.01	0.02	0.03	0.001	0.004	0.004	0.005	0.135	0.014	0.012
Lead	0.03	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.06	0.02	0.04	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.008
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	0.05	<.001	0.010	<.001	<.001	<.001	<.001	0.004
Nickel	<.01	<.01	<.01	0.02	<.01	0.08	<.01	<.01	<.01	0.03	0.01	0.01	<.001	0.001	0.002	0.002	0.006	0.001	0.009
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.001
Zinc	0.02	0.04	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.03	0.07	0.12	0.001	0.003	0.033	0.007	0.077	0.035	0.025
Detections	5	2	1	5	6	6	0	0	6	13	13	11	4	10	15	12	12	9	7

Table 5-1. Summary of nitrate concentrations in turfplot wells.

Downgradient turfplot wells, mg/l

Date	05/14	06/05	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/11	10/22	Means
Month	5.5	6.2	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.2	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.3	22.7	
Down 1	1.6	1.5	1.7	1.9	2.5	6.1	16.6	30.5	50.8	49.9	30.5	30.1	16.6	15.3	9.7	8.3	5.5	4.7	5.3	15.2
Down 2	1.3	1.4	1.9	3.5	8.6	24.3	22.9	30.5	35.6	20.8	22.2	23.8	12.5	11.2	11.0	8.3	6.5	4.2	4.7	13.4
Down 3	1.8	1.8	1.7	4.0	5.1	79.0	31.9	45.8	44.8	54.1	40.2	24.0	15.9	12.8	11.4	10.4	7.6	7.5	4.9	21.3
Down 4	4.9	4.6	4.6	6.4	7.6	35.4	16.6	22.2	38.4	52.7	31.9	19.1	11.8	9.0	14.7	8.7	7.2	5.8	4.7	16.1
Down 5	4.0	6.8	3.1	3.3	4.4	6.4	15.9	26.3	35.6	34.7	16.6	13.2	6.2	6.7	9.0	7.6	8.3	6.2	9.2	11.8
Means	2.7	3.2	2.6	3.8	5.7	30.2	20.8	31.1	41.0	42.4	28.3	22.0	12.6	11.0	11.2	8.7	7.0	5.7	5.7	15.6
Upgradient turfplot wells, mg/l																				
Up 12	na	6.4	4.6	3.0	10.8	13.0	16.4	7.2	16.3	23.6	19.4	3.6	6.7	3.6	2.3	3.7	6.2	7.5	8.0	9.0
Up 13	na	6.5	8.6	11.8	12.5	16.1	13.0	10.5	11.9	15.3	15.3	9.7	6.4	7.4	9.5	7.2	3.1	8.0	2.8	9.8
Up 14	na	2.8	3.5	4.9	8.3	10.8	9.2	10.8	14.6	20.8	12.5	11.8	11.9	10.1	5.8	6.8	4.3	7.2	10.3	9.2
Up 15	na	1.6	1.2	1.2	5.7	2.2	3.1	3.3	13.6	15.3	16.6	21.8	18.7	11.1	6.9	4.2	2.8	2.8	2.1	7.4
Up 16	na	1.5	1.3	1.7	6.2	1.9	2.2	3.3	11.2	9.4	7.2	19.1	9.0	4.9	3.7	2.6	2.1	2.8	3.2	5.2
Means	na	3.8	3.8	4.5	8.7	8.8	8.8	7.0	13.5	16.9	14.2	13.2	10.6	7.4	5.6	4.9	3.7	5.7	5.3	8.1
Net Nitrate		-0.6	-1.2	-0.7	-3.1	21.4	12.0	24.0	27.5	25.6	14.1	8.8	2.1	3.6	5.5	3.8	3.4	0.0	0.5	7.4
1-16 F	na	-0.1	0.4	0.3	-3.7	4.2	14.4	27.2	39.7	40.5	23.3	11.0	7.6	10.3	6.0	5.7	3.5	1.9	2.1	10.0
2-15 F	na	-0.2	0.8	2.3	2.9	22.0	19.8	27.2	22.0	5.5	5.5	2.1	-6.2	0.1	4.0	4.2	3.7	1.4	2.6	6.0
4-13 C	na	-1.9	-4.0	-5.4	-4.9	19.3	3.6	11.6	26.4	37.4	16.6	9.4	5.4	1.6	5.2	1.5	4.2	-2.2	1.9	6.4
5-12 C	na	0.4	-1.5	0.3	-6.4	-6.7	-0.4	19.1	19.3	11.1	-2.8	9.6	-0.5	3.1	6.7	3.9	2.1	-1.2	1.1	2.8
Mean net fert		-0.1	0.6	1.3	-0.4	13.1	17.1	27.2	30.8	23.0	14.4	6.5	0.7	5.2	5.0	4.9	3.6	1.7	2.4	8.7
Mean net cntl		-0.8	-2.8	-2.5	-5.6	6.3	1.6	15.4	22.9	24.3	6.9	9.5	2.5	2.4	5.9	2.7	3.1	-1.7	1.5	5.1

Table 5-2. Summary of nitrate concentrations in stockpile wells.

Upgradient stockpile wells, mg/l

Date	05/14	06/05	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/11	10/22	Means
Month	5.5	6.2	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.2	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.3	22.7	
Up 6	0.3	0.8	0.6	1.0	4.4	11.1	1.1	1.4	1.8	1.4	3.9	2.4	4.3	5.4	4.2	4.7	3.6	2.6	3.1	3.0
Up 7	0.9	1.5	1.0	1.9	2.6	1.4	1.4	2.5	1.3	1.7	2.8	2.6	5.1	4.4	3.3	2.8	3.1	2.8	2.5	2.4
Up 11	1.4	2.1	1.8	2.3	2.5	1.9	1.9	1.7	4.0	4.2	5.8	6.6	4.7	5.8	4.6	4.6	3.6	3.9	4.2	3.5
Means	0.9	1.4	1.1	1.8	3.2	4.8	1.5	1.8	2.3	2.4	4.2	3.9	4.7	5.2	4.0	4.0	3.4	3.1	3.2	3.0
Downgradient stockpile wells, mg/l																				
Down 8	1.5	1.5	1.5	4.0	14.6	3.1	2.5	1.9	8.5	1.9	2.2	4.5	5.6	5.1	5.1	3.9	3.5	2.9	3.5	4.1
Down 9	0.9	1.2	1.0	2.8	14.0	2.8	6.9	2.8	39.7	13.9	43.0	23.6	21.8	20.1	14.9	20.1	9.7	27.7	7.1	14.4
Down 10	0.8	1.0	1.5	2.1	2.2	1.4	2.5	2.5	11.6	6.7	6.9	6.8	5.6	11.8	10.1	5.5	4.9	5.4	8.6	5.2
Means	1.1	1.3	1.3	3.0	10.3	2.4	4.0	2.4	20.0	5.3	17.4	11.6	11.0	12.3	10.0	9.8	6.0	12.0	6.4	7.9
Net NO3	0.2	-0.2	0.2	1.2	7.1	-2.4	2.5	0.6	17.6	2.9	13.2	7.8	6.3	7.1	6.0	5.8	2.6	8.9	3.1	4.9

Table 6-1. Analyses of upgradient stockpile wells for metals.

Upgradient Stockpile Well 6, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	0.001	<.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.001	0.001	<.001	0.000
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	<.001	<.001	<.001	<.001	<.001	0.001	0.002
Copper	0.03	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.02	0.02	0.02	<.01	0.002	0.001	0.004	0.006	0.003	0.003	0.007
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	0.05	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.003
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.01	0.02	<.001	<.001	<.001	<.001	<.001	<.001	0.001
Nickel	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.02	<.01	0.02	<.01	0.06	0.001	<.001	0.003	0.004	0.003	<.001	0.007
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.02	<.01	0.04	0.06	0.06	0.004	0.003	0.033	0.019	0.009	0.027	0.015

Upgradient Stockpile Well 7, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	0.05	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.001	0.003	<.001	0.003
Chromium	<.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	<.01	0.02	<.01	0.03	<.001	<.001	<.001	<.001	0.007	0.001	0.004
Copper	0.01	<.01	<.01	<.01	0.01	<.01	<.01	<.01	0.69	0.02	0.03	<.01	0.004	0.003	0.004	0.005	0.014	0.006	0.044
Lead	<.01	<.01	<.01	<.01	<.01	0.03	<.01	<.01	0.05	<.005	0.04	<.01	<.001	<.001	<.001	<.001	<.001	0.003	0.007
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.01	0.07	<.001	<.001	<.001	<.001	<.001	<.001	0.004
Nickel	0.02	<.01	<.01	0.03	<.01	<.01	<.01	0.02	0.02	0.05	0.02	0.03	<.001	0.002	<.001	0.002	0.008	0.008	0.012
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.05	0.06	0.05	0.004	0.004	0.028	0.010	0.005	0.023	0.014

Table 6-2. Analyses of upgradient stockpile wells for metals.

Upgradient Stockpile Well 11, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	0.001	0.002	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.001	0.010	<.001	0.001
Chromium	<.01	<.01	<.01	<.01	<.01	0.01	<.01	<.01	0.02	0.02	<.01	0.03	<.001	<.001	0.002	<.001	<.001	0.002	0.005
Copper	0.03	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	0.02	<.01	<.01	0.001	0.005	0.002	0.001	0.011	0.003	0.006
Lead	<.01	0.04	<.01	<.01	<.01	<.01	<.01	<.01	0.02	<.005	0.05	<.01	<.001	0.001	<.001	<.001	<.001	<.001	0.006
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	0.05	0.05	<.05	<.05	<.05	0.06	<.01	<.01	<.001	0.001	<.001	<.001	<.001	<.001	0.009
Nickel	0.02	<.01	<.01	0.02	<.01	<.01	<.01	0.02	0.02	0.04	<.01	0.04	<.001	<.001	<.001	0.001	0.001	0.002	0.009
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	0.02	0.03	0.01	<.01	0.03	0.06	0.06	0.01	0.004	0.009	0.001	0.025	0.004	0.015

Mean Upgradient Stockpile Wells, mg/l

Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	Means
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.001	0.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	0.017	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	0.001	0.001	0.005	<.001	0.001
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.013	<.01	0.030	<.01	<.001	0.001	<.001	0.002	0.001	0.003
Copper	0.023	<.01	<.01	<.01	0.010	<.01	<.01	<.01	0.247	0.020	0.017	<.01	<.01	0.003	0.003	0.004	0.009	0.004	0.019
Lead	<.01	0.013	<.01	<.01	<.01	0.010	<.01	<.01	0.023	<.01	0.047	<.01	<.01	<.001	<.001	<.001	<.001	0.001	0.005
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.001	<.001	<.001	<.001	<.001	0.005
Nickel	0.013	<.01	<.01	0.023	<.01	<.01	<.01	0.020	0.013	0.037	<.01	0.043	<.01	0.001	0.001	0.002	0.004	0.003	0.009
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	0.013	0.010	0.010	<.01	0.040	0.060	0.057	0.006	0.004	0.023	0.010	0.013	0.018	0.015
Detections	5	1	0	4	4	5	1	5	8	12	9	11	7	11	12	12	13	12	7

Table 6-3. Analyses of downgradient stockpile wells for metals.

Downgradient Stockpile Well 8, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	0.011	0.011	<.001	0.001
Chromium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	<.001	<.001	<.001	<.001	<.001	0.001	0.002
Copper	<.01	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.02	0.02	<.01	0.03	0.002	0.002	0.004	0.027	0.004	0.005	0.007
Lead	0.05	<.01	0.02	0.02	<.01	<.01	<.01	<.01	0.01	0.01	0.04	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.008
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	0.001	<.001	<.001	0.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	0.20	0.20	<.05	<.05	<.05	<.05	<.05	0.06	0.03	0.02	0.001	<.001	<.001	<.001	<.001	<.001	0.028
Nickel	<.01	<.01	<.01	0.03	<.01	<.01	<.01	0.03	<.01	0.02	<.01	0.03	<.001	<.001	0.003	0.023	<.001	<.001	0.008
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	0.02	<.01	<.01	<.01	0.02	0.05	0.04	0.003	0.005	0.021	1.125	0.016	0.015	0.073

Downgradient Stockpile Well 9, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.002	0.002	0.002	0.002	<.001	0.010	0.001
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	0.001	0.000
Cadmium	0.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	0.002	0.002	0.002	0.001	0.005	0.001
Chromium	<.01	0.04	<.01	<.01	<.01	<.01	<.01	<.01	0.01	0.02	<.01	0.08	<.001	<.001	<.001	<.001	<.001	0.004	0.009
Copper	0.04	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	0.02	0.02	0.11	0.004	0.006	0.003	0.008	0.003	0.039	0.016
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	0.01	0.06	0.02	<.001	<.001	<.001	<.001	<.001	0.007	0.006
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.01	0.10	0.002	0.002	<.001	<.001	<.001	<.001	0.006
Nickel	0.03	<.01	<.01	0.03	<.01	<.01	<.01	0.03	0.02	0.05	<.01	0.04	<.001	0.007	<.001	0.006	<.001	0.049	0.015
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Zinc	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.05	0.09	0.20	0.016	0.009	0.027	0.073	0.075	0.315	0.048

Table 6-4. Analyses of downgradient stockpile wells for metals.

Downgradient Stockpile Well 10, mg/l

Date	06/20	07/18	08/22	09/23	10/18	11/20	12/12	01/07	02/21	03/25	04/29	05/20	06/26	07/07	08/05	09/16	10/22	12/16	Means
Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.002	<.001	<.001	<.001	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	0.001	<.001	0.001	<.001	0.000
Chromium	<.01	0.03	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.06	<.001	<.001	<.001	<.001	<.001	<.001	0.005
Copper	0.02	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	0.02	<.01	0.03	0.004	0.003	0.002	0.001	0.011	0.003	0.006
Lead	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.01	0.02	0.05	0.03	<.001	<.001	<.001	<.001	<.001	0.002	0.006
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.01	0.11	<.001	0.001	<.001	<.001	<.001	<.001	0.006
Nickel	0.02	<.01	<.01	0.03	0.01	0.26	<.01	0.03	<.01	<.01	<.01	0.06	<.001	0.002	<.001	<.001	0.003	0.004	0.023
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.03	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.002
Zinc	<.01	<.01	<.01	<.01	<.01	0.04	<.01	<.01	<.01	0.02	0.08	0.14	0.035	0.006	0.026	0.002	0.150	0.022	0.029

Mean Downgradient Stock Pile Wells, mg/l

Month	6.7	7.6	8.7	9.8	10.6	11.7	12.4	13.5	14.7	15.8	17.0	17.7	18.9	19.2	20.2	21.5	22.7	24.5	Means
Arsenic	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.001	0.001	0.001	0.001	<.001	0.003	0.000
Beryllium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Cadmium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.001	0.001	0.001	0.004	0.004	0.002	0.001
Chromium	<.01	0.023	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.057	<.001	<.001	<.001	<.001	<.001	0.002	0.005
Copper	0.020	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.020	0.020	<.01	0.057	0.003	0.004	0.003	0.012	0.006	0.016	0.009
Lead	0.017	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.010	0.013	0.050	0.017	<.001	<.001	<.001	<.001	<.001	0.003	0.006
Mercury	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.001	<.001	<.001	<.001	<.001	<.001	0.000
Molybdenum	<.05	<.05	0.067	0.067	<.05	<.05	<.05	<.05	<.05	<.05	<.05	0.077	0.001	0.001	<.001	<.001	<.001	<.001	0.012
Nickel	0.017	<.01	<.01	0.030	<.01	0.087	<.01	0.030	<.01	0.023	<.01	0.043	<.001	0.003	0.001	0.010	0.001	0.018	0.015
Selenium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	0.010	<.01	<.01	<.001	<.001	<.001	<.001	<.001	<.001	0.001
Zinc	<.01	<.01	<.01	<.01	<.01	0.020	<.01	<.01	<.01	0.030	0.073	0.127	0.018	0.007	0.025	0.400	0.080	0.117	0.050
Detections	6	2	2	5	2	3	0	3	8	14	8	17	10	12	12	12	10	15	8

Table 7-1. Interlaboratory comparison of metals in turf plot wells.

Mean upgradient turf plot wells, mg/l.

	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
Date	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL
09/23	0.0001	<.01	0.002	<.01	<.01	<.01	<.005	<.01	<.01	<.01	<.05	<.01
10/18	0.0007	<.01	0.006	<.01	<.01	<.01	<.005	<.01	0.01	<.01	<.05	<.01
11/20	0.0003	<.01	0.002	<.01	<.01	<.01	<.005	<.01	<.01	<.01	<.05	<.01
12/12	0.0001	<.01	0.002	<.01	0.03	<.01	<.005	<.01	0.01	<.01	<.05	<.01
01/07	0.0001	<.01	<.002	<.01	<.01	<.01	<.005	<.01	<.01	<.01	<.05	<.01
02/21	0.0002	<.01	<.002	<.01	<.01	0.03	<.005	0.01	<.01	0.02	<.05	<.01
03/25	0.0002	<.01	<.002	<.01	<.01	<.01	<.005	<.01	<.01	0.03	<.05	0.02
04/29	<.0001	<.01	<.002	<.01	<.01	<.01	<.005	0.04	0.03	<.01	0.06	0.03
05/20	0.0001	<.01	0.003	<.01	<.01	<.01	<.005	<.01	0.01	<.01	<.05	0.07
Date	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT
06/26	<.0001	<.001	<.002	<.001	<.01	0.003	<.005	<.001	<.01	<.001	<.05	0.012
07/07	0.0001	<.001	0.002	<.001	0.02	0.002	<.005	<.001	<.01	0.001	<.05	0.003
Means	0.0002	<.01	0.001	<.01	<.01	<.01	<.005	<.01	0.01	<.01	<.05	0.01
Count	0	0	0	0	1	1	2	0	2	4	1	0

Table 7-2. Interlaboratory comparison of metals in turf plot wells.

Mean downgradient turf plot wells, mg/l.

	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
Date	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL
09/23	0.0001	<.01	0.002	<.01	<.01	<.01	<.005	<.01	0.01	0.02	<.05	<.01
10/18	0.0002	<.01	0.003	<.01	<.01	0.01	<.005	<.01	0.01	<.01	<.05	<.01
11/20	0.0002	<.01	0.003	<.01	<.01	<.01	<.005	<.01	0.02	0.08	<.05	0.02
12/12	0.0002	<.01	0.002	<.01	<.01	<.01	<.005	<.01	0.02	<.01	<.05	<.01
01/07	0.0001	<.01	<.002	<.01	<.01	<.01	<.005	<.01	<.01	<.01	<.05	<.01
02/21	0.0001	<.01	<.002	0.02	<.01	<.01	<.005	0.06	<.01	<.01	<.05	<.01
03/25	0.0002	<.01	<.002	0.01	<.01	<.01	<.005	0.02	0.01	0.03	<.05	0.03
04/29	<.0001	<.01	0.002	0.01	<.01	0.02	<.005	0.04	0.01	0.01	0.09	0.07
05/20	<.0001	<.01	<.002	0.02	<.01	0.03	<.005	<.01	<.01	0.01	<.05	0.12
Date	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT
06/26	<.0001	<.001	<.002	<.001	0.02	0.001	<.005	<.001	<.01	0.001	<.05	0.001
07/07	<.0001	<.001	0.003	<.001	<.01	0.004	<.005	<.001	<.01	0.001	<.05	0.003
Means	0.0001	<.01	<.002	0.01	<.01	0.01	<.005	0.01	0.01	0.01	<.05	0.02
Count	0	0	3	1	3	0	3	0	1	2	1	0

Table 7-3. Interlaboratory comparison of metals in stock pile wells.

Mean upgradient stock pile wells, mg/l.

	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
Date	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL
01/07	0.0001	<.01	<.002	<.01	<.01	<.01	<.005	<.01	<.01	0.02	<.05	0.01
02/21	<0.0001	<.01	0.002	<.01	<.01	0.25	<.005	0.02	0.01	0.01	<.05	<.01
03/25	<0.0001	<.01	<.002	0.01	<.01	0.02	<.005	<.01	<.01	0.04	<.05	0.04
04/29	<0.0001	<.01	<.002	<.01	<.01	0.02	<.005	0.05	0.03	<.01	<.05	0.06
05/20	<0.0001	<.01	0.002	0.03	<.01	<.01	<.005	<.01	0.01	0.04	<.05	0.06
Date	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT
06/26	<0.0001	<.001	<.002	<.001	0.01	0.002	<.005	<.001	<.01	<.001	<.05	0.006
07/07	<0.0001	<.001	0.009	<.001	0.02	0.003	<.005	<.001	<.01	0.001	<.05	0.004
Means	<0.0001	<.01	0.002	0.01	<.01	0.04	<.005	0.01	0.01	0.01	<.05	0.02
Count	0	0	0	1	3	0	2	0	2	1	2	0

Table 7-4. Interlaboratory comparison of metals in stock pile wells.

Mean downgradient stock pile wells, mg/l.

	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
Date	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL	CAES	PEL
01/07	<0.0001	<.01	0.002	<.01	<.01	<.01	<.005	<.01	<.01	0.03	<.05	<.01
02/21	0.0002	<.01	<.002	<.01	<.01	0.02	<.005	0.01	0.01	0.01	<.05	<.01
03/25	0.0002	<.01	<.002	0.01	<.01	0.02	<.005	0.01	<.01	0.02	<.05	0.03
04/29	<0.0001	<.01	<.002	<.01	<.01	0.01	<.005	0.05	0.03	<.01	0.11	0.07
05/20	0.0001	<.01	<.002	0.06	0.02	0.06	<.005	0.02	0.01	0.04	<.05	0.13
Date	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT	CAES	ACT
06/26	0.0001	0.001	0.002	<.001	0.02	0.003	<.005	<.001	0.01	<.001	0.05	0.018
07/07	0.0002	0.001	0.003	0.001	<.01	0.004	<.005	<.001	0.01	0.003	<.05	0.007
Means	0.0001	<.01	<.002	0.01	0.01	0.01	<.005	0.01	0.01	0.01	0.02	0.03
Count	0	0	2	1	3	0	4	0	2	2	1	0
Total count	0	0	5	3	10	1	11	0	7	9	5	0

Table 8-1. Rainfall plus irrigation on turf plots at Windsor, 1991.

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1					T	0.13	0.13	0.32			0.01	T
2			0.72	0.09	0.04	0.13		0.29				0.03
3			0.67			0.06		0.23				1.43
4			0.72					0.14	0.02	0.38		0.26
5	0.01		0.02			0.19	0.22		0.10	0.22		T
6		0.07	0.04		2.22	0.01	0.02	0.46	0.35	0.51		0.17
7		0.67	0.31									T
8	T							0.39				
9	0.12						0.18	0.97	0.39			0.01
10	0.29			T	0.45	0.13		0.26			0.10	0.17
11	0.27					0.01				0.38	1.20	
12	0.32									0.05	0.17	
13		0.09		0.01		0.1	0.46	0.27	0.60		0.05	0.17
14		0.64	0.24	0.06	0.09				0.21			0.36
15		0.07	0.39	0.30			0.21	0.28	0.32	0.25	0.08	T
16	0.57					0.76				0.14		
17	0.16				1.85		0.19			0.34		0.13
18		0.09	0.33					0.01		0.22		
19		0.32				0.15	0.23	3.87	0.58			
20	T	0.03						0.50	0.23			
21	0.05			2.11		0.13	0.43	1.25			0.58	0.08
22			0.43	0.15	0.18	0.08					1.90	
23			0.63		0.25	0.04	1.56		0.05		0.04	0.04
24			0.25		0.25				0.02		0.17	
25			0.07				0.03		2.95			
26					0.25	0.18	1.21		0.72			
27		0.09	0.10		0.09	0.13	0.02	0.31				
28	0.08	0.04			0.25	0.69						
29				T	0.25	0.02		0.34			T	0.60
30	0.25		0.09	1.13	0.98	0.32		0.25				0.07
31	0.16				0.06					0.07		
Total	2.28	2.11	5.01	3.85	7.21	3.26	4.89	10.14	6.54	2.56	4.30	3.52

Note: Underline indicates irrigation

Total for year 55.67

Table 8-2. Rainfall plus irrigation on turf plots at Windsor, 1992.

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		T		0.09	0.04	1.03	0.33					
2			0.01		0.32				0.51		0.05	0.35
3			0.01		0.46		0.18		0.51		0.79	1.16
4	0.28	T					0.25	0.10	T		0.02	0.01
5	0.06					0.62	0.02				0.15	0.07
6			0.01			2.97	0.29				0.07	
7			0.33					0.42				
8		0.07	0.19		0.03	0.12			0.01			
9	0.14				0.11		0.29	0.86		0.42		
10			0.22	0.03					0.31	1.05		0.02
11		T	0.97	0.19				0.40		0.15	0.17	1.25
12				0.24			0.09			0.27	0.14	0.52
13		0.01			T		0.05				0.72	0.01
14	0.78	0.18					0.12	0.23				
15		0.64				0.33	1.30	0.03		0.14		
16	0.04	0.35		0.42	0.24		0.09	0.53	0.80	0.04		0.01
17	T		T	0.72		0.26		0.52		0.15	T	0.75
18		0.05		0.11	0.02			0.99				
19		0.04	0.25	0.22		0.02	0.01	0.10	0.08	0.02		
20	T					0.50	0.36					0.05
21	T	0.01								0.03	0.04	
22			0.22	0.06			0.31		0.52		0.33	0.05
23	1.50		0.04				0.29		0.25		1.44	T
24		0.07		0.37	0.07	1.33				0.25		T
25		0.21		0.71		0.48					0.14	
26	T	0.78	0.18	0.19	0.02		0.04	0.28	0.55	T	0.54	
27		0.02	0.68		0.20	0.39	0.11		0.09			
28			0.01		T	0.17		0.46				0.02
29		0.05					0.56	0.06				0.38
30			0.02							0.01		0.30
31			0.24		0.38		1.67					0.26
Total	2.80	2.48	3.38	3.35	1.89	8.22	6.36	4.98	3.63	2.53	4.60	5.21

Note: Underline indicates irrigation

Total for year 49.43

The Connecticut Agricultural Experiment Station, founded in 1875, is the first experiment station in America. It is chartered by the General Assembly to make scientific inquiries and experiments regarding plants and their pests, insects, soil and water, and to perform analyses for State agencies. The laboratories of the Station are in New Haven and Windsor; its Lockwood Farm is in Hamden. Single copies of bulletins are available free upon request to Publications; Box 1106; New Haven, Connecticut 06504. ISSN 0097-0905