ORNL/TM-11601

LOCKHEED MARTIN

ENVIRONMENTAL
RESTORATION
PROGRAM

Sludge Application and Monitoring Program on the Oak Ridge Reservation 1986–1993

DISCLAIMER

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Sludge Application and Monitoring Program on the Oak Ridge Reservation, 1986–1993

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LOCKHEED MARTIN ENERGY SYSTEMS, INC.
managing the
Environmental Management Activities at
Oak Ridge K-25 Site Paducah Gaseous Diffusion Plant
Oak Ridge Y-12 Plant Portsmouth Gaseous Diffusion Plant
Oak Ridge National Laboratory
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for the
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PREFACE

Municipal sewage sludge from the city of Oak Ridge, Tennessee, was applied to pastures and tree plantations on the Department of Energy (DOE) Oak Ridge Reservation, Oak Ridge, Tennessee, beginning in 1985. Beginning in 1986, data were collected for sludge characteristics and the volumes of sludge applied to specific locations. Additional data for selected application sites included: characteristics of soils, vegetation, soil water, surface water, and groundwater for treated and reference areas before and after application. Digested sewage sludge from the city of Oak Ridge is similar in chemical composition to sludges from other cities, with the exception of the presence of radionuclides (e.g., U, ^{137}Cs, ^{60}Co, and ^{131}I). This document provides information for sludge constituents, application rates, and the fate and transport of sludge constituents on the DOE Oak Ridge Reservation. This work was supported by the city of Oak Ridge, Oak Ridge National Laboratory Environmental Nuclear and Chemical Waste Program, and DOE Waste Management.

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ABBREVIATIONS AND UNITS

ABBREVIATIONS

AA	atomic absorption spectrophotometry
CEC	cation exchange capacity
DOE	U. S. Department of Energy
EPA	U. S. Environmental Protection Agency
ESD	Environmental Sciences Division (ORNL)
FWHM	full width at half maximum
ICP	inductively coupled plasma
IG	intrinsic germanium
LAA	land application approval
MDL	method detection limit
NIST	National Institute of Standards and Technology
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PSRP	process to significantly reduce pathogens
RCRA	Resource Conservation and Recovery Act
Std	standard deviation
TKN	total kjeldahl nitrogen

UNITS

Bq	bequerel*
ha	hectare
Kev	kiloelectron volts
meq	milliequivalents
Mg	megagram = metric ton = 1,000 kg
mg/kg	milligram per kilogram = ppm, part per million
pCi	picoCurie*

*Note: 1 Bq = 1 disintegration/sec= 27.03 pCi

EXECUTIVE SUMMARY

Municipal sewage sludge has been applied to forests and pastures on the DOE (Department of Energy) Oak Ridge Reservation since 1983, as a method of both disposal and beneficial reuse. Application was carried out under state of Tennessee permits issued to the city of Oak Ridge for land disposal of sewage sludge. In conjunction with these applications, information has been collected concerning sludge quantity and characteristics, soil parameters, soil water constituents, groundwater quality, surface runoff water quality, and various chemical constituents in vegetation on application sites. This information provides (1) a record of sludge application on the DOE reservation, and (2) documentation of changes in soil parameters following sludge application. The information also provides a basis for evaluating the implications of the land application of municipal sewage sludge for soil and water quality and for evaluating the fate of sludge constituents when sludge is either sprayed or injected on pasture sites or surface applied in forested sites. This report covers in detail sludge applications conducted from 1986 through 1993, with some data from the period between 1983 and 1986.

Land application is a common means of disposal for municipal sewage sludge in the United States and has been recommended by U.S. Environmental Protection Agency (EPA) as a desirable alternative for waste disposal. Municipal sewage sludge is in many ways similar to diluted animal manure fertilizer, although it will also contain metals, organic chemicals, human pathogens, and other constituents reflective of the inputs to the municipal sewage treatment plant. When applied to land, nutrients in the sludge improve soil fertility, and minerals and organic matter in the sludge improve soil structure. Under optimal conditions, metals are immobilized and organic chemicals and pathogens are immobilized or destroyed. If not managed effectively, however, sludge constituents (metals, nutrients, pathogens) have the potential to impact human health and the environment.

Anaerobically digested liquid sludge (2% to 4% solids) from the city of Oak Ridge had a relatively high nitrogen content (8% dry weight) and average to low concentrations of potentially problematic metals, compared with typical municipal sludges. Few potentially hazardous organic chemicals were detected in the sludge, and when found, these were at very low concentrations. Oak Ridge sludge is somewhat unique in that it contains radionuclides (^{137}Cs, ^{60}Co, ^{131}I, uranium isotopes, ^{90}Sr, and occasionally ^{99}Tc) at concentrations much higher than typical municipal sludges. As a result of the presence of radionuclides in the sludge, DOE, the city of Oak Ridge, and the state of Tennessee established sludge loading rates to avoid the accumulation of radionuclides in soil to levels that might be problematic under future conditions. On the initial application sites, sludge was applied at rates of 44 to 48 Mg/ha (19 to 21 tons/acre), on a dry weight basis. In 1989 the city began to limit sludge loading to a very conservative 10 Mg/ha (4.4 tons/acre) per year, and a lifetime maximum of 34 Mg/ha (15 tons/acre) dry weight based upon concern for radionuclide accumulation in soils. Subsequent to that, lifetime maximum loading has been extended to approximately 22 tons per acre. These loading rates are substantially below sludge loading rates allowed by either federal regulations (40 CF§ 503.13), based on metal concentrations in the sludge, or Tennessee Department of Environment and Conservation (TDEC) regulations, which also take into account available nitrogen loading. The sludge loading rates allowed by the state Land Application Approval (LAA) are 5 tons per acre per year for a maximum of 10 years, for a total of 50 tons per acre (112 Mg/ha).

Measurement of soil constituents following sludge application indicated that sludge constituents were (1) largely retained in the upper 15 cm of soil, and (2) with the exception of N, Zn, Cd, Cu, Hg, and selected radionuclides, sludge application did not substantially alter the concentrations of soil constituents. Concentrations of Zn and Cu were about doubled, and concentrations of Hg and Cd increased by several fold. These changes are not anticipated to have any adverse impacts on land use, plant growth, or soil organisms. Although nitrogen was added at rates of up to 3000 Kg/ha, variability in soil nitrogen concentrations made it difficult to show significant differences in soil nitrogen concentrations within the upper 15 cm of soil. Apparently, much of the added nitrogen was lost by volatilization, plant uptake, and other mechanisms. Radionuclides were quantitatively retained in the soil; that is, almost all of the quantity of radionuclides in the sludge could be accounted for in the upper 15 cm of the soil. The concentration of uranium and ^{137}Cs in the upper 15 cm increased by less than a factor of two. The concentrations of ^{60}Co increased substantially in the soil, compared to soils where sludge has not been applied, which usually do not contain ^{60}Co. However, final concentrations of ^{60}Co in the soil were low compared with other radionuclides in the soil. It could not be determined if concentrations of other sludge-related radionuclides increased in soils as a result of sludge application. Concentrations of radionuclides in soils on sludge application sites were low enough as not to preclude unrestricted use of those sites.

Soil water constituents provide an indication of the fraction of material in soils that is easily mobile and readily available to plants. Measurements of soil water constituents (at about 40 to 60 cm depth) on sludge application sites and reference plots were made during and following sludge application. Sludge application increased the conductivity and alkalinity of soil water. Concentrations of Ca, K, Mg, Mn, Na, Zn, NO_3^-, and SO_4^{-2} increased by several fold. Nitrate concentrations showed the greatest increases, rising from an average of about 1.7 to 4.7 ppm-N on reference sites to an average of 47 to 66 ppm-N on application sites. Metals and radionuclides were not elevated in soil water on sludge application sites.

Five groundwater wells (three downgradient of the application site) were used to evaluate the potential impacts of sludge application on ground water quality. Two of the downgradient wells were located on the edge of the sludge application site. The third was located about 50 to 100 meters further downgradient. The downgradient wells were quite shallow (20 to 30 ft) and sampled water at the top of the groundwater table at the lowest elevation portion of the application site. These wells responded rapidly to rainfall and were in close communication with local groundwater. One of the downgradient wells on the edge of the sludge field showed increased concentrations of NO_3^- (up to 6 ppm-N) and fecal coliform (up to 9800 colonies per 100 ml). No other constituents were above reference levels in this or the other downgradient wells. The well showing the increased NO_3^- and fecal coliform could be considered a worst possible case for potential groundwater contamination based upon its shallow depth and location. Overall the groundwater data indicated a potential for groundwater contamination from sludge application, similar to that expected from the application of manure or chemical fertilizers.

Samples of surface runoff were collected on sludge fields and in tributaries downgradient of sludge application sites during and following sludge application. Grab or flow proportional composite samples from the application sites were compared with samples from upstream or reference areas. Conductivity, biological oxygen demand, fecal coliform, NO_3^-, and soluble phosphorus were consistently elevated as a result of sludge application. Other parameters (metals, etc.) were not elevated in runoff from sludge sites. Application to pasture sites where the soil surface was disturbed resulted in more surface runoff and runoff of poorer quality compared with sludge applications to tree plantations or forested sites where the ground surface was not disturbed. The quality of surface runoff from pasture application sites was similar to that expected from pastures with grazing animals.

Vegetation (grass, pine needle, weed, and blackberry) samples were collected following sludge application to evaluate both the movement of sludge constituents into the vegetation and the potential for transfer to animals. During sludge application, the vegetation concentrations of N, P, K, Ca, Mg, Fe, Ag, Cu, Na, Pb and Zn were higher than on reference sites. For the most part this was due to surface contamination with sludge. Following sludge application, plant concentrations of N, P, Ca, S, Mg, Fe, Zn, and Al remained higher on the application sites than on adjacent reference sites. Radionuclide concentrations in vegetation may have been slightly elevated; however, concentrations were consistently close to method detection limits. Concentrations of sludge-added radionuclides in vegetation were orders of magnitude lower than concentrations of naturally occurring radionuclides (^{40}K and ^{7}Be) in those plants.

Information collected to date demonstrates that application of municipal sewage sludge from the city of Oak Ridge on the DOE Oak Ridge Reservation has not resulted in any significant impacts on environmental quality or future uses of the application sites. Radionuclides and metals in the sludge are quantitatively retained in the upper 15 cm of soil, and are not found in soil water, groundwater, or surface runoff. Some constituents (nutrients, biological oxygen demand, and fecal coliform) in runoff from sludge sites have the potential to degrade the quality of nearby surface water. Care should be taken to avoid sludge application in areas near surface water. To minimize the potential for poor quality surface runoff from sludge application sites, sludge should be applied at rates which avoid sludge buildup on soil surfaces, appropriate buffer strips between application sites and surface water resources should be provided, and sludge should be sprayed over the surface rather than injected to minimize disturbance of the soil. The potential for groundwater contamination can be minimized by avoiding application in areas with sinkhole or active groundwater wells, and by following the prescribed annual nitrogen loading rates.

Land application of municipal sewage sludge can dilute or destroy problematic sludge constituents while improving soil fertility on application sites. Sludge application must be managed to avoid impacts to human health and the environment. Responsible behavior by the DOE Oak Ridge Operations Office and the city of Oak Ridge have made these sludge applications a model of environmentally responsible waste management.

1. INTRODUCTION

1.1 HISTORY OF SLUDGE APPLICATION AND MONITORING ON THE OAK RIDGE RESERVATION

Oak Ridge municipal sewage sludge has been applied on the Department of Energy's Oak Ridge Reservation (ORR) lands since 1983, both as a disposal method for the city and as a beneficial amendment to the soil which could potentially increase tree growth. Late in 1986 researchers in Oak Ridge National Laboratory's (ORNL) Environmental Sciences Division became involved in the project, and environmental monitoring was initiated in early 1987 as part of the Sludge Land-Farming Research and Demonstration Project.

From 1986 through 1993, anaerobically digested sludge from the city of Oak Ridge wastewater treatment plant was applied to a series of grassy fields and forested sites on the ORR. The sludge, typically between 2 and 4% solids, was applied either by spraying or by subsurface injection, as often as daily, when weather and equipment permitted. Individual application sites are described in Sect. 3.

The formal monitoring program has varied in scope and intensity as specific questions arose and were answered adequately. Parameters monitored at various times included metals, plant nutrients, radionuclides, water chemistry, nitrogen, organics, and coliform bacteria. These parameters were monitored in the sludge itself, in soils, vegetation, soil water, groundwater, and in surface runoff during various stages of the monitoring program. Specifics of the monitoring program are discussed in Sect. 3 and in sections on the individual environmental media monitored.

2. SLUDGE CHARACTERISTICS

2.1 SAMPLING: PARAMETERS OF INTEREST AND METHODS

The treatment process for Oak Ridge municipal sludge includes both primary and secondary treatment. Sewage passes through a primary sedimentation and clarification process, and a settled activated sludge process. Sludge from these units is then pumped to two anaerobic digesters maintained at 35 °C with an average 30-day detention time. The sludge is then transferred to a secondary digester with a 30-day detention time, for an approximate total detention time of 50 to 60 days. The anaerobic digesters constitute a "process to significantly reduce pathogens (PSRP)." The sludge then passes to a final holding tank, called a storage digester, and from there is loaded into a tank truck holding 5400 gallons, which is used to deliver sludge from the sewage treatment plant to the application site. At the application site, sludge is transferred to a smaller application vehicle holding approximately 1500 gallons. As many as six tank truckloads may be applied in a single day if weather and staffing permit.

During much of the period covered by this report, samples were taken from each tank load of sludge as it left the treatment plant. They were saved for a weekly composite sample which was analyzed for radionuclides at ORNL Environmental Sciences Division by gamma ray spectrometry using high purity intrinsic germanium detectors. The details of these radionuclide analyses are given in Appendix A.

A monthly composite sample was sent to A&L Laboratories, Memphis, Tennessee, for analysis of nutrients and metals, by these methods: wet chemistry, inductively coupled plasma (ICP) spectrometry, and atomic absorption spectrophotometry (AA). Organics (volatiles, semi-volatiles and pesticides) were measured twice a year, according to EPA methods by Eckenfelder, Inc., Nashville, Tennessee. Total uranium in dried sludge was determined (monthly starting in 1989) by the neutron activation method [Oak Ridge Associated Universities (ORAU)]. Neutron activation data for a few other metals (Fe, Ag, Ba, Co, and Mn) is also provided, for reference only, for metals where no data were available from the A&L analysis. Strontium-90 and ^{99}Tc were also determined on a few samples by the ORNL Analytical Chemistry Division.

2.2 VARIATION IN SLUDGE CHARACTERISTICS OVER TIME

Table 2.1 shows average annual concentrations of various nutrients and heavy metals in the sludge from 1988 to 1993, along with the number of monthly composite samples contributing to the mean. Data are on a dry weight basis, and total percent solids in the liquid sludge is also shown. Table 2.2 contains limited data on metals from the earlier years, 1984 through 1986, along with the number of weekly samples used to compute the mean. Concentrations of several of the constituents, including the major plant nutrients, have remained fairly constant over the years (1984–1993), but the concentrations of several metals of concern, e.g., Cr, Cu, Ni, Pb, and Zn, have decreased markedly during this time period. Concentrations of uranium were particularly high in 1988 (165 mg/kg, n=1) and 1989 (85 ± 25 mg/kg) but decreased in subsequent years to 33.9 ± 4.2 in 1991 and 31.9 ± 1.5 mg/kg in 1992 (Table 2.1).

Some radionuclides which may be at least partially attributed to industrial or medical origins were routinely detected in sludge by gamma emission spectrometry. These were ^{60}Co, ^{137}Cs, and ^{131}I. In addition, ^{238}U, an indicator of total U, was present above detection limits in some samples. A summary of the radionuclide analyses (in the form of mean annual concentrations) for 1988 through 1992 is provided in Tables 2.3a, b, and c. Appendix B (pages 7 through 24) contains the radionuclide data from each weekly composite sample during this time period, in both pCi/Kg and Bq/Kg. Conversion factors for these units is given in the Abbreviations and Units at the beginning of this report. Standard deviations for the means in Table 2.3 tend to be high because the concentrations may vary from below detection limits one week to very high concentrations the next as a pulse of the radionuclide travels through the treatment system (see Appendix B). Sludge concentrations of these radionuclides, plus naturally occurring and atmospherically deposited radionuclides (for 1990), may also be found in Larsen et al. (1992). Total Sr (essentially ^{90}Sr) analyzed in four of the weekly sludge samples collected in 1992 was 5.0 ± 8.9, 1.6 ± 7.6, 13.0 ± 10, and 12.0 ± 10 Bq/kg for samples from 2/92, 3/93, 6/92, and 9/92, respectively. Levels of ^{99}Tc in the 2/92 and 9/92 samples were 13.0 ± 13 and 0 ± 11 Bq/Kg respectively.

The concentrations of regulated organics and pesticides in Oak Ridge sludge have generally been below analytical detection limits. For specific analyses, the reader is referred to the annual reports for the city of Oak Ridge wastewater treatment plant's biosolids management. For example, in 1992, analyses from Eckenfelder, Inc., as reported in the 1992 annual report, listed six estimated concentrations of organics, three of which were between the method detection limit and the practical quantitation limit, and three of which were actually below the listed method detection limit.

2.3 COMPARISON WITH OTHER MUNICIPAL SLUDGES

Municipal sludges can generally be divided into sludges which are suitable for land application and those sludges which are much higher in concentrations of heavy metals, e.g., Cd and Pb, or organics, both of which are disposed of by landfilling or incineration. Table 2.4 shows the 5-year average (1988–1992) concentrations of selected constituents of Oak Ridge sludge in comparison with their concentrations in other municipal sludges that were land applied [for purposes of fertilization, soil conditioning, and reclamation (Mumma et al. 1984)]. These sludge samples were from Baltimore, Maryland (used for land reclamation and compost, and landfilled); Knoxville, Tennessee (landfill); Lexington, Kentucky (fertilizer/soil conditioner for farmland); Philadelphia, Pennsylvania (land application and reclamation); Portland, Oregon (land disposal and reclamation); and Salt Lake City, Utah (park and farmland application). Data for these other municipalities was taken from Mumma et al. (1984) and represent the analysis of a single sample from each treatment plant. In comparison with these sludges, the concentrations of N, P, K, Fe, Ca, and Mg (major and minor plant nutrients) were above or near the high end of the ranges shown in Table 2.4, whereas the concentrations of other metals, except Mn and U, were generally within the concentration range of sludges from other cities or substantially lower. Uranium concentrations were higher in Oak Ridge sludge than in other sludges, but concentrations have been decreasing since 1988 (Tables 2.2 and 2.3). Concentrations of Cd and Cr in Oak Ridge sludge are at the low end of the range shown in Table 2.4, and Ni and Pb concentrations are lower in Oak Ridge sludge than in sludges from other cities cited in Table 2.4.

Radionuclide concentrations in other municipal sludges is not generally available but has been determined locally. Data for radionuclide analysis of other sludge samples collected by E. A. Stetar from treatment plants in this region is given in Table 2.5. Samples were counted in 1 L Marinelli beakers overnight at the Environmental Sciences Division, ORNL (methods, Appendix A). These data can be compared to the means in Table 2.3b and to the weekly data in Tables . Levels of ^{131}I, ^{137}Cs, ^{7}Be, ^{40}K, and ^{228}Ra in Oak Ridge sludge were comparable to levels in regional samples (sometimes higher, sometimes lower). No ^{60}Co or uranium were detected in the regional samples outside of Oak Ridge (Table 2.5).

2.4 COMPARISON WITH REGULATORY LIMITS

The U.S. Environmental Protection Agency (EPA) encourages the reuse of municipal sewage sludges to provide fertilization and soil conditioning to improve marginal lands. They set standards for the use or disposal of sewage sludge under the authority of the Clean Water Act (40 CFR §§ 257, 403 and 503), including (§ 503.13) pollutant limits for bulk sewage sludge applied to agricultural, forest, or public lands. Standards include ceiling concentrations, monthly average concentrations and annual and cumulative pollutant loading rates for metals and selected organics. Standards were proposed on February 6, 1989, and were changed and updated on February 19, 1993. The final rule became effective March 22, 1993.

The 1989 proposed rule regulated concentrations of 10 metals and 12 organic pollutants only in sludge applied to non-agricultural lands. Sludge application to agricultural lands was regulated not in terms of concentration, but in terms of annual and cumulative loading rates. The 1993 final rule, however, includes cumulative pollutant loading rates (Table 2 of § 503.13) and monthly average pollutant concentrations (Table 3 of § 503.13) for 10 metals in sludge applied to agricultural land, forest, public contact sites, or reclamation sites, stating that either the cumulative loading rate shall not exceed the Table 2 standards or that the concentration shall not exceed the Table 3 standards. The final (1993) rule defers promulgating a numerical limit for the organic compounds and pesticides listed in the 1989 proposed rules until more data are available, and there are currently no numerical limits for organics. The city of Oak Ridge National Pollutant Discharge Elimination System (NPDES) permit, although it requires that sludge be tested for several organic compounds, sets no numerical limits for these compounds, nor for radionuclides. As reported in Sect. 2.2, organic pollutants in Oak Ridge sludge are normally below detection limits.

Table 2.6 compares the concentration of the 10 regulated metals in Oak Ridge sludge with the proposed regulatory concentration limits effective during the application period as well as with the new regulations taking effect in 1993. With the exception of molybdenum and mercury, the concentrations of these metals in Oak Ridge sludge (Tables 2.6, 2.1 and 2.2) were well below even the new regulatory limits for monthly average concentrations (Table 3 of 40 CFR § 503.13) and far below the new ceiling concentrations in Table 1 of 40 CFR § 503.13. Although historical mercury concentrations were close to the new monthly average limit of 17 mg/kg, monthly composite concentrations have not exceeded that value since May, 1991, and never exceeded the 1989 limit of 30 mg/kg or the 1993 ceiling concentration of 57 mg/kg. Although molybdenum concentrations sometimes exceeded 19 February 1993 limits of 18 mg/kg, they were always below the 1989 limits of 230 mg/kg and below the 19 February 1993 ceiling concentration of 75 mg/kg, the limits of which could also be satisfied by monitoring the cumulative loading rate of molybdenum. For example, the site with the highest cumulative sludge loading to date has been the Rogers site (48 Mg sludge/ha). Using the 5-year average molybdenum concentration, the cumulative molybdenum loading rate for 48 Mg sludge/ha would be 1.2 kg molybdenum/ha, well below the 2/19/93 regulatory limit of 18 kg molybdenum/ha. Furthermore, the 2/19/93 limits for molybdenum, except the ceiling concentration limit of 75 mg/kg, were deleted by amendment of 40 CFR § 503 on 2/25/94, pending reconsideration of appropriate, presumably higher, molybdenum limits. Regulatory limits for loading rates of other metals will be addressed further in Sect. 3.

3. SLUDGE APPLICATION: METHODS, APPLICATION SITES, AND ENVIRONMENTAL MONITORING

3.1 SLUDGE APPLICATION

Anaerobically digested municipal sewage sludge from the city of Oak Ridge wastewater treatment plant was applied to a series of grassy fields and forested sites on the ORR, described below. This sludge was typically between 2 and 4% solids and was applied either by surface application (dispensed from jets behind the truck or from a spray gun mounted on top of the delivery vehicle) or by subsurface injection. Photos from this operation appear in Oakes et al. (1984). Initially some sites (McCoy site during application, Rogers site after application ended) were tilled periodically to incorporate the sludge into the upper soil horizon. Sludge was applied whenever the weather was favorable, as often as daily during dry periods, although inclement weather, equipment malfunctions or employee absences could all delay applications. For example, sludge land application occurred on only 196 days in 1991.

Application of sludge shifted from one site to another based on several considerations. Temporary shifts from one field to another occurred frequently because weather conditions resulted in poor traction for the application vehicle or because the annual loading of nitrogen (N) had been reached. On several of these sites application resumed later in the year when weather was drier or 12 months after reaching the allowable loading rate for N. Other sites were considered permanently closed, either because the planned loading rate for experimental purposes had been achieved (e.g., Sycamore site, Pine site), or in the case of the McCoy site, because higher than anticipated levels of ^{60}Co and ^{137}Cs were applied (Oakes et al. 1984).

3.2 APPLICATION SITES

Individual sites are described below and illustrated in Fig. 3.1, which shows an overview of the ORR with each application site marked. Site numbers on Fig. 3.1 correspond to the original map numbers used by the city and ORNL and are listed with the site descriptions below. Not all original site numbers were actually used, and some sites share a map number. More detailed maps (Figs. 3.2 through 3.5 indicate features such as sampling wells, positions of flow samplers, etc. For each site corresponding reference areas (where sludge was never applied) were available for comparison; these are also noted on the detailed maps. Table 3.1 summarizes some of the application information described below.

3.2.1. Sycamore site (near number 0 on Fig. 3.1)

In 1978 a single application of deterred digested sludge was applied and diked in to an approximately 0.5 ha plot off Lewis Road, west of New Zion Patrol Road. This sludge application corresponded to a total N load of 1500 kg/ha N (Van Miegroet, Boston, and Johnson 1989). Following sludge application a plantation of American sycamore (*Platens occidentals* L.) was established on this site. There is a limited amount of data available from this site.

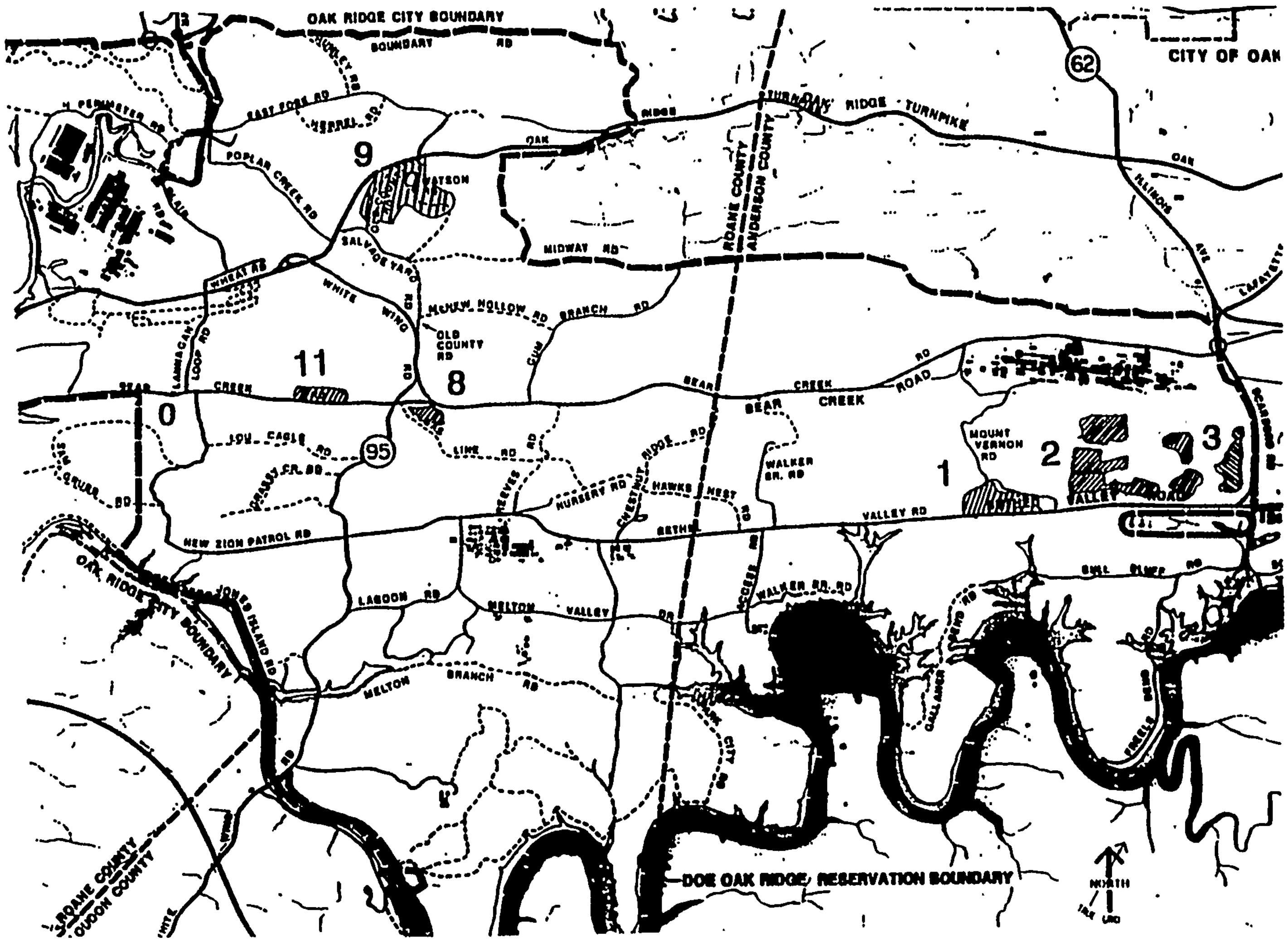

Fig. 3.1. Map of the Oak Ridge Reservation and surrounding area showing the sludge application sites.

Numbers correspond to the original numbering scheme used by Dennis Bradburn, Harry Boston, and the city of Oak Ridge to define the sludge application areas. Missing numbers indicate proposed sites that were never used. Area designations are as follows: (*a*) 0: Sycamore; (*b*) 1: McCoy; (*c*) reading from grid north: Pine Plantion, High Pasture, and Rogers; (*d*) reading clockwise starting at grid northwest (upper left): Upper Hayfield, Scarboro, Upper Hayfield 2; (*e*) Site 8; (*f*) Watson Road; (*g*) Cottonwood.

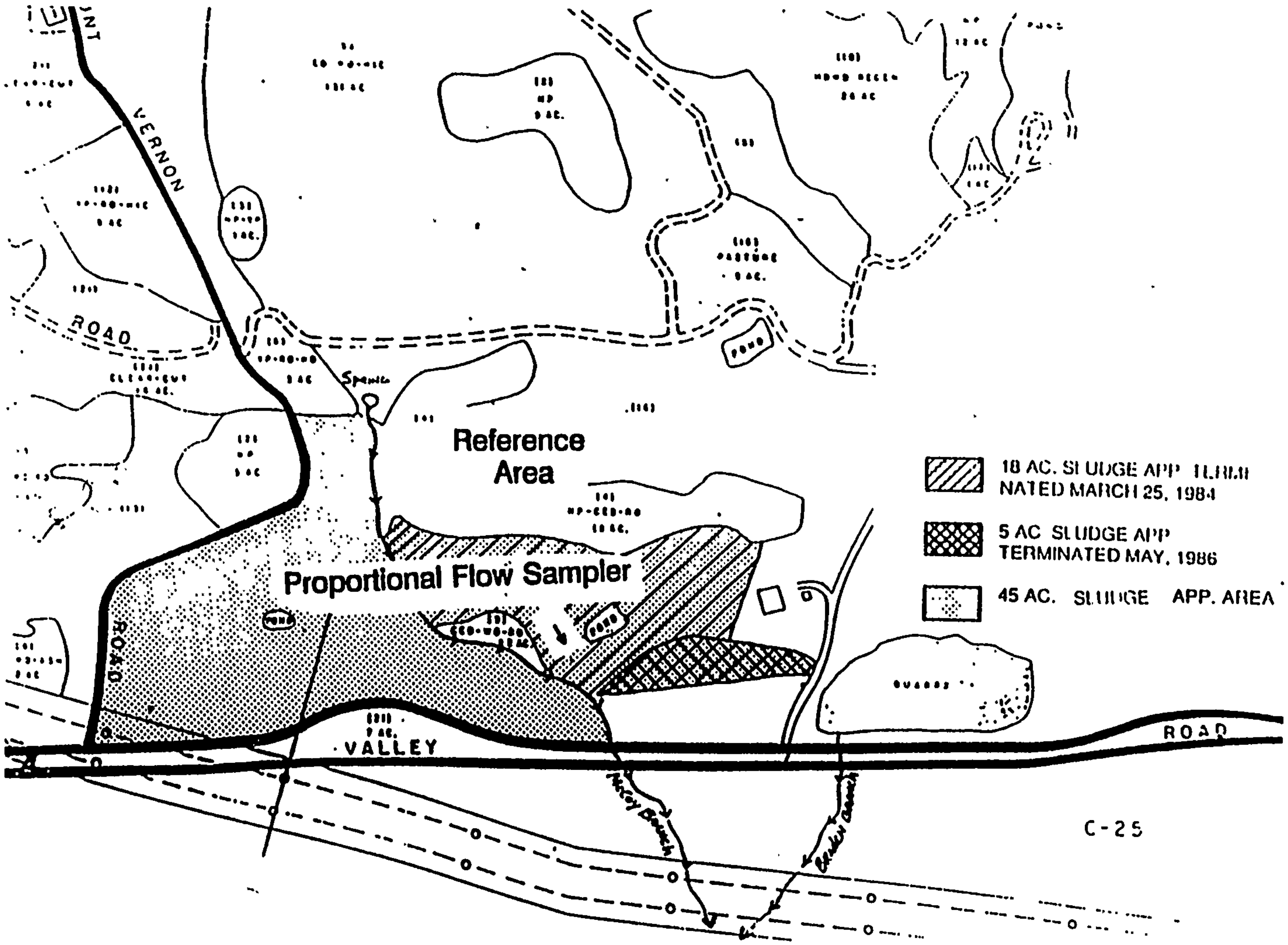

Fig. 3.2. The McCoy sludge application area showing reference area and location of proportional flow sampler (source of "composite" samples). Modified from ORNL DWG 88-5960.

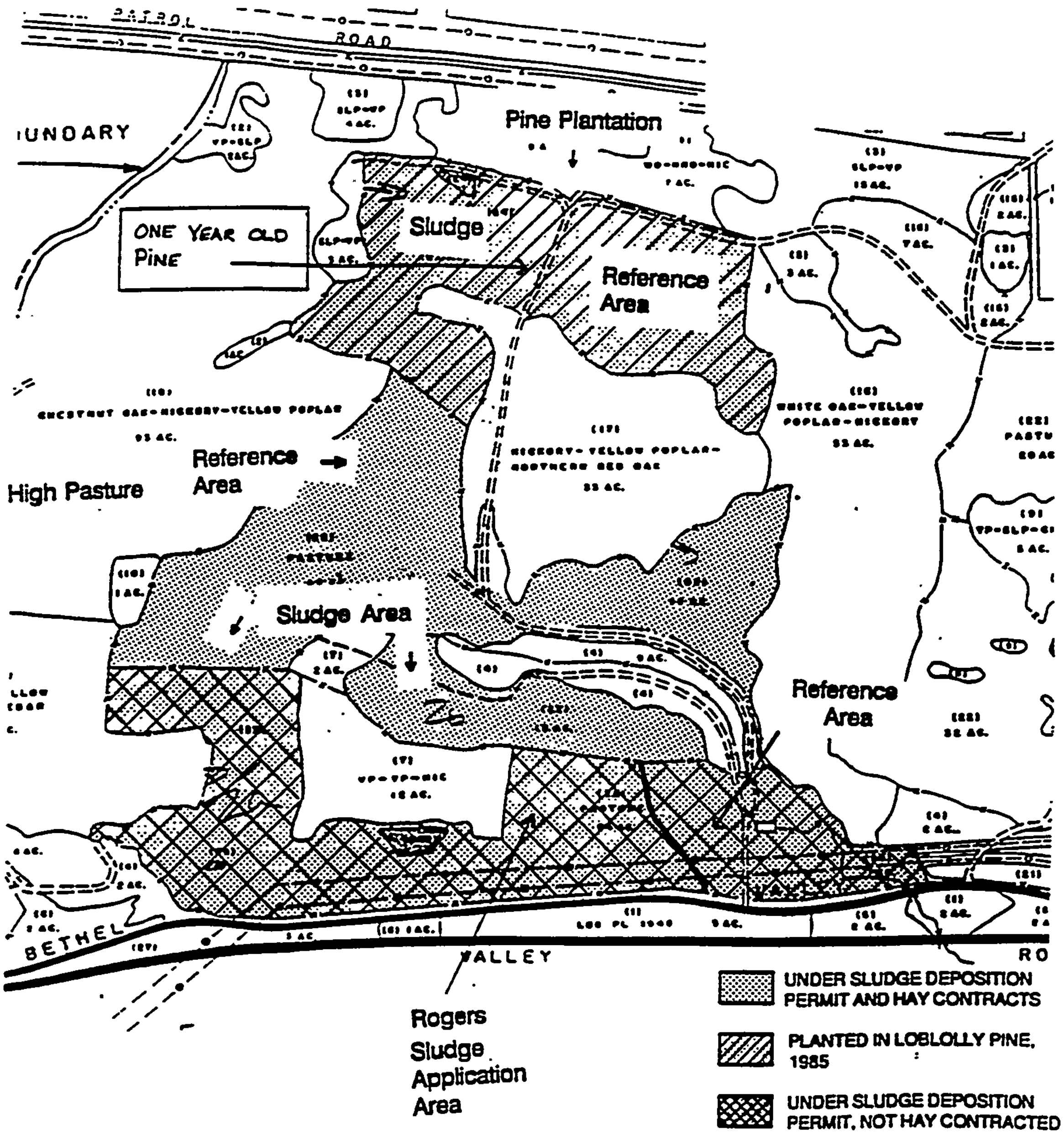

Figure 3.3. Map of area 2: Pine Plantation (top), High Pasture (center), and Rogers site (bottom). Note reference areas as well as sludge application areas (not all permitted areas had sludge applied). Modified from RNL DWG 88-5961.

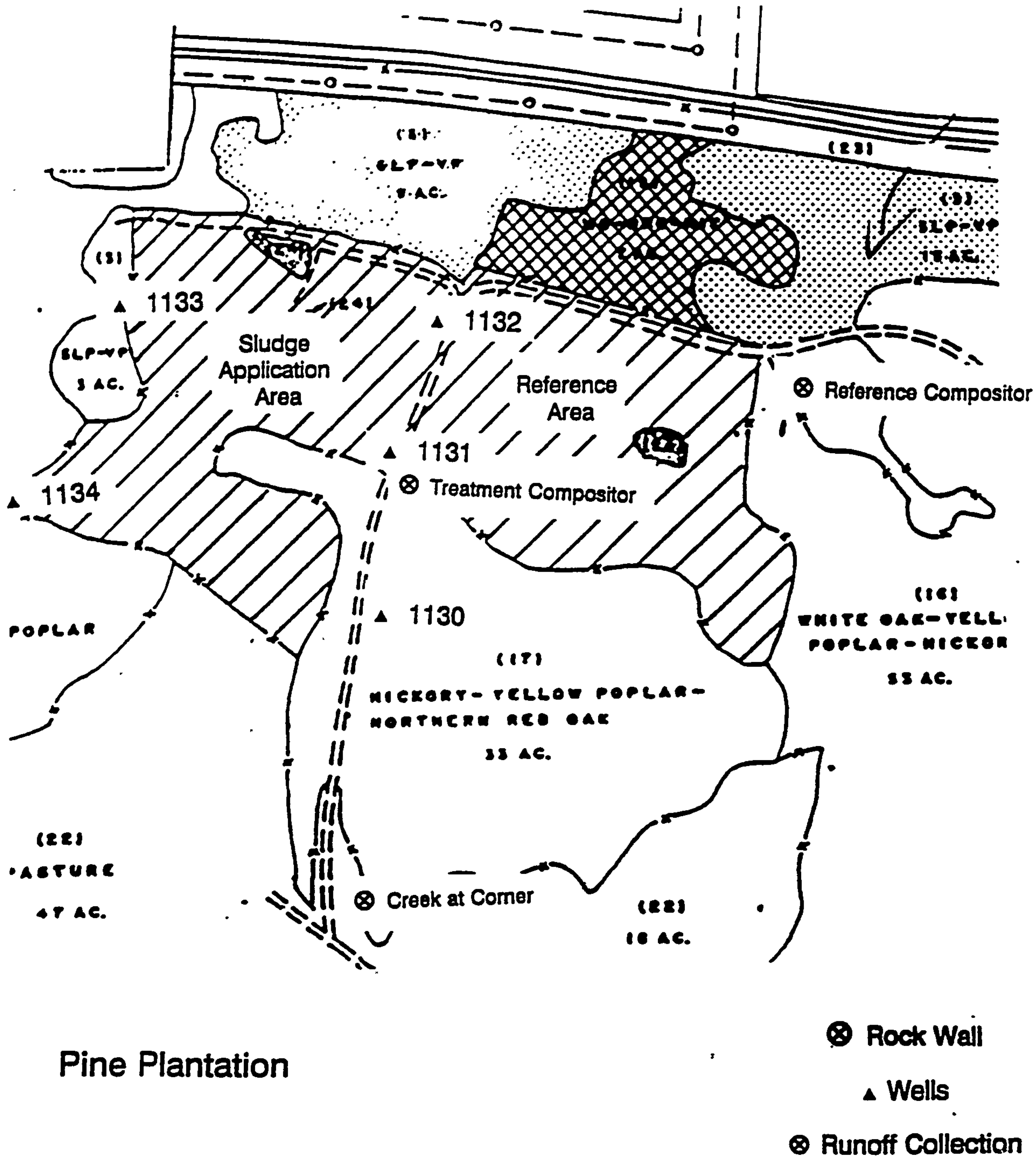

Fig. 3.4. Detail of Pine Plantation showing application area and reference area, wells, and runoff collection sites.

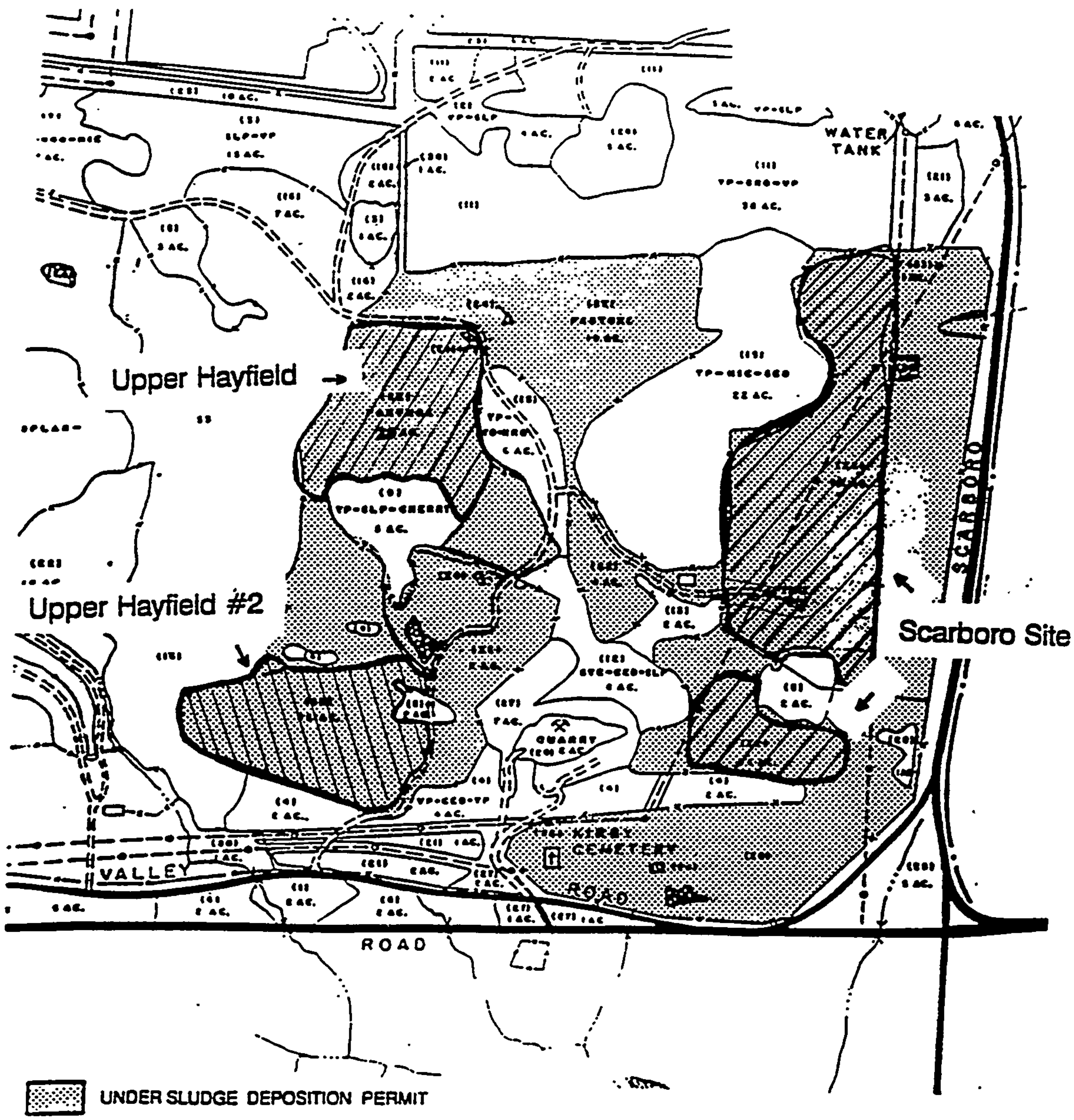

Fig. 3.5. Map of area 3: Upper Hayfield site, Scarboro site (two sections), and Upper Hayfield 2 site. There was not a designated reference area for these three sites, but samples from adjoining unsprayed pasture areas were used as references for all three. Modified from ORNL DWG 88-5962.

3.2.2. McCoy site (number 1 on Figs. 3.1 and 3.2)

During the period of November 1983 through September 1986, sludge was applied to a 29 ha 68 acre) pasture near Bethel Valley Road at Mount Vernon Road referred to as the "McCoy site." Most of the sludge was spread on a 18 ha (45 acre) main application area, with an application rate of approximately 44 Mg/ha (18.7 tons/acre). Sludge was applied directly to the surface and by subsurface injection. The application site was occasionally tilled to a depth of about 15 cm. The site is officially closed. (Additional information on this site, including description and monitoring results may be found in Oakes et al. 1984.)

3.2.3. Rogers site (lower part of site number 2 on Figs. 3.1 and 3.3)

Sludge was applied to this 12 ha (30 acre) pasture site on Bethel Valley Road between September 1986 and December 1988 by a combination of subsurface injection (10 cm depth) and surface application for a total of 48.2 Mg/ha. Monitoring was done at three slope positions (upper, middle, and lower portions of the slope). After June of 1988, most sludge went to the Pine Plantation site described below, except during wet weather. A small portion of the sludge applied to the eastern portion of the Rogers site was mixed with cement kiln dust as a thickener and pH adjustment (liming substitute). A similar pasture further to the east on Bethel Valley Road was available as a reference (Fig. 3.3). This site is officially closed.

3.2.4. Pine Plantation site (upper part of site number 2 on Figs. 3.1 and 3.3, also Figs. 3.3 and 3.4)

This 10-ha (25-acre) plantation of 4-year-old loblolly pine (*Pinus taeda* L.) trees growing on Chestnut Ridge was sprayed with 27 Mg/ha, applied over the canopy with a spray nozzle mounted on the delivery vehicle. This site was used between June 1988 and June 1989 and was set up as an experimental system to assess the effects of sludge application on growth of pine and quality of groundwater. The sludge application area was subdivided into sections with sludge only and sections with either sawdust application (to temporarily immobilize nitrogen) or herbicide application (to reduce growth of weeds within the pine stand, reducing total N uptake into plants and potentially causing N to be leached more rapidly from the system). Monitoring was done by plot within each treatment section and at three slope positions (upper, middle, and lower portions of the slope). Three 20 m by 30 m plots were set out in each sludge treatment section (one per slope position). Three reference plots were also included in the experimental design. This site is officially closed.

3.2.5. Cottonwood site (number 11 on Fig. 3.1)

This 7-ha (17-acre) site of cottonwood saplings was used three times, beginning June through September 1989, and again January and February 1990, and April through May 1991, for a total of 8 months. Sludge was sprayed into the stand from roads within the stand as in the pine plantation. No sludge has been applied to this site since 1991, but the cumulative loading rates have not been exceeded, and it is not officially closed. Total application has been 25.4 Mg/ha.

3.2.6. Site 8 (part of site number 8 on Fig. 3.1)

This 4.8-ha (12-acre) site was used only in March and April of 1990. Approximately 40 dry tons of sludge were applied to this site by surface application. This site was abandoned because sludge accumulated on the surface leaf litter and moved down the slope. No monitoring data are available from this site.

3.2.7. Watson Road site (number 9 on Fig. 3.1)

Approximately 16 ha (40 acres) of woodland at this site (partly mixed hardwood and partly mature loblolly pine plantation) has been used for sludge application by spraying into the woods with the truck-mounted spray nozzle. This site has been used four times: from September to December 1990, from June through October 1991, from August through December 1992, and again, July through December 1993. A total of 29.7 Mg/ha had been applied through 1993. The site is still in active use by the ongoing sludge application program.

3.2.8. Scarboro site (eastern portion of site number 3 on Figs. 3.1 and 3.5)

Approximately 18 ha (45 acres) of this large hayfield site have been used for surface application of sludge, beginning in August 1990. Application continued until October of that year, was repeated during January/February and June/July of 1991, and again from November 1991 until May 1992. Sludge was again applied January through July of 1993. During some of these time periods, but on different days, sludge was also applied to Upper Hayfields 1 and 2. Total sludge applied to the Scarboro site by the end of 1993 was 19.8 Mg/ha. This site is still active.

3.2.9. Upper Hayfield, or Upper Hayfield l, or "the Wet Weather site" (northwest portion of site number three on Figs. 3.1 and 3.5)

This 10-ha (25-acre) hayfield has been used intermittently since December 1986, originally only when the soil was too wet on the somewhat steeper regular site (Rogers) for the application vehicle to maneuver safely and then as part of the overall site rotation schedule. Sludge was applied from December 1986 to April 1987, from December 1988 through April 1989, and August through December 1989. The site was used again in February 1990, February through March 1991, March through May 1992, and again from January through June 1993, all by surface application (spraying). Despite the long period of time that sludge has been applied (intermittently), the sludge applied to this site through 1993 had been only 30 Mg/ha. This site is still active.

3.2.10. Upper Hayfield 2 (southwest portion of site number 3 on Figs. 3.1 and 3.5)

This 8-ha (20-acre) hayfield near Upper Hayfield 1 has been in use since November/ December 1989. It was used again in March and April 1990, April and October/November 1991, from March to May 1992, and again in 1993, from January through July. A total of 30.5 Mg/ha was applied through the end of 1993. This site is still active.

3.2.11. High Pasture site, or Rogers High Pasture (middle section of site number 2 on Figs. 3.1 and 3.3)

This 10-ha (25-acre) hayfield was first used for sludge application between May and July 1990, when the annual allowable loading rate, based on N, was exceeded by 0.5 ton/acre (the 12-month running average concentration of N limited loading to 4.1 ton/acre during this period). No sludge was applied to this site in 1991, but application resumed from May to August 1, 1992. No sludge was applied in 1993 because of site access problems, but the site is still part of the ongoing sludge land application program. A total of 18 Mg/ha of sludge had been applied to this site through 1993 by surface application.

3.3 MONITORING AT EACH SITE

The scope and intensity of the formal monitoring program varied over its lifetime as specific questions arose and as others were answered. Table 3.1 indicates the media which were monitored at each site and for which data are available. Those data are discussed in subsequent sections of this report. Table 3.1 also summarizes the application information from each site.

The majority of the initial monitoring data from the McCoy site were collected after sludge application had ended, although some data was collected in March 1984. At that time, radiological sampling of soil and air was performed because it was determined that the sludge then being applied was contaminated with ^{137}Cs and ^{60}Co (Oakes et al. 1984). Post-application sampling addressed soil levels of metals, nutrients and radionuclides, as well as stream and sediment levels of these parameters plus organics. Soil water, groundwater, and surface runoff were analyzed for metals, nitrates, organics, and radionuclides. Runoff was analyzed for fecal coliform bacteria. Specific sampling methods will be addressed in later sections on soil and water.

The Rogers and Pine Plantation sites were the most thoroughly monitored sites. Data were collected from soil and vegetation, from soil water (using lysimeters), from groundwater (wells, Pine site only), and surface runoff. Sampling was performed before (Pine only), during, and after sludge application. Soil, groundwater, and surface runoff from the Cottonwood site were also analyzed. Later sites (Watson Road, Scarboro, Hayfields, and High Pasture) were monitored chiefly for changes in soil chemistry, which is the only environmental monitoring required by state regulations. Limited measurements of surface runoff at the Watson Road site were also made. Monitoring of sludge characteristics (chemistry and radionuclide analysis) has also continued throughout the application and monitoring program.

3.4 APPLICATION RATE AND CUMULATIVE LOADING OF SPECIFIC CONSTITUENTS: COMPARISON WITH REGULATORY LIMITS

The cumulative sludge application rate, in Mg/ha (dry weight), is given in Table 3.1 for each site, as of December 1993. At that point, the greatest application rate had been to the Rogers site (44 Mg/ha), and the least to the High Pasture site (18 Mg/ha).

Annual sludge application, as mentioned previously, is limited by the total nitrogen concentration in the sludge based on the fertilizer requirements of the vegetation growing on the site, according to state guidelines in the land application permit. Based on the average nitrogen concentration in the sludge, the average allowable annual sludge application rate was 9.8 Mg/ha per year (4.38 tons/acre). Actual annual application rates for each site were determined using the 12-month running average nitrogen concentration.

The cumulative loading rates for each of the regulated metals mentioned in Sect. 2.4 can be calculated from the average concentrations of each of these metals during the active application period for each site (Table 3.2) and the total sludge loading rates in Table 3.1. Those calculated loading rates for each site are given in Table 3.3 along with the regulatory limits from Table 2 of 40 CFR § 503.13. As this table shows, none of the site loading rates have approached the regulatory limits.

4. SOIL

4.1 METHODS OF SAMPLING AND ANALYSIS

Soil core samples were taken periodically (see results for sampling dates at specific sites) from each of the sludge application areas and from reference plots adjacent to or near the application plots that were similar in terms of topography and vegetation type. Samples were taken with a stainless steel soil probe or auger, generally from the upper 0-15 cm of the soil, but in some cases also from deeper soils, and occasionally in smaller increments in the shallow soils. For most samples, six to ten cores taken from each topographic area of a site were composited prior to chemical analysis (Van Miegroet et al. 1989). For sites where samples were taken at multiple slopes positions, position did not affect soil metal concentrations (Van Miegroet et al. 1989), and averages were calculated across all slope positions. Soil analyses included pH, total Kjeldahl nitrogen (TKN), cation exchange capacity, metals, and radionuclides. Inductively coupled plasma atomic emission spectrometry (ICP) provided some elemental analyses (e.g., metals) with later analyses for cadmium done by graphite furnace AA to improve the detection limits. TKN, pH, CEC, and ICP analyses were done by ORNL Analytical Chemistry Division, A&L Agricultural Laboratory, Memphis Tennessee, University of Georgia Soil Testing and Plant Analysis Laboratory, and/or by Analytical Resources in Seattle, Wash. Total uranium was measured by Elbert Carlton, ORAU, by the neutron activation method. Other radionuclides were measured by I. L. Larsen, ORNL Environmental Sciences Division, by gamma ray spectrometry.

4.2 RESULTS

4.2.1 Soil Conditioning: Nitrogen, pH, Cation Exchange Capacity

The major benefit of land application of municipal sewage sludge is the fertilization and improvement of soil physical properties (soil conditioning) resulting from the high organic matter and nutrient content of the sludge, as illustrated in Table 2.1 (e.g., N, P, K concentrations). Table 4.1 compares the concentrations of total soil nitrogen (Kjeldahl method) at eight sludge application sites and their associated reference areas. In all post-treatment soils analyzed, N levels were slightly higher in the top 0 to 15 cm of sludge-amended soils than in reference soils, 1 month to 12 years after sludge application. Because of high variability in the N values, however, the higher N concentration was statistically significant only at the Sycamore site.

At the Pine Plantation site, the sludge-application plots had lower N concentrations than did the reference plots before the applications began (pretreatment values, Table 4.1), and this relationship was reversed in the upper soil layer (0 to 15 cm) after one year of sludge application. A comparison of the soil N concentrations before and after sludge application on a plot by plot basis (plots described in Sect. 3.2, paired t-tests) shows that the N concentrations were significantly higher after sludge application in the top 0 to 15 cm (Table 4.1). The Pine Plantation sludge application area was divided into plots with and without sawdust application (to immobilize and retain the N) or herbicide application (to reduce understory vegetation and potentially cause N to be lost from the system). See Sect. 3.2. However, there were no differences in post-application soil N among any of the sludge-treated plots in the Pine Plantation experiment, regardless of additional treatment. The data from the "sludge-only" plots are presented in Table 4.1., but post-treatment N concentrations were significantly higher than the pre-treatment concentrations in all three sludge treatments. Table 4.4 shows the mean N concentration across all three types of sludge treatment plots.

Additional measurements of soil nitrogen, as well as soil pH and cation exchange capacity, are presented in Table 4.2 from soil samples taken in January of 1991 showing residual effects from past application on the Rogers and Pine sites, and effects of more recent sludge application on the Cottonwood plantation site and the four grassy sites designated Scarboro, Hayfield 1, Hayfield 2, and High Pasture. As noted before, soil nitrogen concentrations were slightly, but not significantly higher in sludge-application areas. There were no apparent trends in either CEC or soil pH with sludge treatment, although differences were statistically significant (Table 4.2) in three cases: one higher CEC, one lower CEC, and a lower pH in one case.

4.2.2 Metals and Radionuclides

The land application of sludge may be expected to increase soil concentrations of elements such as Ca, Zn, Cu, and Cd, depending on the concentrations in the sludge and the loading rates used. For example, at the Rogers site an increase in soil concentrations of Ag, Cd, Cr, Cu, K, P, Pb, and Zn may be expected based on calculations of average concentrations in sludge during the application period (Table 3.2) and the amount of sludge applied to the site (Table 3.1). Table 4.3 confirms concentrations significantly higher in sludge-treated soils than in reference soils for Ca, P, Zn, U, and Cs (only in the top 15 cm), some increase in Zn (not significant), and much smaller (not significant) changes in Cd, Cu, or Pb.

In general, a comparison of sample and reference soils from each of the sites sampled indicates that sludge application may increase the concentrations of some metals in the upper 15 cm of the soil (Table 4.3, 4.4, 4.5, and 4.6) but not usually significantly (at the p=0.05 level, with a sample size of 3 to 9). At the Pine Plantation site, only Cu, Zn, Hg (Table 4.4), ^{60}Co, and total U (Table 4.5) were significantly higher in the sludge-treated plots, again, only in the upper 15 cm. Additional sectioning and radionuclide analysis of the Pine Plantation soil from samplings in July 1989 and May 1990 showed that elevated levels of ^{137}Cs were largely confined to the upper 2 cm initially but that U and ^{60}Co had moved into the 2 to 7 cm strata (Boston et al., 1990). By May 1990, the majority of the U, ^{137}Cs, and ^{60}Co was still in the upper 7 cm of the soil, but there was some evidence of radionuclide movement into the 7 to 15 cm depth in individual soil cores, although average concentrations were not higher (Boston et al., 1990).

The soil samples taken at the Cottonwood and Upper Hayfield 1 and 2 sites in January 1991 (see also Table 4.2) were also analyzed for metal concentrations (Table 4.6). As at the other sites, some metals were slightly higher in the sludge application areas. However, only Cu and Zn concentrations at the Scarboro site were significantly higher, and four metals were significantly *lower* in concentration at this site. Statistical comparisons were not done for Hayfields 1 and 2.

Radionuclides were also measured in soil samples taken from five sites in 1992 and 1993. Table 4.7 shows ^{99}Tc, ^{90}Sr, and total uranium concentration in these soils, as the mean ± the standard deviation. The levels tended to be slightly higher on the sludge-treated sites than on the reference sites but in most cases only slightly higher. Mean pCi/g of ^{137}Cs and ^{60}Co are shown in Table 4.8, along with the naturally occurring ^{40}K. The values for ^{137}Cs and ^{40}K were similar on both the sludge-treated and reference sites in most cases. Cobalt-60, although low on sludge-treated sites, was usually not detectable at all on the reference sites. The radiation from added ^{60}Co and ^{137}Cs is, in any case, much lower than the radiation from the naturally occurring ^{40}K.

Radionuclides analyzed in soils from sludge application sites can also be compared to other non-application areas within Oak Ridge. Background soil characterization for the Oak Ridge Reservation has been reported in document DOE/OR/01-1175/V2, ESD Publication Number 4144, October 1993. Soil sections in 5 cm intervals from the surface to a depth of 30 cm were collected at various locations and analyzed for radionuclides. ^{60}Co was absent from these samples but fallout ^{137}Cs as well as natural radionuclides were present. ^{137}Cs surface soil concentrations (0-5 cm) ranged from approximately 0.4 to 4 pCi/g and concentrations of ^{238}U and ^{235}U values in surface soils ranged from not detected to a high of nearly 11 pCi/g and 0.9 pCi/g, respectively.

4.2.3 Organics

Analyses for organic contaminants in soil, i.e., pesticides, PCBs (USEPA methods 8080/8081), base neutral and acid compounds (USEPA method 8270), were performed on several occasions by Eckenfelder Inc., Nashville, Tenn. In general, none of the organics tested for have been detected in the soils. An exception to this was in the soils collected on May 12, 1993, from the Scarboro (2 samples) and Upper Hayfield 1 (2 samples) sites (sites being actively used at that point) and nearby reference areas (2 samples). Three of four samples from sludge-treated areas had detectable concentrations of pesticides: heptachlor epoxide [one sample, 4.9 mg/kg soil; method detection limit (MDL) 2.5 mg/kg], alpha-chlordane (one sample, 7.2 mg/kg; MDL 2.5 mg/kg), and gamma-chlordane (2 samples, 6.9 and 4.9 mg/kg; MDL 2.5 mg/kg). No other pesticides or semivolatile organic compounds were detected (96 compounds were analyzed for). Neither reference sample had detectable concentrations of any of the organics.

4.3 SUMMARY

In general, the application of Oak Ridge municipal sewage sludge on the Oak Ridge Reservation has improved soil fertility [P, N, etc.; see also Van Miegroet et al. (1989)] slightly and has not had an adverse effect on the soils in terms of metals, organics, or radionuclide contamination. The metals tend to be rapidly immobilized and retained in the upper 15 cm of the soil, (see also Van Migroet et al. 1989) and those metals that are elevated in the treatment soils are not generally present at levels significantly above those found in other soils in the U.S. (Chang, Logan, and Page 1986).

5. VEGETATION

5.1 METHODS OF SAMPLING AND ANALYSIS

To address the issue of constituents from sludge entering the food chain, vegetation samples were taken from several sludge application sites between 1988 and 1990. Samples were taken after, and in some cases also before, sludge application. These samples were analyzed for uptake of metals and radionuclides from the soil. Samples of grasses were taken from the Rogers and Hayfield sites, and extensive sampling was done on the Pine plantation site, including "weeds" (vegetative parts of the herbaceous understory, predominantly grasses) and "berries" (primarily blackberries from bushes growing in the understory), as well as needles from the pine trees. Vegetation was clipped from a 1 m^2 area, rinsed with distilled water to remove caked sludge, and dried. Needle samples were obtained from branches snapped off along a transect at mid-crown level and included needles from all age classes.

Analyses of metals were by ICP with some additional analyses for cadmium by graphite furnace atomic absorption spectrophotometry to improve detection limits. Nitrogen and ICP analyses were done by either ORNL Analytical Chemistry Division, A&L Agricultural Laboratory, Memphis, Tenn., or Analytical Resources, Inc., in Seattle, Wash. Total uranium was measured by Elbert Carlton, ORAU, by the neutron activation method. Radionuclides were measured by I. L. Larsen, ORNL Environmental Sciences Division, by gamma ray spectrometry.

5.2 RESULTS

Tables 5.1 through 5.3 present the data on concentrations of metals, nitrogen, and other analytes in vegetation growing on several sludge sites and their reference areas. Concentrations in herbaceous vegetation growing on the Rogers and Hayfield sites, as well as in the weedy understory beneath the Pine Plantation site (Table 5.1a–c), are indicative of the metals which would be available to grazing animals, although only wild animals have access to the sites in the land application program. Table 5.2 shows the concentrations found in pine needles at the Pine Plantation site on three sampling dates: during sludge application, one month after application ended, and one year later. Table 5.3 shows the concentrations in blackberry fruits (and thus theoretically available directly to humans or animals) growing on bushes in the understory of the Pine Plantation one year after application ended. For the Rogers site, during actual sludge application, concentrations were somewhat higher on treated sites than on reference sites for several plant nutrients, such as N, P, K, Ca, Mg, and Fe (Table 5.1a). Concentrations of Ag, Cu, Na, Pb, and Zn were also higher. (No statistical comparisons were performed). Higher concentrations during or immediately after active application periods, however, when sampling was not restricted to post-application growth, could reflect either uptake of soluble forms of the analytes or sample contamination by sludge clinging to leaf surfaces despite rinsing. This is also true of the weeds under the Pine Plantation (Table 5.1c) during application and even one month after application when concentrations of Al, Ca, Cu, Fe, Mg, N, P, S, and Zn appeared to be substantially higher in treated vegetation. At the same time, biomass of the weedy understory vegetation in the Pine Plantation was substantially higher in the sludge application plots during the application period (Fig. 5.1), probably reflecting higher availability of the nutrients found in sludge. Post-application sampling of weeds and grasses (Table 5.1a and b) showed fewer differences in nutrient or metals concentration in foliage, with slightly elevated levels of Ca and P at the Rogers site two years post-treatment (Table 5.1a) and higher Cu, Mg, Mn, P, Zn at the Hayfield site (Table 5.1b) five months after application ended. Some differences in concentrations at the reference sites (e.g. of Al or Cu) between sampling periods may reflect a difference in analytical laboratories.

Concentrations in pine needles of some metals, notably Al, Cu, Fe, and Na, appeared higher during sludge application, but these differences decreased one month post-treatment and were generally gone one year later, suggesting no sustained uptake of these metals from the soil by pines (Table 5.2). Concentrations of Mn and Zn remained elevated in pine needles, however, after the application period ended.

Metal uptake and translocation into berries was minimal, based on samples taken 1 year after treatment (Table 5.3). Concentrations of Co, Mn, Ni, and Zn, however, were apparently elevated in berries from the sludge-treated site.

Radionuclides, in pCi/kg, were also measured in grasses and in pine needles (Table 5.4). Statistical analyses were not performed, but grass at the Rogers and Hayfield sites appeared to be slightly enriched in ^{137}Cs and the naturally-occurring ^{40}K, particularly just as application ended, and slightly enriched in U two years after application at the Rogers site. New growth pine needles 1 year after application ended were slightly higher in ^{137}Cs, ^{60}Co, and U than were needles on the reference plots. Many radionuclides, particularly ^{60}Co, were present below the detection limits in samples from both sludge and reference sites.

6. SOIL WATER

6.1 METHODS OF SAMPLING AND ANALYSIS

Ceramic cup tube lysimeters placed at various depths were used to monitor soil water at several of the sludge application sites, including the Rogers site, the Pine Plantation site, and the Cottonwood site. Three types of lysimeters were used: shallow lysimeters (designated as "A" lysimeters), sampling soil water at 10 to 15 cm, 3-foot lysimeters that sampled soil water from 40 to 60 cm ("B" type), and deep lysimeters (6-foot, or type "C"), sampling soil water from 120 to 150 cm from the surface. Not all types of lysimeters were used at all sites, and even on the Pine Plantation site where all three types were in place, not all types were sampled throughout the project. The "B" lysimeters were sampled throughout and at all three sites, and these are the data on which this report focuses. Soil water pH, conductivity, alkalinity, nitrate nitrogen, ammonium nitrogen, TKN, and total P in the water from these lysimeters were measured in the laboratory [Environmental Sciences Division (ESD), ORNL], and samples were also analyzed by ICP (University of Georgia and/or Analytical Chemistry Division, ORNL) and radionuclides by gamma ray spectrometry, or ICP/mass spectrometry, and neutron activation at ORNL and ORAU, respectively.

The Pine Plantation site had lysimeters at all three depths and at three slope positions in each plot. The experimental design involved four separate treatments with three plots (replicates) in each. One set of plots had sludge application only ("S"), one had sludge application plus sawdust ("D", which would theoretically retain the nitrogen longer), and one had sludge plus an herbicide treatment of the understory vegetation ("H", which would theoretically decrease competition for nutrients between the pines and understory weeds, and possibly release more nutrients to the soil water). One set remained as a reference ("R") with no sludge applied. The "B" lysimeters were monitored during the sludge application period (June 1988 and June 1989) and through April 1990, ten months after application ended. Metals were monitored only through February 1990. Data presented are the mean concentrations in each set of plots, along with the range of all values that were above the detection limits.

The "C" lysimeters (6-foot, sampling soil water from 120 to 150 cm below the surface) at the Pine site were monitored only October 1989 through April 1990, after the application had ended. Water volume in these deep lysimeters was sometimes inadequate for all analyses to be performed.

At the Rogers site, almost all of the samples analyzed were from 3-foot lysimeters, which were placed in both sludge-treated and untreated reference areas. Samples were analyzed for water chemistry, nutrients, selected metals, and additional metals by ICP. Not all samples yielded sufficient volume for all analyses. Cottonwood site lysimeters were also of the 3-foot type.

6.2 RESULTS

Table 6.1 shows the metals concentrations (6.1a) and additional soil chemistry data (6.1b) for the "B" lysimeters for each of the four treatment plots in the Pine Plantation. Lysimeters from all three sludge application plots showed elevated concentrations of Ca, K, Mg, Mn, Na, and Zn (Table 6.1a). Mean concentrations in the sludge lysimeters ranged from approximately 5 times (Na and Zn), to 10 to 20 times (Mg, Ca, and K), and 50 to 100 times (Mn) the concentrations in the reference lysimeters. Concentrations of other elements were similar in sludge-treated and reference areas or were not clearly higher. For example, for Al the mean for S plots (but not D or H) was higher but the range of values overlapped significantly, and for Cd no samples from the reference lysimeters had values above the detection limits, but few sludge-treated samples were above these limits either, and all concentrations were very low. Mercury was not detected in any of the samples. "B" lysimeters from sludge-treated sites also had higher conductivity (Table 6.1b), higher nitrate and ammonium nitrogen, and higher total nitrogen and total phosphorus. Mean nitrate concentrations in the sludge lysimeters ranged up to 68 mg/L, compared to 0.15 mg/L in the reference lysimeters.

Table 6.2 shows the data from the "C" lysimeters at the Pine Plantation. Although the means for some metals (Table 6.2a) appeared higher in the S, or sludge-only treated plots, in most cases the range of values for "S" and "R" plots overlapped substantially. This is not true for Ni or Zn, but since neither Ni nor Zn was elevated in the "B" lysimeters, it is more likely that this resulted from the very small sample sizes. None of the metals or other ICP analytes in the "C" lysimeters showed a pattern of higher concentrations in all sludge plots, as some did in the more shallow "B" lysimeters. Other measures of water chemistry (Table 6.2b) suggested a higher conductivity and total N, although sample sizes were still small ($n = 6$ to 12 for "S" and "R" plots, with almost no data for "D" and "H" plots). Means for nitrate and ammonium nitrogen were also higher in the sludge plots, but ranges overlapped those of the reference plots.

Table 6.3 presents the data from the Rogers site, with data on water chemistry, nutrients, and selected metals (see table for methods) from March 1987 through April 1988. Nitrate and total phosphorus data are also presented from the longer sampling period of March 1987 through March 1990). Metals analyzed by ICP are presented for samples taken from March 1987 through February 1990. Nitrate N concentrations were similar to those from the Pine lysimeters (means of 66 and 1.7 mg/L in sludge and reference soil water, respectively), and nutrient levels in general were higher in samples from sludge plots, e.g., NH_4-N, total P, total N, K, Ca, and Mg. Concentrations of most other metals were not substantially elevated, although no statistical analysis was performed. Notably, levels of Cd, Cu, Hg, Pb, Ni were not elevated.

Table 6.4 presents the data on water chemistry, nutrients, and metals in soil water from the Cottonwood site. Sampling was carried out between November 1989 and February 1990. Nitrogen (all forms) was again elevated in the sludge plot lysimeters, as were K and P (by ICP). Ca concentrations were 85 and 24 in the sludge and reference samples, respectively, and Mg, Mn and Na were also elevated. As at the other sites, soil water concentrations of heavy metals were not particularly high.

There was also a limited amount of lysimeter data available from the McCoy and Sycamore sites, limited to data on metals (Table 6.5), showing similar results. Radionuclides in soil water were also measured once in the "sludge-only" and reference lysimeters in the Pine Plantation (Table 6.6), and there was little evidence of ^{137}Cs or ^{60}Co entering the soil water.

7. GROUNDWATER (WELLS)

7.1. METHODS OF SAMPLING AND ANALYSIS

Groundwater sampling was done at the Pine Plantation site, where five Resource Conservation and Recovery Act (RCRA)–type groundwater wells (EPA 1986) were installed prior to sludge application. Wells 1133 and 1134 were upgradient of the sludge application area and can be considered reference wells. One of these (1133) was at 7 m, sampling at the first soil-rock interface, and one (1134) at 57 m deep, at the major bedrock level. Wells 1130, 1131, and 1132 were downgradient from sludge application: two at the edge of the application area (1131 and 1132) and one about 100 m further downgradient of the area (1130). These three wells were all 7 to 8 m deep to intercept the first major soil-rock interface where flow was likely to occur. Locations of these wells are shown in Fig. 3.4.

Except for well 1134, these wells were relatively shallow, and because of the karst geology of the region, might show some degree of infiltration of soil water through fractures and solution cavities in the underlying rock (Van Miegroet et al. 1989). (It should be noted programmatically that sludge land application does not occur where karst formations exist unless at least 15cm of cover soil is present, based on background studies which show the majority of sludge constituents, e.g. metals, are contained in the upper 15 cm of receiving sludge site soils.) Sampling was conducted approximately monthly during, and for up to 19 months after, the sludge application period. During the dry season (July through December) not all wells had enough water to sample, and total number of samples per well was variable.

7.2. RESULTS

Results of the water chemistry, nutrient analyses, and fecal coliform counts, with mean, median, and range of values for each well, are shown in Table 7.1. Table 7.2 has metals concentrations for each well, including mean, range, and number of samples with concentrations above the detection limits for the metal. Table 7.3 shows the radionuclides measured in wells at this site several times during and after sludge application. Most of the downgradient well samples were comparable to the samples in the upgradient wells. The exception was well 1131, which on some occasions had higher levels of fecal coliform, NO_3, total N, and perhaps radionuclides, on one or two occasions. This well was directly in the sludge application area, quite shallow (only 20 feet deep), and may have been sampling soil water directly through a fracture. Peak nitrate concentrations in well 1132 may be clearly seen in Fig. 7.1, which illustrates the concentration of nitrate in all wells plotted against time. Despite the occasional high nitrate concentrations in well 1131, the peak concentration (6.07 mg/L) was still well below the drinking water standard of 10 mg/L. Drinking water standards for metals are also shown in Table 7.2 alongside the data from well 1131 for comparison. These concentrations were not exceeded for well 1131, even though it had the strongest evidence for sludge infiltration based on nitrate and coliform levels. Wells 1130 and 1132, however, were above the manganese standard of 0.05 mg/L on several dates, but this was also true of well 1133, which was upgradient of the application field, suggesting that sludge application was not a factor.

8. SURFACE RUNOFF

8.1 METHODS OF SAMPLING AND ANALYSIS

Surface runoff sampling began in February 1987, with grab samples taken from the McCoy site (application had ended there in 1986) and from the active application area in the Rogers site. Later sampling at these and other sites included sample compositors (Coshocton wheel mechanical proportional-flow samplers) to provide integrated flow samples, as well as grab samples. Samples were taken during or after rain events from surface rivulets, overland flow, standing pools, and creeks running into and out of some sites. Some rain events yielded insufficient sample at some sampling locations, and incomplete data sets occasionally resulted (e.g., no reference at that site for that date, or no sample from the treatment area, or a compositor sample from the treatment area, but only a grab sample from the reference.)

Runoff collection at the McCoy site was conducted from February 1987 through March 1988. Sampling at the Rogers site continued from February 1987 to February 1990. Samples were collected at the Cottonwood plantation site from August 1989 through December 1990, and at the Pine Plantation from July 1988 through February, 1990. Limited sampling was conducted at the Watson Road site from October through December 1990 and at the Scarboro site in December 1990.

Samples were analyzed routinely for water chemistry, nutrients, and metals by ICP. Metals analysis was performed on the total, unfiltered samples, and/or, in some cases, the soluble portion or the particulate portion. Additional analyses for other metals, fecal coliform bacteria, biological oxygen demand, and radionuclides were performed several times. Duplicate samples were analyzed on several occasions, and demonstrated good reproduciblilty of analytical results. Because of the inconsistent nature of the storm events and associated runoff, collections were not always possible from equivalent reference and sample runoff streams. As a result, rigorous statistical analysis was not possible, not all of the data were useful for comparative purposes on a storm-by-storm basis, and the number of samples contributing to each mean was variable.

8.2 RESULTS

Tables 8.1 through 8.4 summarize the water chemistry and nutrient concentrations in runoff at four sites and describe the sampling locations. These tables allow comparison of reference and treatment area runoff samples in several ways. For the Cottonwood site, Table 8.1 gives mean, range, number of samples, and number of paired (both samples available) storm events when the concentration, conductivity, etc., exceeded that in the reference stream. Values were designated as elevated if they were greater than 110% of the reference value for that storm. These data show some elevation in soluble components, particularly in the South Creek samples, which consisted only of water running through the site, whereas the North Creek samples were taken where the runoff had been joined by an additional creek and had less tendency to be elevated.

Table 8.2 gives mean and range for all the treatment streams at the Watson Road site and indicates which treatment area sample locations, if any, were consistently higher for a particular variable. For example, the W1 sample was consistently higher in NO_3, total N, soluble reactive P, and total suspended solids than either of the other treatment creeks, and higher than the reference, whereas W2 and W3 were consistently higher in conductivity and alkalinity than W1 or the reference. In general, the treatment creek(s) not listed as having consistently higher values were comparable to the reference for that component, or, in the case of total P, all three creeks were similarly elevated.

Table 8.3 gives mean, range, and number of storm events when concentrations in the Rogers treatment area runoff exceeded those in comparable reference runoff, separating grab samples from compositor samples and a "worst case" sample from a standing pool in the treatment area. The number of samples analyzed and number compared reflect the fact that there was not always enough water flowing to collect samples at all positions, or there was no standing water on a particular date. Runoff samples from the Rogers treatment area were generally higher in soluble nutrients like NO_3, NH_4, total N, and P, and were higher in conductivity, although they were not necessarily higher in total suspended solids when compared for the same date. Compositor samples from the treatment area tended to be higher in NH_4 than grab samples but lower in NO_3 and total N and P. These patterns were not observed in the reference samples. Another pattern observed in the grab samples was a gradual decline in runoff of all soluble nutrients after sludge application ended, until the last samples (taken in the spring of 1990, slightly more than a year after application ended) were not appreciably different from the reference samples. The samples from the standing pool ranged from much higher, to lower than, or very similar to, the other treatment samples.

Table 8.4 presents runoff data from the Pine Plantation in three ways: (a) mean and standard deviation for the four principal sample locations at the Pine site (grab and compositor),(b) data from all grab sample locations on two typical dates, and (c) all compositor and grab samples for two other dates. Treatment samples were on average (Table 8.4a) higher in all measures of N and P in conductivity and in total suspended solids. Samples in (b) and (c) are arranged from upgradient downward, with P3 and P4 being references upgradient of the site; P1, P2, 1132SP (a spring or surface flow) in the treatment area, and "C at C" and P6 downstream, with possible dilution. For the most part, concentrations (or other measures) can be seen to increase moving down the table into the treatment samples and decrease downstream with dilution as expected.

A one-time grab sample at the Scarboro site (12/17/90) found both treatment samples higher in soluble reactive phosphorus than the reference sample (2.8 and 8.5 versus 0.033 mg/L), somewhat lower in alkalinity (0.3 and 0.46 versus 1.12 μmhos/cm) but no different in suspended solids, pH, or conductivity.

Tables 8.5 through 8.8 present metals concentrations in runoff from the McCoy, Rogers, Pine, and Cottonwood sites, all arranged by sample collection date to allow comparison of concentrations in reference and treatment samples for a particular storm. For the McCoy and Rogers sites, not all dates sampled are presented, but several dates with reasonably complete data were chosen as examples. Compositor as well as grab samples are included where available (Rogers and Pine), and total, soluble, and particulate fractions are all listed where available (McCoy and Rogers sites). Mercury concentrations in runoff from the Rogers site are presented separately in Table 8.9.

Table 8.10 presents radionuclide data from four sites, and Table 8.11 contains biological oxygen demand and fecal coliform data arranged by sampling location and date at three sites.

In general, surface runoff from active sludge application sites tended to have slightly elevated concentrations of some of the soluble constituents, such as nitrate, phosphorus, and the alkali and alkaline earth element ions such as calcium, and sometimes potassium, magnesium, and sodium, and often had higher conductivity. Concentrations of heavy metals such as cadmium, lead, and nickel were not necessarily elevated, and were frequently below detection limits.

Separation of unfiltered samples into soluble and particulate fractions showed that elevated levels of most metals, including any regulated or heavy metals, were usually not found in the soluble fraction (Table 8.5), where they might be of concern in terms of exposure to humans or animals, but in the particulate fraction (Tables 8.5 and 8.6), at least in terms of mg/L contributed by the particulate fraction. Elevated concentrations were usually associated with samples with high suspended solids, that is, samples carrying a larger quantity of soil had higher total concentrations of heavy metals. This was true of both reference and treatment area samples, but because of increased truck traffic and roads, e.g. in the Pine Plantation, the treatment areas were more susceptible to erosion and tended to be higher in suspended solids (Tables 8.1 through 8.4; see especially 8.4). As an example, notice that iron and manganese tended to be high (above drinking water standards) in both treatment and reference runoff and somewhat higher in treatment samples (see total fractions in Tables 8.5 and 8.6), but the soluble fraction (Table 8.5) had negligible concentrations of either.

Concentrations of metals in the particulate fraction itself, in mg/kg, were not usually higher in treatment areas than in reference areas (Tables 8.5 and 8.6) and gave no indication that sludge particles were being transported off the application site even though more soil particles may have been mobilized from application sites.

9. REFERENCES

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Appendix A
METHODS OF SLUDGE ANALYSIS FOR RADIONUCLIDE CONTENT AT ORNL

Samples of sludge were transferred to a 1 liter Marinelli beaker (reentrant beaker) weighed, and if necessary diluted to 1 liter with deionized distilled water. In most instances virtually 1 liter of material was supplied. However, there were a few instances where the material would only partially fill a 1 liter Marinelli beaker, and in these instances, samples were counted in 0.5 liter Marinelli beakers. The sample size in kilograms was then used to quantify the data. One liter of sludge is approximately the same as 1 Kg of sludge. From 1988 through 1990, the majority of the samples were counted for 200 minutes. These samples were then dried and analysis was performed by neutron activation on selected samples for Uranium content. After 1990, the samples were analyzed overnight and the Uranium content quantified by gamma-ray spectrometry. To quantify the U-238, the granddaughter radionuclide Pa-234 m at 1001 Kev was utilized. Because the photon yield from this nuclide is low (< 1%) large uncertainty terms in the quantified value occur especially at low concentrations (< 1 nCi/L). For U-235, the photon energy at 143 Kev was utilized. The Uranium concentrations were reported even though the analytical uncertainties were large in order to indicate the order of magnitude of Uranium present. A comparison with 4 samples analyzed by direct non-destruc tive gamma-ray spectrometry and then by alpha spectrometry is given in Table A.1. Quantification of additional radionuclides were accomplished utilizing the following photon energies. Co-60, 1173 & 1332 Kev; Cs-137, 662 Kev; I-131, 364 Kev; Be-7, 477 Kev; K-40, 1461 Kev; Ra-228 (Ac-228), 911 Kev.

Analyses were performed on an intrinsic germanium (IG) detector having a relative efficiency and resolution (FWHM) at 1332 Kev of 25% and 2.0 Kev, respectively. The detector was mounted inside a lead shield and coupled to a Nuclear Data 6700 microprocessor programmed to acquire spectra in 4096 channels. Corrections for ambient background peaks associated with the system were made from a spectrum counted for a duration longer than the sample count. Software routines for quantifying data were those of the vendor, Nuclear Data, Inc. Efficiency calibration of the detector utilized Amersham mixed gamma standard (QCY 46 or 48) series with traceability to NIST. A known quantity of this material was diluted in a 4 M HCl in the Marinelli beaker and counted for an appropriate amount of time to minimize counting uncertainties. Verification of calibration was performed by analyzing QA/QC samples distributed by the EPA at Las Vegas, Nevada.

Table A.1. Comparison of uranium isotope data by alpha spectrometry versus direct counting non-destructive gamma-ray analysis on the same sludge sample

	U-235 (+/- 1 sigma)		U-238 (+/- 1 sigma)	
Sample	Alpha	Gamma	Alpha	Gamma
9/25/92	8 +/-20	20.5 +/-7.1	290 +/-80	244 +/-196
9/25-10/1/92	10 +/-20	21.5 +/-8.3	290 +/-70	228 +/-133
10/29/92	20 +/-20	34.1 +/-8.6	390 +/-90	228 +/-133
11/29/92	30 +/-20	14.4 +/-8.3	210 +/-60	227 +/-171

To convert to a dry weight basis: 1 kilogram of wet sludge on average yields 24.5 grams of dry material.

Appendix B
TABLES

Table 2.1. Yearly average concentrations of nutrients and metals in Oak Ridge sewage sludge from 1988 through 1993. Data from A&L Laboratories and ORAU (see text). Concentrations are in % or mg/kg as indicated, on a dry weight basis. The number of monthly samples contributing to each mean is given by *n* for 1988 and 1989. For 1990-1993, 12 samples contributed to each mean except as indicated. Instead of *n*, the sample standard deviation (*Std*) is given for these years. Blank cells indicate no data available.

		1988		1989		1990		1991		1992		1993	
		Mean	n	Mean	n	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Solids	%	2.13	3	2.53	11	2.63	1.02	2.47	0.27	2.64	0.38	2.78	0.32
Kjeldahl N	%	9.19	4	8.07	11	7.84	0.56	8.26	1.87	7.74	0.68	7.18	0.92
NH_4 N	%		0	3.70	11	3.71	0.44	3.18	0.32	3.09	0.41	3.15	0.96
P	%	2.87	6	2.77	11	2.84	0.43	2.97	0.23	2.96	0.35	3.18	0.39
K	%	0.66	5	0.64	12	0.42	0.17	0.47	0.17	0.42	0.10	0.45	0.07
Fe	%	1.90	2	1.85	12	1.90	0.39	1.83	0.15	1.50	0.24		
Ca	%	3.70	4	3.64	11	4.02	3.48	4.04	0.90	4.09	1.81	3.42	0.31
Mg	%	0.60	4	0.49	12	0.44	0.11	0.50	0.04	0.44	0.06	0.45	0.05
Na	%	0.21	2	0.16	12	0.30	0.33	0.39	0.20	0.25	0.09	0.29	0.13
NO_3 N	mg/kg		0	13.6	9	117.5	176	9.8	7.8	14.5	7.0	19.3	9.4
Ag	mg/kg	123.3	3	111.0	12	115.2	11.7	111.0	8.3	108.2	3.6		
As	mg/kg	5.60	1	4.49	12	6.06	5.79	4.05	0.69	3.44	0.79	5.90	5.86
Ba	mg/kg	790	3	728	12	933	134	1012	93	861	93		
Cd	mg/kg	9.92	6	6.75	11	8.93	3.22	7.94	2.75	11.65	3.65	10.37	1.65
Co	mg/kg	17.00	1	11.23	12	18.42	6.15	25.20	5.83	9.76	3.09		
Cr	mg/kg	215.8	6	174.0	12	152.7	71.2	138.6	33.5	160.3	58.6	153.6	28.7
Cu	mg/kg	576.7	6	495.5	12	482.3	65.7	478.8	24.5	472.9	77.4	460.8	83.2
Hg	mg/kg	16.00	2	9.00	12	9.67	5.06	14.54	3.89	8.58	2.74	9.13	3.01
Mn	mg/kg	667	4	1930	12	1490	538	1669	158	1174	523	1269	(*n*=2)

Table 2.1 (continued)

		1988		1989		1990		1991		1992		1993	
		Mean	n	Mean	n	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Mo	mg/kg	60.0	1	18.0	11	28.3	14.4	25.2	9.4	24.4	4.8	27.1	4.08
Ni	mg/kg	66.0	6	40.1	11	50.7	14.8	41.6	7.5	37.3	7.6	40.2	5.3
Pb	mg/kg	167.5	6	116.0	11	80.7	12.5	85.8	12.5	80.2	28.4	69.3	17.0
Se	mg/kg		0	6.96	10	5.70	1.14	7.69	2.45	6.68	1.25	7.61	4.12
U*	mg/kg	165.0	1	85.4	12	40.5	8.8	33.9	4.2	31.5	1.1		
Zn	mg/kg	2001	6	1703	12	1771	310	1731	334	1649	240	1698	188

* U as ^{238}U, pCi/Kg.

Table 2.2. Mean concentrations of metals in Oak Ridge sewage sludge for each year from 1984 to 1986. Means are based on analyses of *n* weekly samples. Metal concentrations are in mg/kg on a dry weight basis; Total solids is as a percent. Source: Boston, H. L. 1988. Environmental Evaluation for the McCoy Sludge Application Site.

		1984		1985		1986	
		Mean	n	Mean	n	Mean	n
Total Solids	%	3.66	47	2.93	47	2.84	15
Kjeldahl N	%						
NH4 N	%						
P	%						
K	%						
Fe	%						
Ca	%						
Mg	%						
Na	%						
NO3 N	mg/kg						
Ag	mg/kg			114	3	104	4
As	mg/kg			14	3	4.5	4
Ba	mg/kg			1090	3	840	4
Cd	mg/kg	18	47	13	46	11	17
Co	mg/kg						
Cr	mg/kg	843	46	546	47	501	17
Cu	mg/kg	1818	47	835	47	797	17
Hg	mg/kg			11	3	19.5	4
Mn	mg/kg						
Mo	mg/kg						
Ni	mg/kg	203	47	112	46	114	16
Pb	mg/kg	198	47	229	47	233	16
Se	mg/kg			<7	3	6.7	4
U	mg/kg			35	3	59	4
Zn	mg/kg	3138	47	2679	47	2336	17

Table 2.3. Yearly average concentrations of radionuclides in Oak Ridge sewage sludge from mid-1988 through 1992. A sample of sludge was taken from each truckload as it left the treatment plant, and these samples were composited and analyzed on a weekly basis. Values for ^{238}U were often below the detection limit after 1988, but were quite variable. Analyses were done at Oak Ridge National Laboratory (Environmental Sciences Division), by gamma emission spectrometry. Weekly values contributing to these means are shown in Appendix B.

a) Annual statistics are mean (± standard deviation where available) of the 52 weekly samples, except where noted. Concentrations are in pCi/g dry weight.

	1988		1989		1990		1991		1992	
	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n
^{60}Co	5.92	32	2.57	52	3.19 (±2.7)	50	1.02 (±0.7)	52	0.71 (±0.53)	52
^{137}Cs	1.17	32	1.23	52	2.49 (±3.3)	50	1.38 (±1.0)	52	0.48 (±0.21)	52
^{131}I	7.09	32	9.17	52	5.42 (±7.9)	50	9.55 (±19)	52	13.9 (±18.7)	52
^{238}U	81.5	31	20.0	52[1]	6.01 (±15.5)	50[2]	4.94 (±155)	52[3]	3.31	18[4]

[1] 15 values below minimum detection limit were treated as zeroes.
[2] 35 values below minimum detection limit were treated as zeroes.
[3] 6 values below minimum detection limit were treated as zeroes.
[4] 4 values below minimum detection limit were treated as zeroes.

b) Means as in Table 2.3a above, but in Bq/g dry weight.

	1988	1989	1990	1991	1992
^{60}Co	0.22	0.10	0.12	0.04	0.03
^{137}Cs	0.04	0.05	0.09)	0.05	0.02
^{131}I	0.26	0.34	0.20	0.35	0.51
^{238}U	3.02	0.73	0.22	0.18	0.12

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) Radionuclide data for Oak Ridge digested sludge
Weekly integrated samples
Data are in pCi/Kg and Bq/Kg wet wt.
Note: 1 Kg wet sludge is typically about 1 liter
Note: N.D. not detected: Below minimum detection limit
Blank weekly areas indicate no sample

RADIONUCLIDES IN SLUDGE 1993

Date Collected	WEEK	CO-60 Bq\Kg	CO-60 PCi\Kg	CS-137 Bq\Kg	CS-137 PCi\Kg	I-131 Bq\Kg	I-131 PCi\Kg	BE-7 Bq\Kg	BE-7 PCi\Kg	K-40 Bq\Kg	K-40 PCi\Kg	RA-228 Bq\Kg	RA-228 PCi\Kg
12/31-01/07	1	1.05	28.4	0.58	15.6	3.7	100	1.1	30.4	6.5	177	0.94	25.3
01/08-01/14													
01/15-01/21		0.76	20.6	0.46	12.4	26.8	725	1.0	27.8	6.1	164	0.38	10.3
01/22-01/28		0.98	26.4	0.36	15.2	82.0	2217	1.4	36.7	5.8	156	1.05	28.5
01/29-02/04	5	0.83	22.3	0.50	13.5	37.8	1023	1.0	27.3	5.0	136	0.54	14.6
02/05-02/11		0.71	19.2	0.41	11.0	30.1	813	1.6	43.8	4.8	130	0.94	25.3
02/12/-02/18													
02/19-02/25		0.95	25.6	1.11	30.0	42.0	1136	1.3	35.0	8.0	217	1.04	28.2
02/26-03/04		0.71	19.1	0.73	19.8	45.6	1233	0.6	16.7	4.2	114	0.45	12.1
03/05-03/11	10	0.65	17.6	1.10	29.6	44.9	1213	1.0	26.1	5.3	144	0.79	21.4
03/12-03/18		0.94	25.5	0.74	20.0	50.2	1357	N.D.	N.D.	5.2	140	0.64	17.2
03/19-03/25		0.85	23.0	0.75	20.2	49.6	1341	1.5	41.1	3.6	97	0.97	26.2
03/26-04/01		0.92	24.9	0.98	26.5	20.9	564	1.3	34.3	11.2	302	1.23	33.3
04/02-04/08		1.05	28.4	1.08	29.1	9.9	268	0.8	22.9	10.7	288	1.24	33.6
04/09-04/15	15												
04/16-04/22		0.53	14.4	0.71	19.2	36.8	995	2.0	53.4	6.1	165	0.80	21.7
04/23-04/29		0.58	15.8	0.71	19.2	88.6	2394	1.9	51.0	10.0	270	0.55	14.8
04/30-05/06		0.58	15.7	0.76	20.6	52.3	1414	1.4	37.4	10.7	288	0.93	25.1
05/07-05/13		0.54	14.5	0.66	17.9	86.3	2332	1.5	39.4	6.5	175	1.06	28.6
05/14-05/20	20	0.53	14.3	0.70	19.0	85.9	2323	1.6	44.1	1.6	44	0.54	14.5
05/21-05/27		0.58	15.8	0.61	16.5	132.8	3590	1.8	48.0	2.7	72	1.04	28.0
05/28-06/03		0.85	23.1	0.69	18.7	157.1	4247	1.2	32.8	5.3	144	0.54	14.7
06/04-06/10		0.51	13.7	0.43	11.6	100.3	2711	1.4	38.3	4.9	133	0.82	22.1
06/11-06/17		0.51	13.7	0.46	12.5	67.9	1836	1.4	36.5	3.8	102	0.85	22.9
06/18-06/24	25	0.39	10.5	1.35	36.4	37.3	1007	2.3	63.1	4.4	120	0.75	20.2
06/25-07/01		0.28	7.7	0.47	12.7	28.4	769	2.5	68.5	6.1	166	0.57	15.3
07/02-07/08		0.37	9.9	0.37	10.1	15.9	429	2.2	60.1	4.2	113	0.68	18.5
07/09-07/15		0.69	18.6	0.67	18.1	5.6	151	2.5	67.1	7.4	199	1.15	31.1
07/16-07/22		0.88	23.7	0.77	20.7	4.1	110	2.7	72.2	6.7	182	0.89	24.0
07/23-07/29	30	0.30	8.1	0.41	11.2	5.0	134	1.8	49.2	4.8	129	0.77	20.8
07/30/-08/05		0.44	11.9	0.62	16.7	2.2	60	2.0	54.8	4.6	123	0.76	20.5
08/06-08/12		0.29	7.9	0.35	9.4	3.6	98	2.3	61.3	4.7	126	0.85	22.9
08/13-08/19		0.53	14.4	0.51	13.9	3.7	101	2.0	52.9	5.3	143	0.78	21.1
08/20-08/26		0.53	14.2	0.63	17.1	16.7	451	3.2	86.3	4.1	111	1.01	27.2
08/27-09/02	35												
09/03-09/09													
09/10-09/16													
09/17-09/23		0.23	6.3	0.47	12.6	22.6	611	1.1	30.8	3.9	105	0.81	22.0
09/24-09/30													
10/01-10/07	40	0.47	12.8	0.51	13.7	16.4	444	1.2	32.1	1.6	42	0.94	25.4
10/08-10/14													
10/15-10/21		0.27	7.3	0.34	9.3	3.7	101	1.7	45.8	6.8	185	0.88	23.7
10/22-10/28		0.41	11.1	0.47	12.6	3.6	97	1.2	31.3	3.4	92	0.51	13.8
10/29-11/04		0.23	6.3	0.32	8.6	26.8	724	1.1	30.6	3.8	104	0.67	18.2
11/05-11/11	45	0.20	5.3	0.31	8.5	64.2	1735	1.1	28.5	3.9	105	0.51	13.9
11/12-11/18		0.20	5.5	0.29	7.9	54.7	1478	1.3	35.3	3.4	92	0.78	21.0
11/19-11/25		0.31	8.5	0.32	8.6	43.1	1164	1.4	38.6	3.8	103	0.41	11.1
11/26-12/02													
12/03-12/09		0.26	7.0	0.41	11.1	14.0	378	1.3	34.7	4.3	117	0.62	16.8
12/10-12/16	50	0.17	4.6	0.31	8.3	9.7	262	1.7	47.2	4.4	118	0.77	20.8
12/17-12/23		0.37	9.9	0.56	15.1	3.1	84	1.2	33.7	4.3	115	1.03	27.9
12/24-12/30													
MIN		0.17	4.6	0.29	7.9	2.2	60	0.6	16.7	1.6	42	0.38	10.3
MAX		1.05	28.4	1.35	36.4	157.1	4247	3.2	86.3	11.2	302	1.24	33.6
MEAN		0.56	15.1	0.60	16.2	39.0	1053	1.6	42.6	5.3	144	0.80	21.5
STD		0.26	6.9	0.24	6.5	36.1	977	0.6	14.7	2.2	59	0.22	5.9
N=		42	42	42	42	42	42	41	41	42	42	42	42

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1993

Date Collected	WEEK	U–235 Bq\Kg	U–235 PCi\Kg	U–238 Bq\Kg	U–238 PCi\Kg
12/31–01/07	1	0.29	7.8	12.43	336
01/08–01/14					
01/15–01/21		0.45	12.2	13.36	361
01/22–01/28		N.D.	N.D.	13.43	363
01/29–02/04	5	0.33	8.8	17.87	483
02/05–02/11		0.55	15.0	15.17	410
02/12/–02/18					
02/19–02/25		0.65	17.7	17.65	477
02/26–03/04		0.14	3.8	14.58	394
03/05–03/11	10	0.60	16.2	7.21	195
03/12–03/18		0.70	18.8	8.40	227
03/19–03/25		0.69	18.6	26.71	722
03/26–04/01		1.04	28.2	17.09	462
04/02–04/08		1.66	45.0	29.34	793
04/09–04/15	15				
04/16–04/22		0.85	23.1	14.69	397
04/23–04/29		0.93	25.1	18.20	492
04/30–05/06		0.37	10.0	17.17	464
05/07–05/13		0.28	7.6	8.73	236
05/14–05/20	20	0.49	13.3	15.80	427
05/21–05/27		0.26	7.0	13.91	376
05/28–06/03		0.94	25.4	N.D.	N.D.
06/04–06/10		0.28	7.7	0.59	16
06/11–06/17		N.D.	N.D.	N.D.	N.D.
06/18–06/24	25	N.D.	N.D.	N.D.	N.D.
06/25–07/01		0.47	12.8	15.72	425
07/02–07/08		0.64	17.4	8.88	240
07/09–07/15		0.61	16.6	15.17	410
07/16–07/22		2.09	56.5	11.43	309
07/23–07/29	30	0.75	20.4	8.44	228
07/30/–08/05		0.37	10.1	5.11	138
08/06–08/12		0.88	23.9	3.77	102
08/13–08/19		0.73	19.7	15.58	421
08/20–08/26		0.49	13.2	6.84	185
08/27–09/02	35				
09/03–09/09					
09/10–09/16					
09/17–09/23		0.56	15.2	6.22	168
09/24–09/30					
10/01–10/07	40	0.18	4.8	N.D.	N.D.
10/08–10/14					
10/15–10/21		0.56	15.2	7.95	215
10/22–10/28		0.44	12.0	7.47	202
10/29–11/04		0.80	21.6	9.17	248
11/05–11/11	45	0.27	7.3	9.06	245
11/12–11/18		0.71	19.1	12.76	345
11/19–11/25		0.44	11.8	3.63	98
11/26–12/02					
12/03–12/09		0.77	20.8	12.06	326
12/10–12/16	50	0.65	17.6	6.36	172
12/17–12/23		0.67	18.1	15.46	418
12/24–12/30					
MIN		0.14	3.8	0.59	16
MAX		2.09	56.5	29.34	793
MEAN		0.63	17.1	12.20	330
STD		0.37	9.9	5.85	158
N=		39	39	38	38

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1992

Date Collected	WEEK	CO-60 Bq\Kg	CO-60 PCi\Kg	CS-137 Bq\Kg	CS-137 PCi\Kg	I-131 Bq\Kg	I-131 PCi\Kg	BE-7 Bq\Kg	BE-7 PCi\Kg	K-40 Bq\Kg	K-40 PCi\Kg	RA-228 Bq\Kg	RA-228 PCi\Kg
12/27-01/02	1	0.58	15.8	0.63	17.1	43.1	1166	0.6	16.7	5.5	150	0.59	15.9
01/03-01/09		0.68	18.4	0.53	14.2	38.3	1036	1.2	32.1	6.1	165	0.60	16.3
01/10-01/16													
01/17-01/23		0.63	16.9	0.58	15.7	20.0	540	1.6	43.2	7.9	214	0.78	21.2
01/24-01/30	5	0.56	15.2	0.45	12.1	12.1	326	1.1	30.8	6.2	168	0.81	22.0
01/31-02/06		0.57	15.4	0.57	15.4	9.0	244	1.1	29.6	6.4	172	0.91	24.6
02/07-02/13		0.96	26.0	0.55	15.0	14.7	398	0.9	24.3	6.4	172	0.77	20.9
02/14-02/20		0.48	13.0	0.61	16.5	14.0	378	N.D.	N.D.	7.9	213	0.53	14.2
02/21-02/27		0.66	17.9	0.76	20.6	4.5	122	0.6	16.7	5.8	156	0.78	21.0
02/28-03/05	10	0.24	6.6	0.22	6.0	4.2	114	1.1	29.1	5.3	142	0.49	13.3
03/06-03/12		0.33	8.9	0.25	6.7	2.3	63	N.D.	N.D.	5.1	139	0.35	9.5
03/13-03/19		0.28	7.6	0.23	6.2	1.4	37	1.1	29.2	4.5	121	0.23	6.2
03/20-03/26		0.30	8.2	0.26	7.0	1.3	35	0.7	19.6	3.3	90	0.25	6.7
03/27-04/02		0.33	8.9	0.42	11.4	2.5	69	1.5	39.3	5.0	134	0.37	10.0
04/03-04/09	15	0.31	8.4	0.32	8.7	1.9	51	1.5	41.2	6.4	174	0.67	18.2
04/10-04/16		0.29	7.9	0.28	7.6	1.3	34	1.4	37.0	6.0	162	0.84	22.7
04/17-04/23		0.26	7.1	0.22	6.0	0.5	15	1.1	29.9	4.3	117	0.60	16.3
04/24-04/30													
05/01-05/07		0.34	9.1	0.31	8.4	N.D.	N.D.	0.9	23.3	5.3	144	0.70	18.9
05/08-05/14	20	0.36	9.8	0.33	8.9	N.D.	N.D.	1.6	42.7	5.0	134	0.49	13.3
05/15-05/21		0.54	14.7	0.42	11.4	N.D.	N.D.	1.3	34.8	5.8	156	0.58	15.8
05/22-05/28		0.37	10.0	0.31	8.5	0.2	6	1.1	30.3	4.3	117	0.85	23.1
05/29-06/04													
06/05-06/11		0.24	6.4	0.36	9.6	10.5	284	1.4	37.0	5.3	143	0.63	17.1
06/12-06/18	25												
06/19-06/25		0.30	8.0	0.29	7.8	5.1	137	1.2	33.4	3.0	81	0.01	0.4
06/26-07/02		0.19	5.1	0.23	6.1	28.0	756	1.1	30.2	3.8	104	N.D.	N.D.
07/03-07/09		0.28	7.7	0.23	6.1	70.8	1913	1.2	31.3	2.9	77	N.D.	N.D.
07/10-07/16		1.63	44.0	0.41	11.0	40.6	1097	1.2	33.0	3.3	90	1.81	49.0
07/17-07/23	30	0.46	12.5	0.41	11.2	20.0	541	1.2	33.6	2.8	76	N.D.	N.D.
07/24-07/30		0.34	9.1	0.36	9.8	13.6	368	0.6	16.3	4.3	116	0.65	17.7
07/31-08/06													
07/07-07/13		0.41	11.0	0.44	12.0	46.6	1260	1.3	34.6	4.1	112	0.90	24.4
08/14-08/20		0.25	6.8	0.23	6.2	14.4	390	1.0	27.6	2.4	64	0.41	11.0
08/21-08/27	35	0.90	24.3	0.80	21.5	79.8	2156	1.6	44.1	4.1	111	0.83	22.4
08/28-09/03		1.15	31.2	0.60	16.2	39.6	1070	1.0	28.2	4.7	127	1.21	32.6
09/04-09/10		1.38	:37.4	0.49	13.3	44.7	1207	1.8	47.9	5.4	147	0.68	18.5
09/11-09/17													
09/18-09/24		N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	1.9	50.3	4.1	111	0.79	21.3
09/25-10/01	40	1.98	53.5	0.56	15.2	12.8	345	1.2	31.4	3.3	89	0.70	19.0
10/02-10/08		1.50	40.6	0.41	11.2	6.3	169	1.8	48.7	3.0	82	0.55	15.0
10/09-10/15		2.31	62.4	1.13	30.6	2.8	76	0.8	21.6	5.4	145	1.25	33.9
10/16-10/22		1.82	49.1	0.46	12.4	3.2	87	1.1	28.4	4.7	126	0.63	17.1
10/23-10/29		1.47	39.8	0.61	16.5	3.2	88	0.8	21.1	4.1	111	0.49	13.2
10/30-11/05	45												
11/06-11/12		1.14	30.8	0.94	25.5	5.3	142	1.3	35.4	3.1	83	0.46	12.5
11/13-11/19		1.21	32.6	0.71	19.1	4.7	127	1.6	44.2	4.0	107	0.58	15.7
11/20-11/26		1.19	32.1	0.71	19.3	3.5	95	1.4	38.6	6.1	165	0.77	20.7
11/27-12/03		0.94	25.3	0.61	16.5	4.6	124	1.2	32.6	3.6	98	0.55	15.0
12/04-12/10	50	1.12	30.4	0.75	20.2	5.2	140	2.1	55.5	5.0	134	0.80	21.7
12/11-12/17		1.19	32.3	0.77	20.7	5.5	150	2.1	57.5	5.6	152	0.60	16.1
12/18-12/24													
12/25-12/31													
MIN		0.19	5.1	0.00	6.0	0.2	6	0.6	16.3	2.4	64	0.01	0.4
MAX		2.31	62.4	1.13	30.6	79.8	2156	2.1	57.5	7.9	214	1.81	49.0
MEAN		0.74	20.4	0.47	13.1	16.1	434	1.2	33.6	4.8	129	0.67	18.2
STD		0.54	14.6	0.22	5.7	19.3	523	0.4	9.8	1.3	35	0.29	7.9
N=		43	43	43	43	40	40	42	42	44	44	41	41

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1992

Date Collected	WEEK	U−235 Bq\Kg	U−235 PCi\Kg	U−238 Bq\Kg	U−238 PCi\Kg
12/27−01/02	1	0.8	20.5	17.1	461
01/03−01/09		0.4	11.4	12.7	344
01/10−01/16					
01/17−01/23		0.6	15.7	14.4	388
01/24−01/30	5	0.9	23.9	N.D	N.D
01/31−02/06		1.0	26.6	N.D	N.D
02/07−02/13		0.5	12.8	N.D	N.D
02/14−02/20		N.D	N.D	N.D	N.D
02/21−02/27		0.5	14.6	13.1	354
02/28−03/05	10	0.3	8.6	6.0	161
03/06−03/12		0.2	5.0	9.6	260
03/13−03/19		0.6	17.4	6.6	179
03/20−03/26		0.1	2.4	N.D	N.D
03/27−04/02		0.5	14.3	15.8	428
04/03−04/09	15	0.7	18.6	7.2	194
04/10−04/16		0.5	12.5	8.3	224
04/17−04/23		0.5	13.1	17.6	475
04/24−04/30					
05/01−05/07		0.9	24.7	13.6	368
05/08−05/14	20	0.2	5.8	10.7	290
05/15−05/21		0.6	16.7	10.6	287
05/22−05/28		0.8	21.0	16.9	456
05/29−06/04					
06/05−06/11		0.4	10.7	9.7	262
06/12−06/18	25				
06/19−06/25		0.3	8.9	8.1	220
06/26−07/02		N.D	N.D	14.8	401
07/03−07/09		N.D	N.D	N.D	N.D
07/10−07/16		0.5	13.0	23.5	635
07/17−07/23	30			26.0	703
07/24−07/30		0.5	13.1	9.2	248
07/31−08/06					
07/07−07/13		0.7	20.2	8.9	240
08/14−08/20		0.1	3.9	5.1	138
08/21−08/27	35	1.3	35.1	11.5	312
08/28−09/03		0.5	14.5	12.2	329
09/04−09/10		0.6	16.5	12.7	342
09/11−09/17					
09/18−09/24					
09/25−10/01	40	1.4	38.8	17.9	485
10/02−10/08		0.8	20.7	3.6	98
10/09−10/15		N.D	N.D	0.7	20
10/16−10/22		1.6	42.2	11.0	296
10/23−10/29		0.7	18.5	4.6	123
10/30−11/05	45				
11/06−11/12		0.4	9.6	N.D	N.D
11/13−11/19		0.9	24.4	10.5	284
11/20−11/26		0.8	22.6	11.8	318
11/27−12/03		0.4	9.5	1.5	41
12/04−12/10	50	0.8	21.4	6.7	182
12/11−12/17		0.8	22.6	1.3	36
12/18−12/24					
12/25−12/31					
MIN		0.1	2.4	0.7	20
MAX		1.6	42.2	26.0	703
MEAN		0.6	17.2	10.9	294
STD		0.3	8.8	5.6	152
N=		38	38	36	36

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1991

Date Collected	WEEK	CO−60 Bq\Kg	CO−60 PCi\KG	CS−137 Bq\Kg	CS−137 PCi\KG	I−131 Bq\Kg	I−131 PCi\KG	BE−7 Bq\Kg	BE−7 PCi\Kg	K−40 Bq\Kg	K−40 PCi\Kg	RA−228 Bq\Kg	RA−228 PCi\Kg
12/28−01/03	1	1.4	39	2.6	69	41.1	1112	1.1	30.4	4.5	121	0.63	17.1
01/04−01/10		1.6	42	2.8	77	4.1	111	0.7	19.4	3.6	98	0.70	19.0
01/11−01/17		1.6	43	3.0	80	7.0	188	1.6	43.7	3.5	94	0.61	16.5
01/18−01/24													
01/25−01/31	5	1.1	30	1.9	51	3.4	93	1.5	41.2	4.9	132	0.54	14.7
02/01−02/07		1.3	36	1.9	51	2.0	53	1.1	28.9	5.9	160	0.72	19.4
02/08−02/14		1.1	29	1.3	34	1.5	41	0.7	19.5	2.9	79	0.68	18.3
02/15−02/21													
02/22−02/28		1.0	28	1.6	43	1.1	31	1.1	30.7	4.0	108	0.37	10.0
03/01−03/07	10	1.1	29	1.4	39	3.7	99	1.6	42.3	7.3	198	0.86	23.2
03/08−03/14		1.7	47	3.2	87	0.1	3	2.2	58.7	9.4	254	1.01	27.3
03/15−03/21		1.6	42	2.4	65	4.1	110	2.1	57.6	4.9	134	0.84	22.6
03/22−03/28		1.3	36	2.3	63	5.6	151	1.6	42.8	10.7	290	1.31	35.3
03/29−04/04		2.2	60	1.7	46	6.4	172	1.9	51.8	9.7	263	0.95	25.7
04/05−04/11	15	0.89	24	1.4	38	3.1	84	2.8	76.4	8.5	230	0.73	19.7
04/12−04/18		1.4	38	1.8	50	1.8	50	2.8	75.9	9.5	257	0.98	26.6
04/19−4/25		1.3	34	1.9	52	1.0	26	2.7	74.1	9.4	255	0.94	25.5
04/26−05/02		0.55	15	0.92	25	0.5	14	2.3	61.7	5.7	153	0.35	9.4
05/03−05/09		3.7	101	2.3	63	0.3	8	1.4	37.4	6.3	171	1.32	35.8
05/10−05/16	20	0.89	24	1.4	39	0.2	7	2.7	72.4	7.0	191	1.11	30.1
05/17−05/23		1.0	26	1.1	30	0.5	13	1.7	46.6	5.6	151	1.00	26.9
05/24−05/30		0.55	15	0.78	21	1.1	30	0.7	19.2	6.3	171	0.77	20.9
05/31−06/06		0.48	13	0.63	17	76.9	2079	1.9	52.7	5.3	143	0.62	16.7
06/07−06/13		0.36	10	0.70	19	74.5	2014	1.9	50.8	7.4	200	0.83	22.3
06/14−06/20	25												
06/21−06/27		0.75	20	0.74	20	45.3	1224	2.1	56.2	2.2	59	0.44	11.8
06/28−07/04		0.52	14	0.59	16	25.1	679	2.4	65.5	3.7	99	0.35	9.4
07/05−07/11		0.63	17	0.81	22	14.2	384	1.5	40.4	5.0	135	0.63	17.0
07/12−07/18		0.58	16	0.89	24	13.6	367	2.0	55.0	3.9	105	0.73	19.8
07/19−07/25	30	0.52	14	0.89	24	4.9	132	1.5	40.7	4.2	113	0.64	17.3
07/26−08/01		0.64	17	0.58	16	2.3	63	1.2	32.3	5.1	139	0.25	6.8
08/02−08/08		0.59	16	0.71	19	1.7	46	1.8	50.0	4.1	110	0.67	18.0
08/09−08/15		0.46	12	0.53	14	1.0	27	1.3	34.1	4.5	123	0.66	17.8
08/16−08/22		1.85	50	1.2	32	1.7	46	1.5	39.4	6.7	180	0.96	25.9
08/22−08/29	35	0.52	14	0.87	23	4.8	130	1.4	37.6	4.7	127	0.84	22.8
08/30−09/05		0.73	20	0.53	14	3.5	96	1.1	30.0	5.7	155	0.96	25.9
09/06−09/12		0.70	19	0.52	14	1.9	53	1.3	35.2	3.8	102	0.59	16.0
09/13−09/19		0.74	20	0.83	23	1.5	40	1.6	43.9	4.7	126	0.69	18.6
09/20−09/26		0.57	16	0.68	18	0.5	15	1.7	46.3	5.6	150	0.79	21.4
09/27−10/03	40	0.69	19	0.93	25	0.4	12	0.8	22.3	3.1	85	0.69	18.7
10/04−10/10		0.78	21	0.85	23	0.9	25	1.5	39.6	6.9	187	0.92	24.9
10/11−10/17		0.56	15	0.58	16	2.6	71	1.4	38.9	4.0	107	0.69	18.6
10/18−10/24		0.47	13	0.73	20	2.4	65	1.1	28.6	5.1	137	0.50	13.6
10/25−10/31		0.48	13	0.49	13	5.3	143			4.4	119	0.31	8.4
11/01−11/07	45	0.71	19	0.76	21	5.5	149	0.3	7.9	6.5	175	0.43	11.5
11/08−11/14		0.51	14	0.50	13	6.4	174	0.6	15.4	4.6	125	0.36	9.6
11/15−11/21		0.40	11	0.37	10	7.2	195	0.5	14.4	5.0	136	0.50	13.6
11/22−11/28													
11/29−12/05													
12/06−12/12	50	0.47	13	0.53	14	2.3	63	1.1	29.1	2.6	70	0.55	15.0
12/13−12/19		0.40	11	0.45	12	2.3	61	0.5	12.7	3.9	105	0.61	16.6
12/20−12/26		0.49	13	0.47	13	46.9	1267	1.8	49.8	4.6	124	0.60	16.3
MIN		0.36	10	0.37	10	0.1	3	0.3	7.9	2.2	59	0.25	6.8
MAX		3.7	101	3.2	87	76.9	2079	2.8	76.4	10.7	290	1.32	35.8
MEAN		0.93	25	1.2	32	9.5	256	1.5	41.3	5.5	148	0.71	19.1
STD		0.61	16	0.75	20	17.7	478	0.6	16.9	2.0	53	0.24	6.5
N		47	47	47	47	47	47	47	47	47	47	47	47

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1991

Date Collected	WEEK	U-235 Bq\Kg	U-235 PCi\Kg	U-238 Bq\Kg	U-238 PCi\Kg
12/28-01/03	1	0.11	3.1	21.1	570
01/04-01/10		1.00	27.0	10.2	277
01/11-01/17		0.74	20.0	19.7	532
01/18-01/24					
01/25-01/31	5	0.67	18.0	8.4	226
02/01-02/07		0.34	9.2	6.1	165
02/08-02/14		0.33	9.0	4.1	111
02/15-02/21					
02/22-02/28		0.15	4.0	1.2	33
03/01-03/07	10	0.59	16.0	6.4	174
03/08-03/14		0.81	22.0	10.1	274
03/15-03/21		0.36	9.8	10.2	276
03/22-03/28		0.52	14.0	N.D.	N.D.
03/29-04/04		0.27	7.3	8.0	215
04/05-04/11	15	0.12	3.3	N.D.	N.D.
04/12-04/18		1.00	27.0	11.4	309
04/19-4/25		0.52	14.0	12.6	340
04/26-05/02		0.41	11.0	N.D	N.D
05/03-05/09		0.81	22.0	10.2	276
05/10-05/16	20	0.44	12.0	11.8	318
05/17-05/23		0.18	4.9	0.3	8
05/24-05/30		0.07	2.0	12.5	338
05/31-06/06		0.41	11.0	7.1	191
06/07-06/13		N.D.	N.D.	1.0	28
06/14-06/20	25				
06/21-06/27		0.57	15.5	16.6	448
06/28-07/04		0.24	6.4	4.8	130
07/05-07/11		0.63	17.0	1.9	51
07/12-07/18		0.31	8.3	16.6	450
07/19-07/25	30	0.63	17.0	15.2	412
07/26-08/01		0.51	13.9	17.9	483
08/02-08/08		0.54	14.6	5.8	157
08/09-08/15		0.23	6.3	7.4	201
08/16-08/22		0.71	19.1	20.5	554
08/22-08/29	35	0.51	13.9	0.6	15
08/30-09/05		0.67	18.2	15.1	407
09/06-09/12		0.55	14.9	7.5	202
09/13-09/19		0.95	25.8	16.6	449
09/20-09/26		0.43	11.6	7.5	202
09/27-10/03	40	0.99	26.8	22.9	618
10/04-10/10		0.51	13.9	10.5	285
10/11-10/17		0.53	14.3	N.D.	N.D.
10/18-10/24		0.65	17.7	N.D.	N.D.
10/25-10/31		0.31	8.3	N.D.	N.D.
11/01-11/07	45	0.35	9.4	5.8	158
11/08-11/14		N.D.	N.D.	6.8	184
11/15-11/21		0.33	8.9	5.2	140
11/22-11/28					
11/29-12/05					
12/06-12/12	50	0.53	14.2	6.8	183
12/13-12/19		0.59	16.1	12.3	332
12/20-12/26				7.3	196
MIN		0.07	2.0	0.3	8
MAX		1.00	27.0	22.9	618
MEAN		0.49	12.3	9.6	259
STD		0.25	6.7	6.0	161
N		45	45	41	41

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1990

Date, Collected	WEEK	CO-60 Bq/Kg	CO-60 PCi/Kg	CS-137 Bq/Kg	CS-137 PCi/Kg	I-131 Bq/Kg	I-131 PCi/Kg	BE-7 Bq/Kg	BE-7 PCi/Kg	K-40 Bq/Kg	K-40 PCi/Kg	RA-228 Bq/Kg	RA-228 PCi/Kg
12/30-01/04	1	1.2	32	4.6	123	0.6	16	N.D	N.D	9.4	254	N.D	N.D
01/05-01/11		1.0	26	0.6	16	0.1	3	N.D	N.D	4.4	118	1.1	31
01/12-01/18		0.8	22	0.7	19	0.2	5	1.3	36.4	7.9	213	N.D	N.D
01/19-01/25		0.7	19	0.9	24	1.0	27	N.D	N.D	6.7	181	1.0	26
01/26-02/01	5	0.6	15	0.7	18	5.3	143	0.6	16.1	3.5	94	N.D	N.D
02/02-02/08		0.6	17	0.7	18	4.6	124	N.D	N.D	4.5	121	0.63	17
02/09-02/15		0.6	15	0.3	9	3.0	82	N.D	N.D	5.1	138	0.67	18
02/16-02/22		0.4	11	0.7	20	1.6	42	0.3	8.5	5.8	156	0.85	23
02/23-03/01		0.7	18	1.1	31	1.0	26	2.2	58.9	4.9	133	2.0	53
03/02-03/08	10	0.7	19	1.2	32	4.8	130	3.2	86.8	9.2	250	2.0	54
03/09-03/15		0.6	17	1.1	30	8.5	230	1.1	29.0	7.0	188	0.85	23
03/16-03/22		0.9	25	1.0	28	11.0	298	N.D	N.D	10.0	270	2.3	62
03/23-03/29		0.9	25	0.9	24	5.4	146	N.D	N.D	10.0	270	2.5	67
03/30-04/05		2.1	58	0.7	19	3.5	94	1.3	36.1	8.7	236	2.8	75
04/06-04/12	15	2.8	75	0.7	18	2.1	57	N.D	N.D	11.1	301	0.75	20
04/13-04/19		5.5	150	1.6	43	1.0	26	N.D	N.D	4.5	122	2.6	72
04/20-04/26		8.0	217	0.7	20	1.3	35	N.D	N.D	4.2	114	1.5	40
04/27-05/03		8.8	239	0.9	24	0.8	22	N.D	N.D	6.9	186	1.1	30
05/04-05/10		7.4	199	0.6	15	0.6	17	N.D	N.D	7.1	191	2.3	63
05/11-05/17	20	9.0	243	1.0	27	1.0	26	2.6	71.4	7.6	206	2.5	68
05/18-05/24		10.8	292	0.8	21	0.3	7	N.D	N.D	6.8	185	N.D	N.D
05/25-05/31		3.8	104	2.0	54	0.3	7	N.D	N.D	13.1	354	3.0	82
06/01-06/07		4.8	130	0.8	22	0.1	4	N.D	N.D	7.5	202	0.92	25
06/08-06/14		5.4	145	1.0	27	0.1	3	N.D	N.D	4.7	128	N.D	N.D
06/15-06/21	25												
06/22-06/28		5.0	136	0.9	24	0.1	3	3.7	99.7	8.5	230	1.6	42
06/29-07/05		4.3	117	0.9	24	0.1	2	3.2	86.4	10.7	290	1.2	33
07/06-07/12		3.7	99	1.9	52	1.2	31	1.1	28.7	7.5	202	0.55	15
07/13-07/19		3.0	82	0.7	19	2.5	67	N.D	N.D	8.4	228	1.0	26
07/20-07/26	30	2.3	63	0.6	16	16.6	448	1.3	35.8	5.0	136	0.48	13
07/27-08/02		3.2	86	0.6	16	15.3	413	2.3	61.3	7.5	204	0.18	5
08/03-08/09		2.3	62	0.6	17	30.0	811	0.9	24.4	6.4	174	0.49	13
08/10-08/16		2.3	63	0.7	19	16.1	435	1.7	45.1	6.4	172	0.83	23
08/17-08/23		2.3	62	0.9	23	10.5	283	1.9	51.4	6.8	184	0.74	20
08/24-08/30	35												
08/31-09/06		2.4	64	0.9	24	3.9	106	1.6	42.1	6.6	179	0.89	24
09/07-09/13		1.4	37	0.7	20	6.7	181	1.4	39.0	7.4	199	0.68	18
09/14-09/20		1.6	42	1.8	48	6.5	175	2.5	68.6	7.7	207	0.59	16
09/21-09/27		2.6	69	1.7	46	1.8	49	N.D	N.D	8.4	226	0.89	24
09/28-10/04	40	4.6	124	7.3	196	1.5	41	1.3	34.0	5.8	158	1.0	26
10/05-10/11		4.6	124	9.2	249	0.9	23	1.1	29.8	3.4	91	0.48	13
10/12-10/18		5.3	143	15.4	415	1.1	29	1.1	30.5	9.0	244	1.4	39
10/19-10/25		2.5	67	7.3	198	1.0	28	1.5	41.6	4.8	129	0.59	16
10/26-11/01		3.9	106	11.5	310	2.2	60	N.D	N.D	5.5	148	0.78	21
11/02-11/08	45	3.2	87	9.6	260	4.2	114	N.D	N.D	5.5	148	0.26	7
11/09-11/15		2.4	64	6.7	182	2.6	70	1.0	27.0	4.5	121	0.33	9
11/16-11/22		1.8	48	4.5	121	1.4	37	1.2	33.6	2.7	74	0.49	13
11/23-11/29		1.3	36	3.0	82	25.2	682	1.3	35.9	4.6	125	0.57	15
11/30-12/06		2.0	54	4.8	131	25.1	678	N.D	N.D	3.0	81	N.D	N.D
12/07-12/13	50	1.1	31	2.1	58	27.7	749	1.0	27.1	3.5	94	0.43	12
12/14-12/21													
12/22-12/28		N.D	N.D	N.D	N.D	N.D	N.D	1.1	30.4	4.5	121	0.63	17
MIN		0.4	11	0.3	9	0.10	2	0.3	8.5	2.7	74	0.18	5
MAX		10.8	292	15.4	415	30.0	811	3.7	99.7	13.1	354	3.0	82
MEAN		3.0	81	2.4	66	5.3	145	0.9	24.8	6.6	179	1.0	27
STD		2.5	67	3.3	88	7.7	208	1.0	27.0	2.3	62	0.80	22
N=		48	48	48	48	48	48	28	28	49	49	43	43

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1990

Date Collected	WEEK	U−235 Bq\Kg	U−235 PCi\Kg	U−238 Bq\Kg	U−238 PCi\Kg
12/30−01/04	1	0.16	4	N.D.	N.D.
01/05−01/11		0.48	13	N.D.	N.D.
01/12−01/18		0.41	11	5.6	151
01/19−01/25		0.59	16	N.D.	N.D.
01/26−02/01	5	0.59	16	N.D.	N.D.
02/02−02/08		0.15	4	16.1	436
02/09−02/15		0.16	4	N.D.	N.D.
02/16−02/22		0.15	4	N.D.	N.D.
02/23−03/01		2.74	74	N.D.	N.D.
03/02−03/08	10	2.81	76	N.D.	N.D.
03/09−03/15		0.48	13	N.D.	N.D.
03/16−03/22		0.23	6	N.D.	N.D.
03/23−03/29		0.18	5	N.D.	N.D.
03/30−04/05		2.03	55	88.2	2385
04/06−04/12	15	0.19	5	N.D.	N.D.
04/13−04/19		0.21	6	N.D.	N.D.
04/20−04/26		1.81	49	49.4	1335
04/27−05/03		1.26	34	N.D.	N.D.
05/04−05/10		0.16	4	N.D.	N.D.
05/11−05/17	20	0.20	5	N.D.	N.D.
05/18−05/24		0.19	5	N.D.	N.D.
05/25−05/31		0.20	5	32.6	880
06/01−06/07		1.04	28	N.D	N.D
06/08−06/14		2.15	58	N.D	N.D
06/15−06/21	25				
06/22−06/28		0.15	4	N.D	N.D
06/29−07/05		0.74	20	N.D	N.D
07/06−07/12		0.59	16	6.7	180
07/13−07/19		0.10	3	N.D	N.D
07/20−07/26	30	0.20	5	10.0	269
07/27−08/02		0.70	19	14.7	398
08/03−08/09		0.07	2	12.0	325
08/10−08/16		0.33	9	12.6	341
08/17−08/23		0.27	7	24.9	672
08/24−08/30	35				
08/31−09/06		0.63	17	16.0	433
09/07−09/13		0.25	7	N.D.	N.D.
09/14−09/20		18.8	508	N.D.	N.D.
09/21−09/27		11.1	299	1.1	31
09/28−10/04	40	0.44	12	N.D.	N.D.
10/05−10/11		0.21	6	N.D.	N.D.
10/12−10/18		1.3	36	N.D.	N.D.
10/19−10/25		1.1	31	N.D.	N.D.
10/26−11/01		0.96	26	2.3	63
11/02−11/08	45	0.24	6	N.D.	N.D.
11/09−11/15		0.78	21	N.D.	N.D.
11/16−11/22		0.55	15	0.5	14
11/23−11/29		0.09	2	N.D.	N.D.
11/30−12/06		0.85	23	N.D.	N.D.
12/07−12/13	50	0.09	2	N.D.	N.D.
12/14−12/21		N.D.	N.D.	N.D.	N.D.
12/22−12/28		0.96	26	N.D.	N.D.
MIN		0.07	2	0.5	14
MAX		18.8	508	88.2	2385
MEAN		1.2	33	19.5	158
STD		3.0	81	22.2	408
N=		49	49	15	15

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1989

Date Collected	WEEK	CO-60 Bq\Kg	CO-60 PCi/Kg	CS-137 Bq\Kg	CS-137 PCi/Kg	I-131 Bq\Kg	I-131 PCi/Kg	BE-7 Bq\Kg	BE-7 PCi/Kg	K-40 Bq\Kg	K-40 PCi/Kg	RA-228 Bq\Kg	RA-228 PCi/Kg
12/30-01/05	1	5.0	135	1.0	27	16.4	442	1.4	39.1	6.6	179	N.D.	N.D.
01/06-01/12		5.3	143	0.8	21	14.6	395	N.D.	N.D.	3.8	103	1.0	27.4
01/13-01/19		4.1	111	1.2	33	10.2	276	1.3	36.4	4.3	117	1.9	51.2
01/20-01/26		5.4	146	0.7	19	3.6	97	N.D.	N.D.	7.5	204	1.5	41.0
01/27-02/02	5	4.4	119	1.3	36	2.6	71	1.6	44.3	4.3	117	0.3	9.3
02/03-02/09		4.3	117	1.3	35	1.5	41	1.4	36.8	4.8	129	N.D.	N.D.
02/10-02/16		3.6	96	1.1	30	4.6	125	0.5	14.3	11.2	304	0.7	19.8
02/17-02/23		2.4	64	1.2	33	7.5	202	N.D.	N.D.	4.6	123	N.D.	N.D.
02/24-03/02		2.8	76	1.3	34	8.3	224	N.D.	N.D.	5.0	134	N.D.	N.D.
03/03-03/08	10	2.8	76	1.3	35	6.6	178	0.6	17.4	7.7	209	0.4	12.0
03/10-03/16		10.9	294	1.5	40	2.5	67	N.D.	N.D.	5.7	155	0.3	8.0
03/17-03/23		2.7	72	1.3	34	3.1	83	N.D.	N.D.	7.2	194	N.D.	N.D.
03/24-03/30		2.2	59	1.3	36	6.5	176	1.7	45.5	9.8	264	N.D.	N.D.
03/31-04/06		2.6	71	1.2	33	16.5	445	N.D.	N.D.	9.8	266	0.9	23.6
04/07-04/13	15	5.8	156	1.0	28	19.9	538	0.8	22.4	8.7	236	N.D.	N.D.
04/14-04/20		1.8	48	0.8	21	11.8	319	0.6	16.2	6.5	175	0.4	10.8
04/21-04/27		1.5	41	0.9	23	8.0	216	N.D.	N.D.	8.1	218	0.7	18.5
04/28-05/04		1.2	32	1.1	29	5.3	142	3.3	88.6	6.1	166	1.3	35.7
05/05-05/11		1.7	46	1.3	36	7.0	189	N.D.	N.D.	8.5	229	0.2	4.3
05/12-05/18	20	1.5	40	0.8	22	9.4	255	N.D.	N.D.	6.0	161	1.0	26.0
05/19-05/25		1.9	52	1.2	32	7.9	213	N.D.	N.D.	16.4	444	N.D.	N.D.
05/26-06/01		1.6	43	1.0	28	19.7	533	1.4	37.5	5.6	151	N.D.	N.D.
06/02-06/08		1.6	44	0.9	24	18.5	501	N.D.	N.D.	6.7	182	N.D.	N.D.
06/09-06/15		2.2	60	0.9	23	16.2	438	0.9	25.0	6.9	187	1.3	34.9
06/16-06/22	25	2.0	55	1.0	28	11.1	301	0.7	19.6	6.8	184	N.D.	N.D.
06/23-06/29		1.7	45	0.9	25	5.9	159	1.6	44.5	3.8	103	N.D.	N.D.
06/30-07/06		1.9	52	1.0	28	3.6	97	1.4	37.0	6.8	183	1.4	37.8
07/07-07/13		1.4	37	1.2	32	2.0	54	N.D.	N.D.	6.8	183	N.D.	N.D.
07/14-07/20		1.8	48	1.1	31	1.6	42	3.1	82.7	3.9	106	N.D.	N.D.
07/21-07/27	30	1.6	42	1.2	32	0.8	21	2.1	56.5	8.6	233	0.6	16.4
07/28-08/03		1.8	50	1.9	52	0.7	19	N.D.	N.D.	2.0	54	N.D.	N.D.
08/40-08/10		1.7	47	1.0	28	1.7	45	1.2	32.2	5.6	151	0.5	14.6
08/11-08/17		1.8	50	1.0	27	1.6	44	1.7	44.9	6.8	184	N.D.	N.D.
08/18-08/24		4.6	123	1.3	34	1.4	39	N.D.	N.D.	5.3	142	1.1	29.3
08/25-08/31	35	1.3	35	1.1	31	1.0	27	N.D.	N.D.	3.0	80	N.D.	N.D.
09/01-09/07		1.3	36	1.0	27	11.7	315	1.4	37.0	4.2	113	0.7	19.3
09/08-09/14		1.1	29	2.0	53	46.1	1246	N.D.	N.D.	5.6	152	0.3	8.5
09/15-09/21		1.1	30	1.4	38	31.7	857	0.7	19.4	6.3	170	1.2	32.3
09/22-09/28		1.4	39	1.6	42	13.1	353	N.D.	N.D.	5.1	138	0.7	19.8
09/29-10/05	40	1.3	36	1.3	36	12.8	346	N.D.	N.D.	7.4	201	0.7	18.8
10/06-10/12		1.9	52	1.0	28	7.1	191	N.D.	N.D.	7.5	203	N.D.	N.D.
10/13-10/19		1.4	38	1.6	43	4.9	132	N.D.	N.D.	1.5	41	0.9	25.4
10/20-10/26		1.4	37	1.2	33	3.8	104	N.D.	N.D.	6.4	172	0.3	8.2
10/27-11/02		1.3	36	1.0	26	3.0	80	N.D.	N.D.	0.6	16	N.D.	N.D.
11/03-11/09	45	1.3	35	1.7	46	3.8	103	N.D.	N.D.	6.5	175	1.6	43.2
11/10-11/16		1.3	34	0.9	25	3.6	98	N.D.	N.D.	6.8	185	0.7	18.2
11/17-11/23		1.1	30	1.0	27	2.7	73	N.D.	N.D.	5.3	142	N.D.	N.D.
11/24-11/30		1.0	26	1.2	32	2.1	56	N.D.	N.D.	7.7	207	0.2	4.5
12/01-12/07		1.2	32	1.0	28	1.4	39	2.2	59.8	5.6	152	1.0	28.1
12/08-12/14	50	1.0	28	0.8	21	1.6	44	N.D.	N.D.	5.1	138	0.9	25.5
12/15-12/21		1.2	32	1.2	33	1.0	27	N.D.	N.D.	5.6	152	N.D.	N.D.
12/22-12/28		0.9	23	1.0	28	0.6	15	N.D.	N.D.	10.3	279	1.1	30.0
MIN		0.9	23	0.7	19	0.6	15	0.5	14.3	0.6	16	0.2	4.3
MAX		10.9	294	2.0	53	46.1	1246	3.3	88.6	16.4	444	1.9	51.2
MEAN		2.3	63	1.2	31	7.9	213	1.4	39.0	6.3	171	0.5	13.5
STD		1.7	47	0.3	7	8.4	226	0.7	19.2	2.5	68	0.5	14.4
N=		52	52	52	52	52	52	22	22	52	52	31	31

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1989

Date Collected	WEEK	U-235 Bq\Kg	U-235 PCi/Kg	U-238 Bq\Kg	U-238 PCi/Kg
12/30-01/05	1	N.D.	N.D.	36.9	997
01/06-01/12		N.D.	N.D.	13.4	361
01/13-01/19		0.4	11	24.7	667
01/20-01/26		0.3	8	4.7	126
01/27-02/02	5	1.0	26	N.D.	N.D.
02/03-02/09		1.2	33	49.7	1343
02/10-02/16		N.D.	N.D.	22.2	600
02/17-02/23		0.5	14	N.D.	N.D.
02/24-03/02		1.0	28	19.5	527
03/03-03/08	10	N.D.	N.D.	3.9	105
03/10-03/16		1.8	49	66.4	1796
03/17-03/23		1.3	34	20.7	559
03/24-03/30		2.0	54	16.2	438
03/31-04/06		0.8	22	25.0	676
04/07-04/13	15	N.D.	N.D.	21.8	589
04/14-04/20		N.D.	N.D.	62.3	1683
04/21-04/27		0.8	21	39.1	1056
04/28-05/04		1.8	49	23.5	636
05/05-05/11		N.D.	N.D.	N.D.	N.D.
05/12-05/18	20	N.D.	N.D.	4.3	115
05/19-05/25		N.D.	N.D.	56.7	1532
05/26-06/01		N.D.	N.D.	18.4	497
06/02-06/08		N.D.	N.D.	19.0	514
06/09-06/15		0.4	12	35.3	955
06/16-06/22	25	2.4	65	50.3	1360
06/23-06/29		N.D.	N.D.	36.6	988
06/30-07/06		2.0	55	25.5	688
07/07-07/13		N.D.	N.D.	34.3	928
07/14-07/20		N.D.	N.D.	51.0	1379
07/21-07/27	30	1.6	44	30.7	830
07/28-08/03		0.3	7	7.4	201
08/40-08/10		2.4	64	55.5	1500
08/11-08/17		1.4	38	34.0	920
08/18-08/24		N.D.	N.D.	N.D.	N.D.
08/25-08/31	35	1.4	38	N.D.	N.D.
09/01-09/07		2.1	57	N.D.	N.D.
09/08-09/14		N.D.	N.D.	N.D.	N.D.
09/15-09/21		N.D.	N.D.	N.D.	N.D.
09/22-09/28		0.4	12	N.D.	N.D.
09/29-10/05	40	N.D.	N.D.	N.D.	N.D.
10/06-10/12		2.3	62	N.D.	N.D.
10/13-10/19		N.D.	N.D.	N.D.	N.D.
10/20-10/26		0.4	11	16.9	458
10/27-11/02		N.D.	N.D.	N.D.	N.D.
11/03-11/09	45	0.7	18	11.9	321
11/10-11/16		N.D.	N.D.	N.D.	N.D.
11/17-11/23		1.3	36	22.0	596
11/24-11/30		N.D.	N.D.	5.1	139
12/01-12/07		N.D.	N.D.	N.D.	N.D.
12/08-12/14	50	N.D.	N.D.	4.7	126
12/15-12/21		N.D.	N.D.		
12/22-12/28		N.D.	N.D.	40.5	1096
MIN		0.3	7	3.9	105
MAX		2.4	65	66.4	1796
MEAN		0.6	17	19.8	535
STD		0.8	21	19.3	522
N=		26	26	36	36

ANNUAL SLUDGE DATA SUMMARY 1988 THRU 1993

(1989–1993 includes Uranium Data)

c) (continued)

RADIONUCLIDES IN SLUDGE 1988

Date Collected	WEEK	CO-60 Bq\Kg	CO-60 PCi\Kg	CS-137 Bq\Kg	CS-137 PCi\Kg	I-131 Bq\Kg	I-131 PCi\Kg	BE-7 Bq\Kg	BE-7 PCi\Kg	K-40 Bq\Kg	K-40 PCi\Kg	RA-228 Bq\Kg	RA-228 PCi\Kg
	1												
	5												
	10												
	15												
05/20	20	1.9	51	1.6	43.0	7.9	214	N.D.	N.D.	6.1	164	0.21	5.8
05/27		1.6	44	1.4	37.4	18.1	489	N.D.	N.D.	5.3	142	N.D.	N.D.
06/02		2.2	60	1.8	49.6	9.1	246	1.1	31	7.7	207	0.92	24.9
06/03-06/09		2.7	74	2.1	56.1	15.8	428	1.1	29	17.6	477	0.31	8.3
06/10-06/16		1.7	46	1.7	45.2	12.4	335	N.D.	N.D.	4.4	118	N.D.	N.D.
06/19-06/23	25	17.5	474	11.0	298.0	7.8	211	N.D.	N.D.	5.6	151	N.D.	N.D.
06/24-06/29		4.3	117	3.3	87.9	5.4	146	1.6	44	8.4	228	N.D.	N.D.
07/01-07/05		2.0	54	1.6	43.4	6.0	161	0.9	24	6.1	164	N.D.	N.D.
07/11-07/14		1.8	50	2.4	65.1	1.9	52	0.7	20	4.7	127	N.D.	N.D.
07/15-07/21		1.7	47	1.5	41.2	1.4	37	N.D.	N.D.	5.8	157	N.D.	N.D.
07/22-07/28	30	3.3	89	2.7	74.0	0.8	21	N.D.	N.D.	7.0	189	N.D.	N.D.
07/29-08/04		2.9	78	2.1	55.6	6.7	181	N.D.	N.D.	7.1	192	N.D.	N.D.
08/05-08/11		1.8	49	1.1	29.1	8.9	241	N.D.	N.D.	8.8	237	N.D.	N.D.
08/12-08/18		2.7	74	2.2	60.0	5.4	145	2.5	69	5.4	147	N.D.	N.D.
08/19-08/25		3.2	86	1.7	44.9	4.4	120	2.2	61	8.5	229	0.24	6.4
08/26-09/01	35	3.1	83	1.5	41.8	23.7	641	N.D.	N.D.	12.7	344	1.28	34.7
09/02-09/06		3.2	86	1.2	33.5	1.7	46	N.D.	N.D.	6.4	174	0.81	21.8
09/06-09/15		3.3	89	2.1	56.8	0.8	20	N.D.	N.D.	N.D.	N.D.	0.65	17.6
09/16-09/22		3.9	105	1.5	39.4	0.5	13	N.D.	N.D.	6.0	162	N.D.	N.D.
09/23-09/29		3.9	105	1.7	45.7	0.9	24	0.6	17	7.8	210	1.79	48.3
09/30-10/06	40	4.8	131	2.0	52.9	0.1	2	0.4	10	6.0	161	N.D.	N.D.
10/07-10/13		9.2	249	2.6	70.0	0.2	4	N.D.	N.D.	8.3	225	0.36	9.8
10/14-10/24		8.1	219	1.9	50.8	0.1	3	N.D.	N.D.	3.4	91	0.71	19.3
10/24-10/27		5.1	138	1.3	34.3	0.1	2	N.D.	N.D.	7.6	205	0.19	5.2
10/31-11/03		8.1	220	1.3	34.4	1.0	28	N.D.	N.D.	7.1	193	0.03	0.8
11/04-11/10	45	9.8	266	1.2	33.1	1.4	38	N.D.	N.D.	3.5	95	0.82	22.1
11/11-11/17		9.5	256	0.4	10.9	1.5	39	N.D.	N.D.	6.2	167	0.14	3.9
11/18-11/23		9.2	250	1.7	45.1	0.5	14	N.D.	N.D.	4.5	122	N.D.	N.D.
11/28-12/01		6.5	175	0.9	24.0	16.7	451	N.D.	N.D.	2.9	77	N.D.	N.D.
12/01-12/08		6.5	175	1.7	47.3	15.6	423	N.D.	N.D.	7.2	195	N.D.	N.D.
11/21	50	4.7	127	2.0	53.8	0.2	5	N.D.	N.D.	2.7	72	N.D.	N.D.
12/09-12/15		6.1	165	1.0	27.6	9.1	245	N.D.	N.D.	4.4	118	N.D.	N.D.
12/16-12/22		5.6	152	0.9	23.0	15.4	416	N.D.	N.D.	2.3	61	0.70	19.0
MIN		1.6	44	0.4	10.9	0.1	2	0.37	10	2.3	61	0.03	0.8
MAX		17.5	474.0	11.0	298.0	23.7	641.0	2.5	69	17.6	477	1.8	48.3
MEAN		4.9	132.8	2.0	53.2	6.1	164.9	0.3	33.7	6.3	170	0.3	7.5
STD		3.4	91.1	1.7	45.9	6.4	174.0	0.7	19	3.1	83	0.4	11.8
N		33	33	33	33	33	33	9	9	32	32	15	15

Table 2.4. Comparison of concentrations of various elements in Oak Ridge sewage sludge with those in other municipal sewage sludges used for land application, land reclamation, fertilizer-soil conditioning, and park and farmland application. Oak Ridge data represents the 5-year average (from 1988-1982) of monthly samples (*n*= 43-53). Data for other municipal sludges represents analysis of a single sample as published in Mumma *et al.* (1984). Concentrations units are % or mg/kg on a dry weight basis.

		Oak Ridge (5-year Mean)	Baltimore	Knoxville (4th Creek)	Lexington W. Hickman Cr	Philadelphia NE	Portland	Salt Lake City
N*	%	8.08	3.7	2.2	2.4	0.6	1.5	2.1
P	%	2.88	1.6	0.74	2.8	0.72	0.98	2.6
K	%	0.50	0.01	0.05	0.05	0.06	0.09	0.10
Fe	%	1.81	1.8	3.0	1.8	1.9	2.4	1.2
Ca	%	3.95	2.1	1.0	4.4	2.7	1.5	6.9
Mg	%	0.48	0.2	0.15	0.36	1.3	0.21	0.55
Na	%	0.27	0.13	0.15	0.12	0.2	1.2	0.35
As	mg/kg	4.56	6.0	5.0	2.4	7.1	3.3	25
Ba	mg/kg	881	1258	462	607	52.4	372	3703
Cd	mg/kg	8.96	19.5	7.5	22.9	12.0	31	37
Co	mg/kg	17.1	13.2	7.2	4.3	8.2	21.6	11.9
Cr	mg/kg	162.7	3087	1279	186	1290	572	2450
Cu	mg/kg	493.8	7729	309	7575	907	398	4307
Hg	mg/kg	10.7	12.4	8.1	6.9	3.0	4.8	12.1
Mn	mg/kg	1539	121	233	230	529	277	141
Mo	mg/kg	24.9	22.5	10.7	19.5	10.3	21.9	30.4
Ni	mg/kg	45.4	420	105	68.0	305	215	400
Pb	mg/kg	99.4	160	258	206	475	282	330

Table 2.4 (continued)

		Oak Ridge (5-year Mean)	Baltimore	Knoxville (4th Creek)	Lexington W. Hickman Cr	Philadelphia NE	Portland	Salt Lake City
Se	mg/kg	6.75	13.0	2.7	6.7	1.0	2.1	6.7
U	mg/kg	52.8	6.5	1.7	2.3	3.6	2.3	5.4
Zn	mg/kg	1746	4500	1100	1688	863	1813	1975

* All nitrogen values measured by the Kjehldahl method.

Table 2.5. Radionuclides in regional Wastewater Treatment Plant Sludges. Two duplicate samples were taken from each treatment plant. Approximately 1 Kg (1 liter) of sludge was counted overnight, Marinelli beaker geometry. Samples collected by E. A. Stetar and analyzed at ESD (ORNL). Units are Bq/Kg (wet weight).

Location	Date	I-131	Cs-137	Be-7	K-40	Ra-228
1	8/19/92	34.7	0.10	2.05	11.5	1.05
Dup		37.8	0.14	2.79	11.1	1.32
2	8/19/92	0.18	0.10	2.47	N.D.	0.89
Dup		0.13	0.05	2.27	2.07	0.45
3	8/20/92	2.82	0.05	0.96	N.D.	0.28
Dup		3.16	N.D.	0.81	0.41	0.21
4	8/20/92	0.72	0.10	0.98	4.96	0.96
Dup		0.88	0.23	1.12	6.40	1.28
5	8/20/92	2.38	N.D.	1.56	1.13	0.63
Dup		2.50	N.D.	1.52	2.0	0.59
6	8/19/92	2.03	0.05	1.35	3.0	0.23

1: Knoxville, TN; digested sludge, 3.29% solids.
2: Lenoir City, TN; digested sludge, 1.19% solids.
3: Morristown, TN; digested sludge, 3.84% solids.
4: Sevierville, TN; digested sludge, 2.48% solids.
5: Sevierville, TN; primary sludge, 1.72% solids.
6: Maryville, TN; primary sludge. N.D.: Not detected.

Table 2.6. Oak Ridge sludge composition in comparison to pollutant limits from EPA regulations (40 CFR § 503) for sludge constituents.

Pollutant	Oak Ridge Sludge, 5-year average, mg/kg.	Maximum sludge concentration for non-agricultural land application (mg/kg) (Proposed limits, 2/6/89 40 CFR § 503.15)[1]	Monthly average pollutant concentrations (agricultural)[2] (mg/kg) (Final rule, 2/19/93 40 CFR § 503.13, Table 3)	Ceiling concentrations for any land application (mg/kg) (Final rule, 2/19/93 40 CFR § 503.13, Table 3)
Arsenic	4.56	36	41	75
Cadmium	8.96	380	39	85
Chromium	162.7	3100	1200	3000
Copper	17.1	3300	1500	4300
Lead	99.4	1600	300	840
Mercury	10.7	30	17	57
Molybdenum	24.9	230	18[3]	75
Nickel	45.4	990	420	420
Selenium	6.75	64	36	100
Zinc	1746	8600	2800	7500

[1] Concentrations of Aldrin/dieldrin, Benzo(a)pyrene, Chlordane, DDT/DDE/DDD (total),Dimethyl nitrosamine, Heptachlor, Hexachlorobenzene, Hexachlorobutadiene, lindane, polychlorinated biphenyls, toxaphene, trichloroethylene were also proposed on 2/6/89, but these are not generally detectable above the analytical limits in Oak Ridge sludge during the monitoring program. Numerical limits on organics were deferred in the Final Rule issued 2/19/93.

[2] For sludge applied to agricultural land, forest, or public contact site. Either these concentrations shall not be exceeded or the cumulative loading rate shall not exceed that listed in Table 2 of 40 CFR § 503.13. See Table 3.3 of this report for loading rates.

[3] The 2/19/93 limits for molybdenum, except the ceiling concentration limit of 75 mg/kg, were deleted by amendment of 40 CFR § 503 on 2/25/94, pending reconsideration of appropriate molybdenum limits.

Table 3.1. Sludge application sites and monitoring matrix. The dates of sludge application, the areas, loading rate and application methods, and total dry weight of sludge applied to each site (through 1993) are given. The methods of application included surface application from behind the truck and/or from a truck-mounted spray nozzle ("surface"), and subsurface injection and plowing ("injected"). The environmental media sampled and analyzed for each site as part of the monitoring program are also indicated.

Site	McCoy	Rogers	Pine Plantation	Cotton-wood	Watson Road	Scarboro	Upper Hayfield	Upper Hayfield #2	High Pasture
Application Area	45-68 Acres (18-29 ha)	30 Ac (12 ha)	25 Ac (10 ha)	17 Ac (7 ha)	40 Ac (16 ha)	45 Ac (18 ha)	25 Ac (10 ha)	20 Ac (8 ha)	25 Ac (10 ha)
Dates of Application	11/83—9/86	9/86—12/88	6/88— 6/89	6/89—5/91	9/90—12/93*	8/90— 7/93*	12/86—6/93*	11/89—7/93*	5/90— 8/92*
Application Rate & Method	44 Mg/ha surface/ injected	48 Mg/ha surface/ injected	27 Mg/ha surface	25 Mg/ha surface	29.7 Mg/ha surface	19.8 Mg/ha surface	30 Mg/ha surface	30.5 Mg/ha surface	18 Mg/ha surface
Total Sludge Applied (dry weight)	871 Ton 792 Mg	646 Ton 587 Mg	301 Ton 274 Mg	193 Ton 175 Mg	531 Ton 475 Mg	397 Ton 356 Mg	334 Ton 303 Mg	271 Ton 244 Mg	201 Ton 180 Mg
Soil Analyses	•, *C*	•	•	•	•	•	•	•	•
Vegetation		•	•						
Soil Water	*C*	•	•	•					
Groundwater	*C*		•						
Surface Runoff	•, *C*	•	•	•	•				

• Analyses performed
C Some results previously reported, Oakes *et al.* 1984.
* Continues as an active site

Table 3.2. Average concentration of metals in sludge during the application period for each site (mg/kg), based on the yearly concentrations in Table 2.1 and the dates of application. Averages are calculated through 1993.

Metal	McCoy	Rogers	Pine	Cottonwood	Watson Road	Upper Hay-field	Upper Hay-field #2	High Pasture	Scarboro
As	9.3	5.1	5.1	4.9	4.9	4.9	4.8	5.1	4.9
Cd	14.0	10.5	8.4	7.9	9.8	9.6	9.2	10.5	9.8
Cr	630	359	195	155	153	215	157	158	153
Cu	1150	687	537	486	474	538	479	473	474
Pb	220	201	142	94	81	120	88	79	81
Hg	15.3	17.8	12.5	11.1	10.3	12.2	10.0	8.9	10.3
Mo	n.d.*	60.0	39.0	23.8	26.4	30.6	24.7	26.8	26.4
Ni	143	90.0	53.1	44.1	42.5	55.7	42.0	42.8	42.5
Se	6.7	6.7	7.0	6.8	6.9	6.9	6.9	6.6	6.9
Zn	2718	2169	1852	1735	1706	1838	1705	1697	1706

*n.d. indicates that no data were available for this metal during the application period for that site.

Table 3.3. Total sludge applied (kg per hectare) on each site and cumulative metal loading to date (as of December 1993) for each site, compared to regulatory limits (Table 2 of 40 CFR § 503.13)

	McCoy	Rogers	Pine	Cottonwood	Watson Road	Upper Hayfield	Upper Hayfield #2	High Pasture	Scarboro	Permissible Cumulative Pollutant Loading Rates (kg/ha)
Total sludge applied to each site: (kg/ha)										
	44000	48200	27000	25400	29700	36400	30500	18000	19800	
Cumulative loading of each metal per site: (kg/ha)										
As	0.4	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	41
Cd	0.6	0.5	0.2	0.2	0.3	0.3	0.3	0.2	0.2	39
Cr	27.7	17.3	5.3	3.9	4.6	7.8	4.8	2.8	3.0	3000
Cu	50.6	33.1	14.5	12.3	14.1	19.6	14.6	8.5	9.4	1500
Pb	9.7	9.7	3.8	2.4	2.4	4.4	2.7	1.4	1.6	300
Hg	0.7	0.9	0.3	0.3	0.3	0.4	0.3	0.2	0.2	17
Mo	n.d.*	2.9	1.1	0.6	0.8	1.1	0.8	0.5	0.5	18
Ni	6.3	4.3	1.4	1.1	1.3	2.0	1.3	0.8	0.8	420
Se	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	100
Zn	119.6	104.5	50.0	44.1	50.7	66.9	52.0	30.6	33.8	2800

*n.d. indicates that no data were available for this metal during the application period for that site.

Table 4.1. Concentrations of soil nitrogen (total Kjehldahl N, mg/kg) at eight sludge application sites before, during, or after sludge application, comparing sludge-treated and reference soils. Time elapsed between the last sludge application and the post-treatment sampling varied, but may be determined from the dates provided. Samples were take from a depth of 0-15 cm, except as indicated for the Pine site. Samples were taken from 3 plots on each site.

Site	Date of most recent sludge application	Sampling date	Soil Depth (cm)	Nitrogen, ppm (Mean ± Std)	
				Sludge-treated*	Reference
Sycamore	1978	7/90	0-15	1740 ± 185 [a]	1293 ± 103
McCoy	9/86	7/90	0-15	1976 ± 534	1543 ± 465
Rogers	12/88	7/90	0-15	2353 ± 978	1903 ± 827
Pine	(Pre-treatment)	3/88	0-15	1230 ± 56	1467 ± 168
	(Pre-treatment)	3/88	15-30	363 ± 78	453 ± 165
	(Pre-treatment)	3/88	30+	257 ± 21[a]	407 ± 84
Pine	6/89	11/89	0-15	1733 ± 206[b]	1537 ± 216
	6/89	11/89	15-30	400 ± 98	553 ± 270
	6/89	11/89	30+	240 ± 30	390 ± 225
Cottonwood	2/90	7/90	0-15	2190 ± 702	1187 ± 309
	2/90	1/91	0-15	1867 ± 605	1041 ±59
Scarboro	10/90'	1/91	0-15	1460 ± 369	1383 ± 221
Upper Hayfield 1	12/89	1/91	0-15	1509 ± 389	↑
Upper Hayfield 2	4/90	1/91	0-15	1500 ± 503	↑

* For the Pine site, "sludge-treated" indicates the mean for the "sludge-only" plots-- see text.

↑ No separate reference samples were taken for the Upper Hayfield sites, but the reference from the nearby Scarboro hayfield site may be taken as representative.

[a] Means for treated and reference sites are different at the p=0.05 level (t-test).

[b] (Pine site only) difference between N concentrations in each plot before and after sludge application was significantly different from zero (paired t-test, p<0.05).

Table 4.2. Concentrations of soil nitrogen (TKN, total Kjeldahl N, ppm), cation exchange capacity (CEC, meq/100 g soil), and soil pH at seven sludge application sites and associated reference sites. Samples were taken on January 17, 1991, from the upper 0-15 cm. Samples were taken from 3 plots on each sludge site, and from 2 on each reference (Ref.) site. TKN and CEC were measured by Analytical Resources, Inc., Seattle WA. Measurements of pH were done at Environmental Sciences Division, ORNL.

Site	Date of most recent sludge applic.	Nitrogen, ppm (Mean ± Std)		CEC, meq/100g		pH	
		Sludge-treated	Ref.	Sludge-treated	Ref.	Sludge-treated	Ref.
Rogers	12/88	1351 ±1038	1201 ± 436	1.57[a] ± 0.35	11.05 ± 2.05	5.4 ± 0.5	5.4 ± 0.1
Pine[•]	6/89	1780 ± 126	1732 ± 1056	9.80[a] ± 1.10	5.10 ± 4.75	3.8 ± 0.4	4.8 ± 0.4
Cottonwood	2/90	1867[†] ± 605	1041[†] ± 59	10.80 ± 3.53	6.70 ± 0.42	4.5 ± 0.6	4.8 ± 0.4
Scarboro	10/90	1460[†] ± 369	1383[†] ± 221	6.10 ±1.31	8.55 ± 1.34	4.4[a] ± 0.1	5.0 ± 0.0
Upper Hayfield 1	12/89	1509[†] ± 389	↑	8.63 ± 2.67	↑	4.7 ± 0.4	↑
Upper Hayfield 2	4/90	1500[†] ± 504	↑	9.93 ± .072	↑	5.1 ± 0.1	↑
High Pasture	7/90	1523 ± 1210	↑	7.10 ± 1.39	↑	4.1 ± 0.2	↑

[•] For the Pine site, "sludge-treated" indicates the mean for the "sludge-only" plots-- see text for details.

[†] These TKN data also appear in table 4.1.

↑ No separate reference samples were taken for the Upper Hayfield or High Pasture sites, but the references from the nearby Scarboro hayfield and Rogers pasture sites may be taken as representative.

[a] Means for treated and reference sites are different at the p=0.05 level (t-test).

Table 4.3. (a) Concentrations of ICP analytes, uranium, and radionuclides in soil at the Rogers site, at two soil depths, from sludge-treated and reference soils. Data are mean and standard deviation (Std). Samples were taken in May 1988. Six samples were taken on the sludge treated site (2 each from plots at the top, middle and bottom of the slope), and 3 from the reference site (1 from each slope position). All samples were analysed, but because some values were below the detection limits, some of the reported means and standard deviations are derived from fewer samples. These values are denoted by "<" and the number of values contributing to the means are as follows: Sludge-treated: Cd (n=3 at 0-15 cm and n=2 at 15-30 cm), and Ag at 15-30 cm (n=2). Where no std is given, all values were below detection limits. For the radionuclides listed separately, the number of means above the detection limits were 6 for sludge-treated, except for ^{60}Co at 15-30 cm (n=3), and 3 for reference, except ^{60}Co (n=1 at 0-15 cm, n=0 at 15-30 cm) and ^{137}Cs (n=1 at 15-30 cm). Units are mg/kg for elements Ag through U and pCi/g for the radioisotopes.

	Sludge-Treated Site				Reference Site			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Ag	2.54	1.37	<0.38	0	<0.3	---	<0.3	---
As	<3.0		<3.0		<3.0	---	<3.0	---
Ca	4300†	2690	1795	1019	1333	115	1090	315
Cd	<0.58	0.06	<0.44	0.05	<0.3	---	<0.3	---
Co	16.2	6.1	16.3	5.7	14.9	7.4	14	2.6
Cr	22.8	7.1	17.5	4.3	26.3	7.8	21	7.2
Cu	23.0	6.1	8.1†	1.3	14.0	4.4	14.0	3.0
K	955	691	498	388	637	526	757	289
Mg	1210	494	900	313	1203	693	867	126
Mn	2266	327	1907	7.6	1323	999	1333	664
Mo	<2.4		<2.4		<2.4		<2.4	
Ni	13	2.8	11.2	2.6	10.4	2.4	9.0	3.0
P	1057†	215	250	81.5	250	14	172	113
Pb	39.5	17.7	31.7	13.3	23.8	16.4	21.3	5.0
Se	<3.0		<3.0		<3.0		<3.0	
Zn	82.2†	17.1	33.0	4.2	34.0	1.0	30.7	9.0
Radionuclides								
U	6.23†	1.54	3.79	0.50	3.31	0.35	3.30	0.46
^{137}Cs	1.24†	0.48	0.28	0.29	0.43	0.17	<0.11	---
^{60}Co	0.25	0.10	<0.04	0.02	<0.07	---	<0.02	
^{40}K	5.88	2.71	5.88	2.87	4.8	0.20	7.03	2.87

† Mean statistically different from that of the corresponding reference soil (p=0.05).

Table 4.4. Concentrations of metals and nitrogen at two depths in Pine Plantation soils on sludge-treated and reference (untreated) sites. Soils were sampled 11/16/89, five months after sludge application ended. Metals were determined by Analytical Resources, Inc., Seattle, WA., by ICP and AA. TKN was determined by A&L Agricultural Laboratories, Memphis, TN. Arsenic and mercury (three depths for Hg) were determined by the University of Georgia Soil Testing and Plant Analysis Laboratory. Sample size was N=3 for reference soils, N=9 for sludge-treated (mean from all three types of sludge application plots--see text). Probability <0.05 indicates a significant difference between concentrations in sludge-treated and reference soils.

Element	Depth	Concentration in soil, mg/kg Mean ± Std. Dev.		Significance Probability
		Sludge-treated	Reference	
Ca	0-15 cm	784 ± 161	638 ± 152	0.20
	15-30 cm	529 ± 106	420 ± 186	0.22
Cd	0-15 cm	0.224 ± 0.103	0.119 ± 0.044	0.13
	15-30 cm	0.040 ± 0.025	0.027 ± 0.012	0.41
Cr	0-15 cm	19.6 ± 4.5	18.5 ± 12.1	0.89
	15-30 cm	21.0 ± 10.0	13.1 ± 4.7	0.22
Cu	0-15 cm	16.6 ± 2.0	6.2 ± 3.9	<0.01
	15-30 cm	6.7 ± 1.9	6.3 ± 4.4	0.85
K	0-15 cm	533 ± 100	518 ± 269	0.93
	15-30 cm	565 ± 138	522 ± 232	0.70
Mg	0-15 cm	689 ± 91	632 ± 295	0.78
	15-30 cm	750 ±111	700 ± 303	0.80
Ni	0-15 cm	8.67 ± 1.12	8.00 ± 5.29	0.85
	15-30 cm	7.66 ± 1.22	8.33 ± 5.86	0.86
Pb	0-15 cm	16.4 ± 2.3	14.3 ± 6.5	0.63
	15-30 cm	9.1 ± 2.3	9.0 ± 7.6	0.98

Table 4.4 (continued)

Element	Depth	Concentration in soil, mg/kg Mean ± Std. Dev.		Significance Probability
		Sludge-treated	Reference	
Zn	0-15 cm	80.3 ± 17.0	41.5 ± 22.8	0.01
	15-30 cm	43.9 ± 13.8	33.7 ± 14.4	0.30
N	0-15 cm	1810 ± 280	1537 ± 216	0.16
	15-30 cm	487 ± 136	553 ± 270	0.57
As	0-15 cm	5.74 ± 1.38	6.27 ± 3.13	0.68
	15-30 cm	5.30 ± 1.53	4.59 ± 2.92	0.58
Hg	0-15 cm	0.293 ± 0.08	0.092 ± 0.010	<0.01
	15-30 cm	0.074 ± 0.019	<0.056[a]	
	30+ cm	0.106 ± 0.081	0.067 ± 0.017	0.43

[a] Two of three values below the detection limit of 0.04 mg/kg, one value 0.056 mg/kg.

Table 4.5. Radionuclides at three depths in Pine Plantation soils on sludge-treated and reference (untreated) sites. Soils were sampled 11/16/89, five months after sludge application ended. ^{137}Cs, ^{60}Co, and naturally occurring ^{40}K, included for comparison, were determined by gamma emmission spectroscopy. Total U was determined by Elbert Carlton, ORAU, by INAA (neutron activation method). Sample size was N=3 for each soil, reference and sludge-only plots. ND indicates samples below detection limits—average detection limit noted in parentheses.

Element	Depth	Concentration in soil, Mean ± Std. Dev.	
		Sludge-treated	Reference
^{137}Cs, pCi/g	0-15 cm	0.35 ± 0.27	0.43 ± 0.02
	15-30 cm	0.041 ± 0.013	0.051 ± 0.028
	30+ cm	ND (<0.01)	ND (<0.05)
^{60}Co, pCi/g	0-15 cm	0.093[a] ± 0.011	ND (<0.03)
	15-30 cm	ND (<0.011)	ND (<0.012)
	30+ cm	ND	ND
^{40}K, pCi/g	0-15 cm	3.19 ± 0.56	2.47 ± 0.59
	15-30 cm	3.17 ± 0.49	3.17 ± 1.15
	30+ cm	3.70 ± 1.70	3.83 ± 1.00
U, mg/kg	0-15 cm	7.90[a] ± 0.74	3.81 ± 0.86
	15-30 cm	3.55 ± 0.45	3.37 ± 0.89
	30+ cm	1.05 ± 1.48	0.87 ± 1.50

[a] Mean for sludge-treated soils was significantly different from reference soils (T-test, $p<0.05$) (using the detection limit where the activity or concentration was below the detection limit).

Table 4.6. Concentrations of metals in the upper 0-15 cm in soils at the Cottonwood, Scarboro, and Hayfield 1 & 2 sites on sludge-treated and reference (untreated) areas. Soils were sampled 1/17/90. Metals were determined by Analytical Resources, Inc., Seattle, WA., by ICP and graphite furnace AA (cadmium). Sample size was 2 for reference soils, 3 for sludge-treated. The reference soils for the Scarboro site may also be taken as representative reference soils for the two hayfield sites.

	Concentration in soil, ppm. Mean ± Std. Dev.					
	Cottonwoods		Scarboro		Hayfield 1	Hayfield 2
Element	Sludge-treated	Reference	Sludge-treated	Reference	Sludge-treated	Sludge-treated
Ca	1897 ± 886	956 ± 91	1190 ± 118	1300 ± 155	1250 ± 182	1657 ± 150
Cd	0.502 ± 0.251	0.085 ± 0.007	0.272 ± 0.072	0.173 ± 0.032	0.240 ± 0.060	0.259 ± 0.022
Cr	35.1 ± 15.0	36.7 ± 6.6	29.3 ± 11.2	21.0 ± 3.3	32.0 ± 7.9	22.6 ± 0.9
Cu	48.9 ± 24.0	11.4 ± 3.7	11.6[a] ± 1.2	7.0 ± 0.1	15.1 ± 7.4	10.8 ± 1.5
K	972 ± 551	789 ± 23	450[a] ± 61	855 ± 16	889 ± 384	680 ± 548
Mg	1213 ± 929	841 ± 107	554[a] ± 61	922 ± 23	746 ± 106	1093 ± 45
Ni	18.7 ± 4.7	14.5 ± 2.1	6.0[a] ± 1.7	12.0 ± 1.4	8.7 ± 0.6	14.0 ± 1.0
Pb	47.7 ± 3.1	45.5 ± 7.8	20.0[a] ± 1.0	31.5 ± 2.1	23.7 ± 3.5	30.0 ± 5.3
Zn	177.7 ± 59.7	67.3 ± 16.4	64.9[a] ± 6.9	44.7 ± 3.1	74.4 ± 24.8	63.6 ± 3.9

[a] Mean metal concentration in sludge-treated soils was statistically different from the mean in the corresponding reference soil (p=0.05). (Note that for some metals the means were significantly *lower* in the sludge-treated soils.)

Table 4.7. Mean ^{99}Tc, ^{90}Sr, and total uranium in soils in sludge application areas (4 grassy fields and one wooded area) and associated reference areas. Samples were taken in May 1992, September 1992, and May 1993. Determinations of ^{99}Tc and ^{90}Sr were performed by Analytical Chemistry Division, ORNL. Total uranium was determined by neutron activation by Elbert Carlton of ORAU. Data are mean ± standard deviation; sample numbers are in parentheses. The reference values for the first three sites may be taken as representative references for the Upper Hayfield site as well.

	^{99}Tc, Bq/kg		^{90}Sr, Bq/kg		U, ppm	
	Sludge-treated	Reference	Sludge-treated	Reference	Sludge-treated	Reference
Rogers High Pasture	3.0 ± 0.8 (n=3)	1.5 (n=1)	5.2 ± 2.7 (n=3)	4.3 ± 2.3 (n=3)	4.9 ± 0.2 (n=3)	3.3 ± 0.3 (n=3)
Scarboro	1.5 ± 1.0 (n=3)	ND (n=1)	6.1 ± 1.0 (n=3)	6.7 ± 2.2 (n=3)	4.6 ± 0.8 (n=3)	3.5 ± 0.3 (n=3)
Upper Hayfield	0.5 ± 0.44 (n=3)	0.3 (n=1)	4.4 ± 2.7 (n=3)	2.7 ± 1.3 (n=3)	5.2 ± 1.0 (n=3)	4.1 ± 0.6 (n=3)
Upper Hayfield #2	2.0 ± 0.4 (n=3)		7.1 ± 4.6 (n=3)		4.6 ± 1.0 (n=3)	
Watson Road	3.3 ± 2.2 (n=5)	2.3 (n=1)	6.3 ± 3.5 (n=5)	5.6 ± 2.3 (n=3)	4.1 ± 0.9 (n=5)	4.3 ± 1.2 (n=3)

Table 4.8 Radionuclides in soils in sludge application areas (4 grassy fields and one wooded area) and associated reference areas. Samples were taken in May 1992, September 1992, and May 1993. Determinations were performed by I. L. Larsen, Environmental Sciences Division, ORNL. Data are means ± standard deviations. ND indicates that indicate that ^{60}Co was not detected in any of the samples for that site, with detection limits which varied from 0.005 to 0.012 depending on counting time. Values below detection limits were treated as zeros when calculating mean and standard deviations (only the Upper Hayfield sludge-treated sites had detectable ^{60}Co in all samples). Uranium was only detected in one sample, from the sludge-treated area of the Scarboro site (0.14 ± 0.06 pCi/g of ^{235}U, and 2.2 ± 1.0 pCi/g of ^{238}U). Sample number n=3, except n=5 for Watson Road, sludge-treated area (sampled in both 1992 and 1993). The reference values for the first three sites may be taken as representative references for the Upper Hayfield site as well.

	^{137}Cs, pCi/g		^{60}Co, pCi/g		^{40}K, pCi/g	
	Sludge-treated	Reference	Sludge-treated	Reference	Sludge-treated	Reference
Rogers High Pasture	0.45 ± 0.63	0.47 ± 0.06	0.06 ± 0.059	ND	4.14 ± 0.87	3.13 ± 0.53
Scarboro	0.81 ± 0.28	0.48 ± 0.11	0.03 ± 0.03	ND	3.78 ± 1.51	3.97 ± 1.04
Upper Hayfield	0.57 ± 0.15	0.54 ± 0.08	0.05 ± 0.02	0.01 ± 0.01	2.68 ± 0.20	3.04 ± 0.41
Upper Hayfield #2	0.77 ± 0.05		0.01 ± 0.03		4.80 ± 1.97	
Watson Road	0.59 ± 0.19	0.54 ± 0.15	0.01 ± 0.02	ND	7.45 ± 1.24	11.2 ± 1.70

Table 5.1. Concentrations of metals and nitrogen in herbaceous vegetation (grasses and weeds) from three sludge application sites and reference areas. Units are mg/kg.

A. Rogers site (Dates of Application: 12/86 - 5/88)				
	During Application ("Spring 1988")		2-years Post-Treatment (May 3, 1990)	
	Reference	Treatment	Reference	Treatment
Ag	<0.12	0.44		
Al	91.21	110.72	25	14.7
As	<1.1	<0.83	<0.82	<0.83
B	11.29	11.55	3.5	2.4
Ca	3200	5000	3800	4700
Cd	<0.14	<1.00	<0.082	<.083
Co	<0.098	<0.075		
Cr	0.83	1.32	0.32	0.52
Cu	15.33	39.58	6.0	6.6
Fe	103.50	155.97	50	48
K	15000	29000		
Mg	1600	2600	2000	1400
Mn	82.27	82.42	98	41
Mo	<.66	<.66	<0.65	<0.66
N	14000	23600		
Na	64.32	455.93	<82	<83
Ni	0.46	0.81	0.27	0.40
P	1600	3100	2300	4033
Pb	0.96	1.38	<0.82	<0.83
Se	<.82	<.83	<0.82	<0.83
U	0.13	0.68	<0.01	<0.02
Zn	21.63	48.87	22	28.7

B. Hayfield site (Dates of Application: 1/89 - 12/89)

	Post-Treatment (May 3, 1990)	
	Reference Area	Treatment Area
Al	37	44
As	<0.82	<0.83
B	2.9	3.5
Ca	5450	5400
Cd	<0.082	<0.083
Cr	0.43	0.46
Cu	4.4	7.1
Fe	58	70
Mg	1700	2275
Mn	25.5	72.5
Mo	<0.66	<0.66
Na	<0.82	<117
Ni	0.31	0.38
P	3100	4025
Pb	<0.82	<0.83
Se	<0.81	<0.83
U	<0.01	0.05
Zn	16	27

C. Pine Plantation-- Understory vegetaton (weeds), predominantly grasses. (Dates of Application: 6/88 - 6/89)

	During Application (July, 1988-May 1989)		1 Month Post-Treatment (July 17, 1989)	
	Reference	Treatment	Reference	Treatment
Al	1557	4675	960	1830
B	19	40	17	22
Ca	7280	20750	6700	9800
Cu	17	336	9	109
Fe	1650	8376	1343	2571
K	7480	8200	10500	13800
Mg	1800	3790	1900	2700
Mn	300	446	409	960
N	11800	27700	14600	29300
Na	300	500	100	300
P	1460	13500	1800	6400
S	900	4180	1000	2200
Zn	43	995	42	392

Table 5.2. Concentrations of ICP anlalytes, including metals, and nitrogen in Pine needles from sludge application and reference plots in the Pine Plantation (Dates of Application: 6/88 - 6/89). Units are mg/kg.

	During Application (July, 1988-May 1989)		1 Month Post-Treatment (July 17, 1989)		1 Year Post-Treatment (May 15, 1990)	
	Reference Area	Treatment Area	Reference Area	Treatment Area	Reference Area	Treatment Area
Al	430.00	1065.83	366.67	483.33	410	170
As					<0.83	<0.82
B	17.33	25.28	17.00	21.89	10.3	18.83
Ca	3100	4700	3400	3700	3775	4150
Cd					0.26	0.57
Cr					0.28	0.34
Cu	7.33	41.86	9.33	16.33	3.98	4.20
Fe	235.08	980.58	125.67	375.00	43	54
K	7700	8200	7900	8100		
Mg	1100	1400	1100	1100	1080	1008
Mn	306.42	333.64	264.33	529.00	532.5	1192
Mo					<0.66	<0.66
N	14800	20700	14100	18600		
Na	100	300	100	100	<83	<82
Ni					0.54	1.34
P	1800	2900	700	1800	1275	1500
Pb					<0.83	<0.82
S	600	900	500	600		
Se					<0.83	<0.9
U					0.03	0.11
Zn	48.25	172.89	51.33	87.11	47.75	105

Table 5.3. Concentrations of ICP analytes and nitrogen in berries from the Pine Plantation (dates of application: 6/88 - 6/89). Means (± std) for each element are reported for reference and treatment plots. When one or more values were below the detection limit, then the mean is given as "< *xx.x*", indicating the maximum possible mean, that is, assuming that the values less than the detection limit were in fact equal to the detection limit. Superscripts indicate the number of values greater than the detection limit of the measurement. The range of reported detection limits is listed in the next column. Only Mn concentrations were significantly different in berries from the treatment and reference sites (p<0.01).

	1 Year Post-Treatment (June, 1990)		
	Reference Area	Treatment Area	Detection limits (if some < limit)
	(n=3)	(n=3)	
Ag	$<0.09^{2}$	$<0.33^{1}$	0.083
Al	49.0 (±38)	22.0 (±5.2)	
As	1.90 (±1.1)	1.57 (±0.4)	
B	23.0 (+18)	20.0 (±1.7)	
Ba	16.0 (+5.0)	12.5 (±6.9)	
Be	$<0.007^{1}$	$<0.02^{0}$	0.005--0.053
Ca	2283 (±752)	2433 (±945)	
Cd	$<0.07^{1}$	0.16 (±0.015)	
Co	$<0.42^{2}$ (±0.007)	3.24 (±3.9)	0.064
Cr	0.44 (±0.31)	0.21 (±0.02)	
Cu	12.0 (±4.0)	7.13 (±3.4)	
Fe	48.0 (±36.4)	62.3 (±58.6)	
Li	$<250^{0}$	$<250^{0}$	240--250
Mg	2967 (±2454)	1833 (±208)	

Table 5.3 (continued)

	1 Year Post-Treatment (June, 1990)		
	Reference Area	Treatment Area	Detection limits (if some < limit)
Mn	43 (±26)	270 (±70)	
Mo	<0.50[1]	<0.66[0]	0.17-0.66
Na	<81.00[1]	<0.83[0]	0.83
Ni	0.44 (±0.16)	4.32 (±5.79)	
P	1867 (±666)	2600 (±265)	
Pb	<5.00[1]	<0.83[0]	0.83
Sb	<0.82[0]	<0.82[0]	
Se	<0.82[0]	<28.00[0]	0.8-83
Si	6.00 (±4.36)	<4.50[2]	3.3
Sn	<0.82[0]	<28[0]	0.8-83
Sr	37.6 (±54)	6.5 (±2.59)	
Ti	<0.49[1]	<0.33[0]	0.33
V	<0.10[1]	<0.033[0]	0.033
Zn	19.0 (±8.5)	26.0 (±5.0)	
Zr	<0.33[0]	<0.33[0]	0.33

Table 5.4. Radionuclides in vegetation on sludge application and reference areas (dry weight basis). Values are means ± std deviations *or* ranges [in brackets] for n = 3 to 6 treatment samples and n = 2 to 3 reference samples. Data for the Rogers pasture and Pine Plantation sites taken from Boston *et al.* 1990.

I. Grasses			
Site -- Sampling		Sludge-treated	Reference
Rogers -- 1988 (at the end of application)			
	^{137}Cs (pCi/kg)	61 ± 52	[61 - <200]
	^{60}Co (pCi/kg)	[59 - <200]	<86
	^{40}K (pCi/kg)	27400 ± 5800	18900 ± 4420
	^{7}Be (pCi/kg)	5360 ± 2930	13800 ± 8200
Rogers -- 1990 (two years after application)			
	U (mg/kg)	[<0.01 - 0.03]	<0.01
	^{137}Cs (pCi/kg)	[<14 - 34]	[<16 - 26]
	^{60}Co (pCi/kg)	<16	<24
	^{40}K (pCi/kg)	26100 ± 5200	22300 ± 1660
	^{7}Be (pCi/kg)	1490 ± 662	3440 ± 383
Hayfield 1 and 2 -- 1990 (one to three months after application)			
	^{137}Cs (pCi/kg)	44 ± 9	14.2 ± 1.6
	^{60}Co (pCi/kg)	<14.2	<14.3
	^{40}K (pCi/kg)	22018 ± 4242	19440 ± 4766
	^{7}Be (pCi/kg)	2337 ± 523	1334 ± 556
II. Pine needles (new growth)			
Site -- Sampling		Sludge-treated	Reference
Pine Plantation -- 1990 (one year after application)			
	U (mg/kg)	0.11 ± 0.08	0.03 ± 0.01
	^{137}Cs (pCi/kg)	[<15 - 34]	<15
	^{60}Co (pCi/kg)	[<12 - 29]	<15
	^{40}K (pCi/kg)	3618 ± 287	3811 ± 602
	^{7}Be (pCi/kg)	1913 ± 67	2381 ± 359

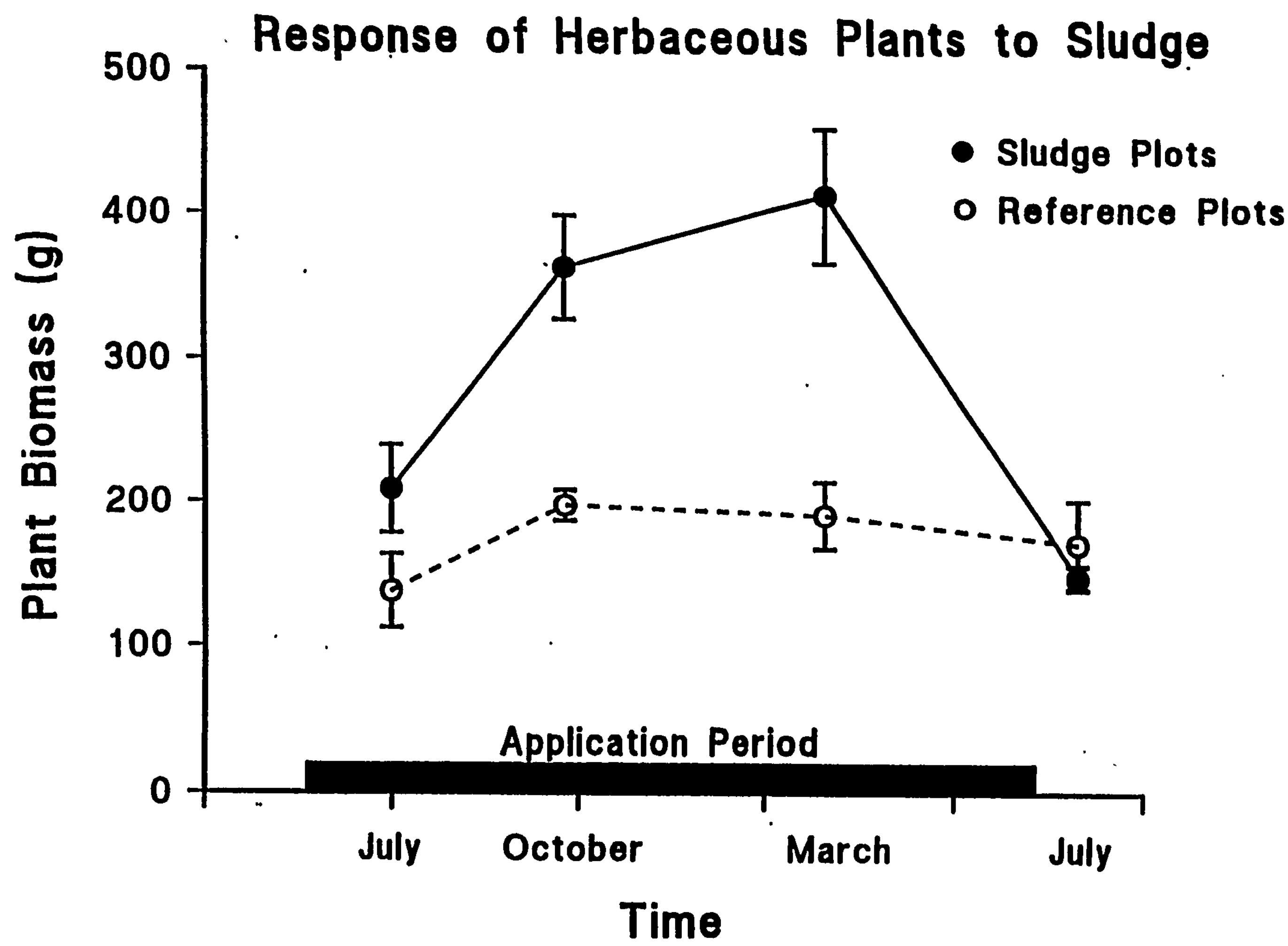

Fig. 5.1. Response of herbaceous plants to sludge application.
Mass of plants growing in the understory of a young pine plantation on the Oak Ridge Reservation. Samples were dried and weighed. The black bar indicates the sludge application period, from June 10, 1988 to June 30, 1989. Values indicated are g/m^2, mean ± standard error for nine samples per treatment.

Table 6.1. Soil water chemistry (including metals) from lysimeters at the Pine Plantation site. These 3-foot, or "B" depth lysimeters sampled soil water from 40-60 cm deep in the soil profile. The four treatment codes designate the following: "S"= sludge application only, "D"= sludge application plus sawdust, "H"= sludge appplication plus herbicide to the understory, and "R"= reference (no sludge applied).

a. Metals Data. The mean listed is the mean of those values which were above the detection limits for the analysis method used for each measurement. ND indicates that no samples had detectable levels of the metal. Mercury data is for both "A" (10-15 cm) and "B" lysimeters. Units are mg/L for all metals.

	Detection Limit (ppm)	Treatment	# Detects/ Total	Mean	Range
Al	0.05	S	49/89	0.604	0.051- 3.41
		D	25/31	0.230	0.054- 0.634
		H	26/30	0.219	0.057- 1.044
		R	32/63	0.238	0.054- 2.002
B	0.02	S	86/89	0.049	0.021- 0.114
		D	29/31	0.049	0.023- 0.095
		H	29/30	0.044	0.024- 0.080
		R	41/63	0.034	0.020- 0.073
Ca	1.0	S	89/89	90.41	17.2- 301.2
		D	31/31	88.09	16.3- 198.5
		H	30/30	78.77	25.2- 220.0
		R	63/63	4.88	1.91- 17.97
Cd	0.001- 0.01	S	7/89	0.0058	0.001- 0.019
		D	3/31	0.0024	0.001-0.003
		H	3/29	0.0016	0.001- 0.002
		R	0/63	ND	
Cr	0.001- 0.005	S	28/89	0.013	0.001- 0.044
		D	11/32	0.017	0.003- 0.035
		H	9/29	0.014	0.001- 0.029
		R	18/63	0.023	0.002- 0.056
Cu	0.01- 0.02	S	14/89	0.030	0.011- 0.055
		D	10/31	0.040	0.012- 0.162

Table 6.1 (continued)

	Detection Limit (ppm)	Treatment	# Detects/ Total	Mean	Range
		H	6/30	0.018	0.011- 0.027
		R	3/63	0.028	0.011- 0.042
Fe	0.003- 0.004	S	79/89	0.026	0.003- 0.209
		D	28/30	0.026	0.006- 0.124
		H	28/30	0.029	0.004- 0.195
		R	36/63	0.032	0.003- 0.365
K	0.05	S	76/89	3.763	0.262- 20.54
		D	30/31	6.356	0.351- 17.81
		H	30/30	6.185	1.736- 17.94
		R	26/63	0.250	0.060- 0.589
Mg	0.5	S	89/89	24.16	3.61- 71.26
		D	31/31	22.19	6.22- 60.65
		H	30/30	20.67	5.87- 60.44
		R	63/63	1.92	0.95- 4.38
Mn	0.005	S	85/89	1.55	0.006- 18.79
		D	31/31	2.23	0.139- 14.21
		H	30/30	2.89	0.052- 16.16
		R	45/63	0.029	0.006- 0.242
Mo	0.02	S	19/87	0.045	0.021- 0.045
		D	7/31	0.038	0.022- 0.100
		H	9/29	0.035	0.023- 0.048
		R	3/63	0.023	0.020- 0.029
Na	0.5	S	89/89	6.33	0.754- 26.26
		D	31/31	5.24	1.74- 13.79
		H	30/30	5.05	1.02- 17.05
		R	60/63	0.877	0.503- 1.68
Ni	0.005	S	43/88	0.014	0.005- 0.042

Table 6.1 (continued)

	Detection Limit (ppm)	Treatment	# Detects/ Total	Mean	Range
		D	17/31	0.016	0.007- 0.037
		H	17/29	0.015	0.006- 0.032
		R	19/63	0.011	0.005- 0.023
Pb	0.01- 0.02	S	0/89	ND	
		D	0/31	ND	
		H	2/30	0.016	0.011- 0.020
		R	1/63	0.021	0.021
Zn	0.01	S	89/89	0.218	0.026- 1.854
		D	31/31	0.185	0.030- 0.817
		H	30/30	0.230	0.029- 0.921
		R	63/63	0.044	0.013- 0.209
Hg	0.0008	S	0/33	ND	
		R	0/33	ND	

b. Additional water chemistry for Pine Plantation "B" lysimeters. Units for conductivity are μmhos/cm; for alkalinity, mg/L; for NO_3-N, mg N/L; for NH_4-N, μg N/L; and for Total N and P, mg/L.

	Treatment	Sample size (*n*)	Mean	Range
Conductivity	S	109	639	103-2300
	D	39	588	80-1787
	H	36	631	120-1953
	R	78	49	24-150
pH	S	105	5.85	3.94-7.53
	D	39	5.97	4.68-7.39
	H	36	5.58	4.39-6.83
	R	75	5.96	4.94-7.42
Alkalinity	S	63	9.30	0.3-38.5
	D	25	16.9	0.2-68
	H	18	4.33	0.1-27
	R	41	9.85	0.22-90
NO_3-N	S	110	68.32	0.436-277
	D	33	58.06	0.489-201
	H	37	64.82	4.09-233
	R	78	0.146	0-3.81
NH_4-N	S	109	703.49	0-15060
	D	33	1050	4.92-10898
	H	37	1214	4.76-11976
	R	79	19.87	0-545.6
Total N	S	106	70.94	0.206-278.0
	D	33	61.71	0.959-207.7
	H	33	69.53	0.57-231.86
	R	64	0.544	0.053-3.85
Total P	S	106	0.757	0.009-8.90
	D	33	0.720	0.012-2.655
	H	32	0.87	0.01-4.26
	R	64	0.0132	0-0.122

Table 6.2. Soil water chemistry (including metals) from deep lysimeters at the Pine Plantation site. These 6-foot, or "C" depth lysimeters sampled soil water from 120-150 cm depth in the soil profile. The four treatment codes designate the following: "S"= sludge application only, "D"= sludge application plus sawdust, "H"= sludge appplication plus herbicide to the understory, and "R"= reference (no sludge applied).

a. Metals Data. The mean listed is the mean of those values which were above the detection limits for the analysis method used for each measurement. ND indicates that no samples had detectable levels of the metal. No samples were large enough for mercury analyses. Units are mg/L for all metals.

	Detection Limit (ppm)	Treatment	# Detects/ Total	Mean	Range
Al	0.05	S	3/4	0.770	0.095-1.740
		D	0/1	ND	
		H	1/2	0.060	
		R	3/5	1.242	0.132-3.305
B	0.02	S	4/4	0.033	0.028-0.041
		D	0/1	ND	
		H	1/2	0.028	0.028
		R	4/5	0.031	0.023-0.048
Ca	1.0	S	4/4	26.85	3.11-42.37
		D	1/1	3.89	3.89
		H	2/2	11.16	4.44-17.87
		R	5/5	13.52	2.29-56.71
Cd	0.001- 0.01	S	0/4	ND	
		D	0/1	ND	
		H	0/2	ND	
		R	0/5	ND	
Cr	0.001- 0.005	S	1/4	0.0235	0.0235
		D	0/1	ND	
		H	0/2	ND	
		R	3/5	0.0103	0.007-0.015
Cu	0.01- 0.02	S	1/4	0.0234	0.0234
		D	0/1	ND	

Table 6.2.a (continued)

	Detection Limit (ppm)	Treatment	# Detects/ Total	Mean	Range
		H	0/2	ND	
		R	0/5	ND	
Fe	0.003- 0.004	S	5/5	0.0058	0.003-0.0083
		D	0/1	ND	
		H	2/2	0.016	0.011-0.022
		R	3/5	0.0069	0.003-0.014
K	0.05	S	5/5	1.366	0.114-2.172
		D	1/1	0.495	0.495
		H	2/2	0.497	0.254-0.740
		R	5/5	0.825	0.363-2.492
Mg	0.5	S	5/5	9.213	0.677-15.32
		D	1/1	0.897	0.897
		H	2/2	3.608	0.889-6.327
		R	5/5	5.55	0.977-22.53
Mn	0.005	S	5/5	0.443	0.083-0.840
		D	1/1	0.016	0.016
		H	2/2	0.0289	0.0103-0.047
		R	5/5	0.1996	0.015-0.910
Mo	0.02	S	1/5	0.020	0.020
		D	0/1	ND	
		H	0/2	ND	
		R	0/4	ND	
Na	0.5	S	5/5	2.87	0.97-3.79
		D	1/1	0.878	0.878
		H	2/2	1.075	0.953-1.196
		R	5/5	1.987	1.005-4.667

Table 6.2.a (continued)

	Detection Limit (ppm)	Treatment	# Detects/ Total	Mean	Range
Ni	0.005	S	4/5	0.224	0.104-0.383
		D	1/1	0.0083	0.0083
		H	1/2	0.0081	0.0081
		R	5/5	0.0806	0.052-0.128
Pb	0.01- 0.02	S	0/5	ND	
		D	0/1	ND	
		H	0/2	ND	
		R	0/5	ND	
Zn	0.01	S	5/5	0.125	0.043-0.241
		D	1/1	0.031	0.031
		H	2/2	0.034	0.022-0.047
		R	5/5	0.057	0.029-0.118

b. Additional water chemistry for Pine Plantation "C" lysimeters. Data were not usually available from D or H lysimeters (see text). Units for conductivity are µmhos/cm; for alkalinity, mg/L; for NO_3-N, mg N/L; for NH_4-N µg N/L; and for Total N and P, mg/L.

	Treatment	Sample size (*n*)	Mean	Range
Conductivity	S	12	354.5	111-562
	R	9	41.9	25-70
pH	S	10	5.56	4.45-7.24
	R	9	5.67	4.96-6.16
Alkalinity	S	8	10.42	0.40-64.4
	R	8	9.84	0.046-65.84
NO_3-N	S	10	48.48	11.55-145.39
	D	1	11.01	11.01
	R	7	9.84	0.046-65.85
NH_3-N	S	10	105.78	32.45-173.32
	D	1	6.64	6.64
	R	7	40.33	5.00-71.63
Total N	S	8	39.30	11.31-90.21
	R	6	0.66	0.15-1.19
Total P	S	8	0.021	0.01-0.04
	R	6	0.013	0.006-0.021

Table 6.3. Soil water chemsitry and metals at the Rogers site, measured in 40 to 60 cm deep lysimeters.

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
pH through Pb(graphite furnace), 3/87- 4/88						
pH	Sludge	52	NA	6.81	5.26- 8.33	---
	Reference	42	NA	6.73	5.48- 8.06	---
Alkal. (mg/L)	Sludge	38	---	88.4	3- 448	---
	Reference	33	---	28.11	1.05- 109	---
Conduct. (μmhos/cm)	Sludge	58	---	627	34- 1668	---
	Reference	46	---	108	37- 520	---
NO_3-N (mg N/L)	Sludge	65	---	66	0- 472	---
	Reference	52	---	1.69	0- 27.9	---
NH_4-N (μg N/L)	Sludge	36	---	188	0- 2027	---
	Reference	26	---	66.2	1.4- 362.2	---
TKN (mg N/L)	Sludge	15	---	20.16	0.25- 100	---
	Reference	12	---	0.52	0.14 -1.38	---
Total P (mg/L)	Sludge	21	20	0.290	0- 1.45	0.02
	Reference	18	18	0.047	0.004- 0.16	---
SO_4 (mg/L)	Sludge	22	22	54.60	4.83- 278	---
	Reference	14	14	19.52	6.08- 33.6	---
Cl (mg/L)	Sludge	8	8	5.53	1.16- 11.1	---
	Reference	4	4	3.48	1.56- 8.18	---
Cd (μg/L) (graphite furnace)	Sludge	13	4	0.55	0.1- 1.5	1
	Reference	11	3	0.96	0.1- 2.6	0.1- 1
Hg (μg/L) (cold vapor)	Sludge	13	1	0.1	---	0.1- 0.2
	Reference	12	1	0.3	---	0.1- 0.2
Pb (μg/L) (graphite furnace)	Sludge	14	13	2.34	0.6- 5.0	1
	Reference	12	11	2.73	0.7- 6	1
NO_3 (mg/L) (3/87- /90)	Sludge	109	109	54.69	0.014- 472	---
	Reference	83	83	1.28	0.001- 27.9	---

Table 6.3 (continued)

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
Total P (mg/L) (11/88-3/90)	Sludge	40	40	0.227	0- 1.58	---
	Reference	45	45	0.858	0- 10	---
ICP: 3/87-2/90 where available. (mg/L)						
Ag	Sludge	7	0	---	---	0.006- 0.1
	Reference	0	---	---	---	---
Al	Sludge	36	27	0.043	0- 0.14	0- 0.4
	Reference	19	14	0.015	0- 0.047	0- 0.06
As	Sludge	7	0	---	---	0.017- 0.2
	Reference	0	---	---	---	---
B	Sludge	34	28	0.036	0.006- 0.208	0.035- 0.16
	Reference	19	15	0.026	0.006- 0.132	0
Ba	Sludge	13	12	0.146	0.012- 0.36	0.33
	Reference	10	9	0.070	0.006- 0.43	0.02
Be	Sludge	9	1	0.00048	---	0.0003- 0.004
	Reference	0	---	---	---	---
Ca	Sludge	38	38	94.55	12- 360	---
	Reference	29	29	17.16	2- 49.45	---
Cd	Sludge	26	0	---	---	0- 0.01
	Reference	16	0	---	---	0- ?
Co	Sludge	9	2	0.0040	0.002- 0.006	0.0017- 0.4
	Reference	2	1	0.0031	---	0.0017
Cr	Sludge	32	14	0.0135	0- 0.0564	0- 0.8
	Reference	20	8	0.0027	0- 0.009	0- 0.006

Table 6.3 (continued)

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
Cu	Sludge	38	21	0.0168	0.0002- 0.092	0.003- 0.04
	Reference	22	9	0.0137	0- 0.048	0- 0.02
Hg	Sludge	4	4	0.0056	0.0008- 0.0199	---
	Reference	2	2	0.0021	0.0013- 0.003	---
Fe	Sludge	37	28	0.012	0.0008- 0.033	0.005- 0.06
	Reference	21	14	0.004	0- 0.026	0- ?
Ga	Sludge	7	0	---	---	0.05- 0.6
	Reference	0	0	---	---	---
K	Sludge	38	35	3.415	0- 21	0- 0.4
	Reference	27	22	0.663	0- 4	0-0.4
Li	Sludge	7	0	---	---	0.088- 0.4
	Reference	0	0	---	---	---
Mg	Sludge	38	38	11.54	2.19- 32	---
	Reference	29	29	1.78	0.079- 3.9	---
Mn	Sludge	38	36	0.0503	0.0008- 0.269	0.005- 0.03
	Reference	28	25	0.0316	0- 0.545	0.005
Mo	Sludge	33	18	0.0099	0- 0.059	0.0067- 0.08
	Reference	19	11	0.0005	0- 0.002	0- ?
Na	Sludge	38	37	4.755	0.944- 17.18	5
	Reference	29	29	1.788	0.717- 3.2	---
Ni	Sludge	31	15	0.004	0- 0.0112	0.006- 0.12
	Reference	21	12	0.002	0- 0.009	0- 0.006

Table 6.3 (continued)

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
P	Sludge	35	30	0.436	0.0096-2.35	0.3- 0.6
	Reference	21	9	0.29	0.0026-2.35	0.05- 0.3
Pb	Sludge	32	11	0.0053	0- 0.0364	0- 0.4
	Reference	19	7	0.0006	0- 0.0022	0- ?
Sb	Sludge	7	0	---	---	0.03- 0.4
	Reference	0	---	---	---	---
Se	Sludge	7	0	---	---	0.033- 0.4
	Reference	0	---	---	---	---
Si	Sludge	13	13	2.931	1.4-7.2	---
	Reference	12	12	3.008	1-5.4	---
Sn	Sludge	7	0	---	---	0.0083-0.1
	Reference	0	---	---	---	---
Sr	Sludge	13	13	0.19	0.066- 0.44	---
	Reference	12	12	0.037	0.0044-0.21	---
Ti	Sludge	9	2	0.00435	0.0042-0.0045	0.003- 0.04
	Reference	1	0	---	---	0.0033
V	Sludge	12	8	0.0405	0.01- 0.094	0.008- 0.04
	Reference	5	3	0.0353	0.024-0.058	0.004- 0.02
Zn	Sludge	38	37	0.062	0.005-0.185	0.003
	Reference	27	24	0.0439	0.0134-0.24	0.008- 0.02
Zr	Sludge	8	3	0.023	0.0092-0.04	0.003-0.04
	Reference	0	---	---	---	---

Table 6.4. Soil water chemistry and metals in 3-foot lysimeters (sampling 40 to 60 cm depth) at the Cottonwood site.

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
pH	Sludge	13	13	5.80	4.82- 6.58	---
	Reference	15	15	6.71	5.55- 7.81	---
Alkal. (mg/L)	Sludge	11	11	15.15	3.0- 62.1	---
	Reference	15	15	70.61	3.0- 248	---
Conduct. (µmhos/cm)	Sludge	14	14	389.1	37- 883	---
	Reference	15	15	101.6	5.0- 316	---
NO_3-N (mg N/L)	Sludge	18	18	47.34	2.46- 112.5	---
	Reference	15	15	4.74	0.01- 51.7	---
NH_3-N (µg N/L)	Sludge	18	18	1581	7.0- 13000	---
	Reference	15	15	286.4	5.0- 3310	---
Total N (mg N/L)	Sludge	9	9	63.64	21.49- 108.79	---
	Reference	15	15	2.47	0.064- 30.58	---
Total P (mg/L)	Sludge	9	9	0.655	0.01- 3.64	---
	Reference	15	15	0.690	0.01- 10	---
Al-Zn (mg/L) 11/89-2/90				If detect. limits = 0	(Except Hg)	
Al	Sludge	14	14	0.22	0.01- 0.85	
	Reference	10	10	0.04	0.008- 0.076	
B	Sludge	14	14	0.042	0.02- 0.067	
	Reference	10	10	0.021	0.013- 0.032	
Ca	Sludge	14	14	84.62	9.68- 209.5	
	Reference	10	10	23.95	3.64- 77.41	

Table 6.4 (continued)

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
Cd	Sludge	14	0			
	Reference	10	1	0.0005		
Cr	Sludge	14	8	0.029	0.0029-0.063	
	Reference	10	4	0.024	0.0029-0.053	
Cu	Sludge	14	7	0.013	0.006- 0.02	
	Reference	10	3	0.031	0.004-0.059	
Hg	Sludge	6	0			4
	Reference	5	0			4
Fe	Sludge	14	13	0.0224	.005-0.074	
	Reference	10	8	0.0105	0.0016-0.0453	
K	Sludge	14	14	3.56	0.023- 12.8	
	Reference	10	10	0.752	0.061- 2.08	
Mg	Sludge	14	14	9.50	0.957-21.34	
	Reference	10	10	1.90	0.51- 5.54	
Mn	Sludge	14	14	0.878	0.01- 3.26	
	Reference	10	10	0.087	0.0008-0.54	
Mo	Sludge	14	14	0.0130	0.0003-0.0438	
	Reference	10	7	0.0079	0.0008-0.0214	
Na	Sludge	14	14	8.77	2.49- 17.18	
	Reference	10	10	1.33	0.81- 2.14	

Table 6.4 (continued)

	Treatment	Number of Samples Analyzed	Values Above Detection Limits			Range of Detection Limits
			Number	Mean	Range	
Ni	Sludge	14	8	0.0110	0.0025-0.291	
	Reference	10	1	0.0107		
P	Sludge	14	14	1.374	0.0035-6.699	
	Reference	10	8	0.028	0.0035-0.0595	
Pb	Sludge	14	2	0.0013	0.0008-0.0017	
	Reference	10	1	0.0011		
Zn	Sludge	14	14	0.104	0.036-0.198	
	Reference	10	10	0.036	0.028-0.056	

Table 6.5. Soil water metal concentrations at the McCoy and Sycamore sites, from lysimeter samples.

a. McCoy site, sampled 12/15/87 and 1/19/88.

	Treatment	Number of samples above detection limit/ Number of samples analyzed	Mean, mg/L, assuming values below detection limit=0
Al	Sludge	3/4	0.114
	Reference	3/4	0.063
As	Sludge	0/1	
	Reference	0/0	
B	Sludge	0/1	
	Reference	0/0	
Ba	Sludge	9/9	0.173
	Reference	6/7	0.048
Be	Sludge	0/5	
	Reference	0/0	
Ca	Sludge	9/9	238.9
	Reference	7/7	26.1
Cd	Sludge	0/2	
	Reference	0/0	
Co	Sludge	0/2	
	Reference	0/0	
Cr	Sludge	0/2	
	Reference	0/0	
Cu	Sludge	0/2	
	Reference	0/0	
Hg	Sludge	1/1	0.089
	Reference	0/0	
Fe	Sludge	5/8	0.030
	Reference	5/6	0.039
K	Sludge	9/9	0.721
	Reference	7/7	0.763
Mg	Sludge	9/9	10.52
	Reference	7/7	2.37

Table 6.5.a (continued)

	Treatment	Number of samples above detection limit/ Number of samples analyzed	Mean, mg/L, assuming values below detection limit=0
Mn	Sludge	6/8	8.200
	Reference	2/2	0.006
Na	Sludge	9/9	7.28
	Reference	7/7	1.31
Ni	Sludge	0/1	
	Reference	0/0	
P	Sludge	0/2	
	Reference	0/0	
Pb	Sludge	0/2	
	Reference	0/0	
Si	Sludge	5/5	3.1
	Reference	2/2	3.0
Sn	Sludge	1/3	0.015
	Reference	0/0	
Sr	Sludge	8/8	0.223
	Reference	7/7	0.060
Ti	Sludge	1/2	0.025
	Reference	0/0	
V	Sludge	5/5	0.0852
	Reference	2/2	0.086
Zn	Sludge	6/7	0.031
	Reference	5/5	0.014

b. Sycamore site, sampled 03/03/89, 5/12/89 and 6/13/89.

	Treatment	Number of samples above detection limit/ Number of samples analyzed	Mean, mg/L, assuming values below detection limit=0
Al	Sludge	6/10	0.031
	Reference	5/7	0.029
B	Sludge	10/10	0.024
	Reference	6/7	0.023
Ca	Sludge	10/10	12.63
	Reference	7/7	4.12
Cd	Sludge	0/10	
	Reference	0/7	
Cr	Sludge	3/10	0.002
	Reference	3/7	0.001
Cu	Sludge	1/10	0.001
	Reference	1/7	0.006
Hg	Sludge	3/3	0.0116
	Reference	0/0	
Fe	Sludge	4/7	0.0015
	Reference	4/7	0.0093
K	Sludge	9/10	0.537
	Reference	5/7	0.142
Mg	Sludge	10/10	1.32
	Reference	7/7	0.87
Mn	Sludge	10/10	0.093
	Reference	7/7	0.051
Mo	Sludge	2/10	0.0075
	Reference	3/7	0.0083
Na	Sludge	10/10	1.40
	Reference	7/7	1.07

Table 6.5.b (continued)

	Treatment	Number of samples above detection limit/ Number of samples analyzed	Mean, mg/L, assuming values below detection limit=0
Ni	Sludge	6/10	0.0064
	Reference	1/7	0.0004
P	Sludge	6/10	0.0172
	Reference	3/7	0.0072
Pb	Sludge	1/10	0.0006
	Reference	2/7	0.0035
Zn	Sludge	10/10	0.0486
	Reference	7/7	0.0411

Table 6.6. Radionuclides measured in lysimeters at the Pine Plantation site at the end of the sludge application period (6/88 through 6/89), and one sample before sludge application began.

Radionuclides in soil water				
Plot Number	Treatment of Plot	Sample Date	Cs 137 (pCi/L)	Co 60 (pCi/L)
3	Sludge only	07/05/89	<2.6	<2.05
6	Sludge only	07/05/89	<2.6	2.9
8	Sludge only	07/05/89	<2.2	<2.9
12 & 13	Reference	07/05/89	<2.3	<2.5
8	"Sludge only" (Before Treatment)	10/14/87	<5.4	<5.4

Table 7.1. Groundwater chemistry at the Pine Plantation site. Some samples had inadequate volume to perform all analyses. Data reflect sample collections during and for 19 months after sludge application. Wells numbered 1133 and 1134 can be considered upgradient of the sludge application area, (reference wells), and those numbered 1130, 1131, and 1132 can be considered down-gradient. Units for fecal coliform are colonies/100mL, for conductivity, µmhos/cm, for alkalinity meq/L, for NO_3 mg/L, for NH_4 µg/L, for total N mg/L, and for total P, mg/L.

Well number: 1130 (Downgradient)

	Mean	Median	Range	Number of samples analyzed
Fecal Coliform	0	0	0-0	19
Conductivity	212.1	220.5	31-250	32
Alkalinity	2.39	2.36	1.92-3.18	31
pH	7.66	7.57	7.0-9.0	31
NO_3	0.327	0.298	0.21-0.72	32
NH_4	10.9	7.17	1.6-27.0	19
Total N	0.43	0.345	0.15-1.28	9
Total P	0.010	0.011	0.005-0.012	9

Well number: 1131 (Downgradient)

	Mean	Median	Range	Number of samples analyzed
Fecal Coliform	779	14	1-9800	13
Conductivity	193.6	198	31-248	31
Alkalinity	1.78	1.77	0.84-2.64	30
pH	7.0	7.1	6.2-7.5	30
NO_3	2.24	1.84	0.23-6.07	29
NH_4	10.44	7.02	0.74-29.0	17
Total N	2.61	2.134	0.38-6.88	8
Total P	0.014	0.014	0.008-0.027	8

Well number: 1132 (Downgradient)

	Mean	Median	Range	Number of samples analyzed
Fecal Coliform	1.58	0	0-10	19
Conductivity	29.7	28.8	7-50	30
Alkalinity	0.28	0.17	0.01-1.48	24
pH	5.73	5.75	5.03-6.45	29
NO_3	0.68	0.69	0.43-0.81	28
NH_4	10.3	10.5	0.01-25.2	17
Total N	0.713	0.739	0.61-0.77	8
Total P	0.009	0.008	0.003-0.014	8

Well number: 1133 (Upgradient)

	Mean	Median	Range	Number of samples analyzed
Fecal Coliform	2.3	0	0-16	10
Conductivity	17.8	17.2	5-33.7	12
Alkalinity	0.16	0.09	0.06-0.60	7
pH	5.35	5.30	4.96-5.81	12
NO_3	0.193	0.144	0.073-0.67	12
NH_4	17.41	10.70	5.09-76.8	10
Total N	0.10	0.092	0.08-0.13	3
Total P	0.018	0.017	0.009-0.031	4

Well number: 1134 (Upgradient)

	Mean	Median	Range	Number of samples analyzed
Fecal Coliform	0.5	0	0-2	16
Conductivity	274	285	46-310	31
Alkalinity	2.85	2.96	0.02-3.34	30
pH	7.88	7.87	7.51-8.25	30
NO_3	0.326	0.295	0.004-1.99	31
NH_4	11.004	10.00	3.28-27.61	19
Total N	0.343	0.392	0.02-0.45	8
Total P	0.011	0.009	0.003-0.021	8

Table 7.2 Metal concentrations (mg/L) in wells at the Pine Plantation during and for 9 months after sludge application. Analyses were by ICP. Hg was analyzed only twice for each well (5/89 and 7/89) and was below the detection limit of 0.0005 for all samples. Total U was analyzed one time for each well, six months after application ended (6/90), and was below the detection limit of 0.001 for all samples. Means are listed as "<" the maximum detection limit (different samples were sent to labs with different detection limits) if all values were below the detection limit (no range for concentrations given), or as "<" the mean of the detectable concentrations if some but not all of the values were below the detection limits for that element. Well identities are described in the text and in Table 7.1. Detection limits (or ranges of them) are given if some samples concentrations were reported as below the detection limits.

Well number: 1130 (Downgradient)

	Mean	Range	Detection Limit	Number of samples above detection limit	Number of samples analyzed
Ag	<0.006		0.006	0	7
As	<0.06		0.06	0	7
Ba	0.032	0.014 - 0.048		5	5
Ca	25.3	16 - 31		10	10
Cd	<0.007		0.001 - 0.007	0	10
Cr	<0.007	<0.004 - 0.023	0.004 - 0.01	7	10
Cu	<0.02		0.005 - 0.02	0	10
Fe	<0.048	0.0006 - 0.07	0.003 - 0.02	0	10
K	<1.88	<0.02 - 6.09	0.02	6	8
Mg	12.7	0.02 - 16		10	10
Mn	<0.007	0.004 - 0.018	0.002 - 0.04	6	10
Na	<2.5	<0.5 - 5.0	0.5	8	10
Pb	<0.05		0.01 - 0.05	0	8
Se	<0.06		0.01 - 0.06	0	8
Sr	0.023	0.018 - 0.035		4	4
Zn	<0.02	0.006 - 0.046	0.005 - 0.008	8	10

Well number: 1131 (Downgradient)

	Mean	Range	Detection Limit	Number of samples above detection limit	Number of samples analyzed	D.W.S.*
Ag	<0.006		0.006	0	6	0.05
As	<0.06		0.06	0	6	0.05
Ba	0.109	0.04 - 0.18		4	4	1.0
Ca	19.3	0.23 - 27.9		10	10	
Cd	<0.007		0.001 - 0.007	0	10	0.01
Cr	<0.004	≤0.004 - 0.006	0.005	4	10	0.05
Cu	<0.018		0.001 - 0.01	0	10	1.0
Fe	<0.056	0.003 - 0.14	0.003 - 0.02	8	10	0.3
K	1.6	1.2 - 2.1		8	8	
Mg	11.1	5.8 - 14.0		10	10	
Mn	<0.007	<0.002 - 0.023	0.002	7	10	0.05
Na	<6.6	<0.5 - 12	0.5	9	10	
Pb	<0.05		0.01 - 0.05	0	10	0.05
Se	<0.06		0.01 - 0.06	0	8	0.01
Sr	0.028	0.024 - 0.030		4	4	
Zn	<0.064	0.014 - 0.215	0.008 - 0.05	7	9	5.0

* State and Federal drinking water standards, mg/L.

Well number: 1132 (Downgradient)

	Mean	Range	Detection Limit	Number of samples above detection limit	Number of samples analyzed
Ag	<0.006		0.006	0	7
As	<0.06		0.06	0	7
Ba	0.089	0.057 - 0.15			5
Ca	1.43	0.048 - 45		10	10
Cd	<0.007		0.001 - 0.007	0	10
Cr	<0.005	<0.004 - 0.006	0.004 - 0.005	3	10
Cu	<0.012	0.007 - 0.02	0.007 - 0.02	3	10
Fe	<0.128	0.004 - 0.53	0.003 - 0.02	6	10
K	1.15	0.18 - 5.46		8	8
Mg	0.33	0.23 - 0.46		10	10
Mn	0.086	0.01 - 0.21		10	10
Na	<5.7	<0.5 - 9.1		8	10
Pb	<0.05	0.01 - <0.05	0.01 - 0.05	1	10
Se	<0.06		0.01 - 0.06	0	8
Sr	0.0097	0.0066 - 0.012		5	5
Zn	0.055	0.009 - 0.116		10	10

Well number: 1133 (Upgradient)

	Mean	Range	Detection Limit	Number of samples above detection limit	Number of samples analyzed
Ag	<0.006		0.006	0	2
As	<0.06		0.06	0	2
Ba	0.089			1	1
Ca	1.73	0.93 - 2.78		4	4
Cd	<0.007		0.007	0	4
Cr	<0.02	0.002 - 0.046	0.004 - 0.006	2	4
Cu	<0.015	<0.005 - 0.015	0.005	1	4
Fe	<0.011	0.006 - 0.02	0.003 - 0.01	3	4
K	1.22	0.71 - 2.17		3	3
Mg	0.51	0.34 - 0.91		4	4
Mn	0.10	0.06 - 0.14		4	4
Na	1.05	<0.05 - 1.2	0.5	2	3
Pb	<0.05		0.001 - 0.05	0	3
Se	<0.06		0.001 - 0.06	0	3
Sr	0.01			1	1
Zn	0.054	0.01 - 0.11		3	3

Well number: 1134 (Upgradient)

	Mean	Range	Detection Limit	Number of samples above detection limit	Number of samples analyzed
Ag	<0.006		0.006	0	5
As	<0.06	<0.05 - 0.065	0.06	1	5
Ba	0.073	0.037 - 0.12		4	4
Ca	33.6	20.0 - 45.0		9	9
Cd	<0.007		0.001 - 0.007	0	9
Cr	<0.0045	0.0035 - 0.0053		4	9
Cu	<0.01		0.005 - 0.01	0	9
Fe	<0.14	0.01 - 0.65	0.003 - 0.18	5	9
K	1.3	<0.05 - 3.41	0.05	6	7
Mg	19	17 - 21		8	8
Mn	<0.013	<0.002 - 0.036	0.002	4	9
Na	<1	<0.5 - 1.34	0.5	1	10
Pb	<0.05	0.026 - <0.05	0.01 - 0.05	1	10
Se	<0.06		0.01 - 0.06	0	6
Sr	0.0578	0.033 - 0.094		4	4
Zn	<0.021	0.003 - 0.050	0.008	8	9

Table 7.3. Radionuclides measured in wells at the Pine Plantation site during and after sludge application (application period 6/88 through 6/89). Well 1134' was a replicate sample.

Radionuclides in water				
Well Number	Sample Date	Cs 137 (pCi/L)	Co 60 (pCi/L)	Uranium (ppm)
1130	06/23/88	5.8	<3.7	
1130	11/15/88	<5.8	<9.4	
1130	06/22/89			0.040
1130	02/05/90			0.039
1130	05/07/90			<0.001
1131	06/23/88	9.9	<7.3	
1131	11/15/88	<5.3	<6.3	
1131	06/22/89	<2.1	<1.8	0.060
1131	02/05/90			0.433
1131	05/07/90			<0.001
1132	11/15/88	<3.0	<3.0	
1132	06/22/89	<2.2	<2.1	0.100
1132	02/05/90			0.008
1132	05/07/90			<0.001
1133	06/22/89	<2.5	<2.2	
1133	02/05/90			0.148
1133	05/07/90			0.001
1134	11/15/88	4.7	<5.5	
1134	06/22/89	<2.4	<2.3	0.070
1134	02/05/90			0.163
1134	05/07/90			<0.001
1134'	05/07/90			<0.001

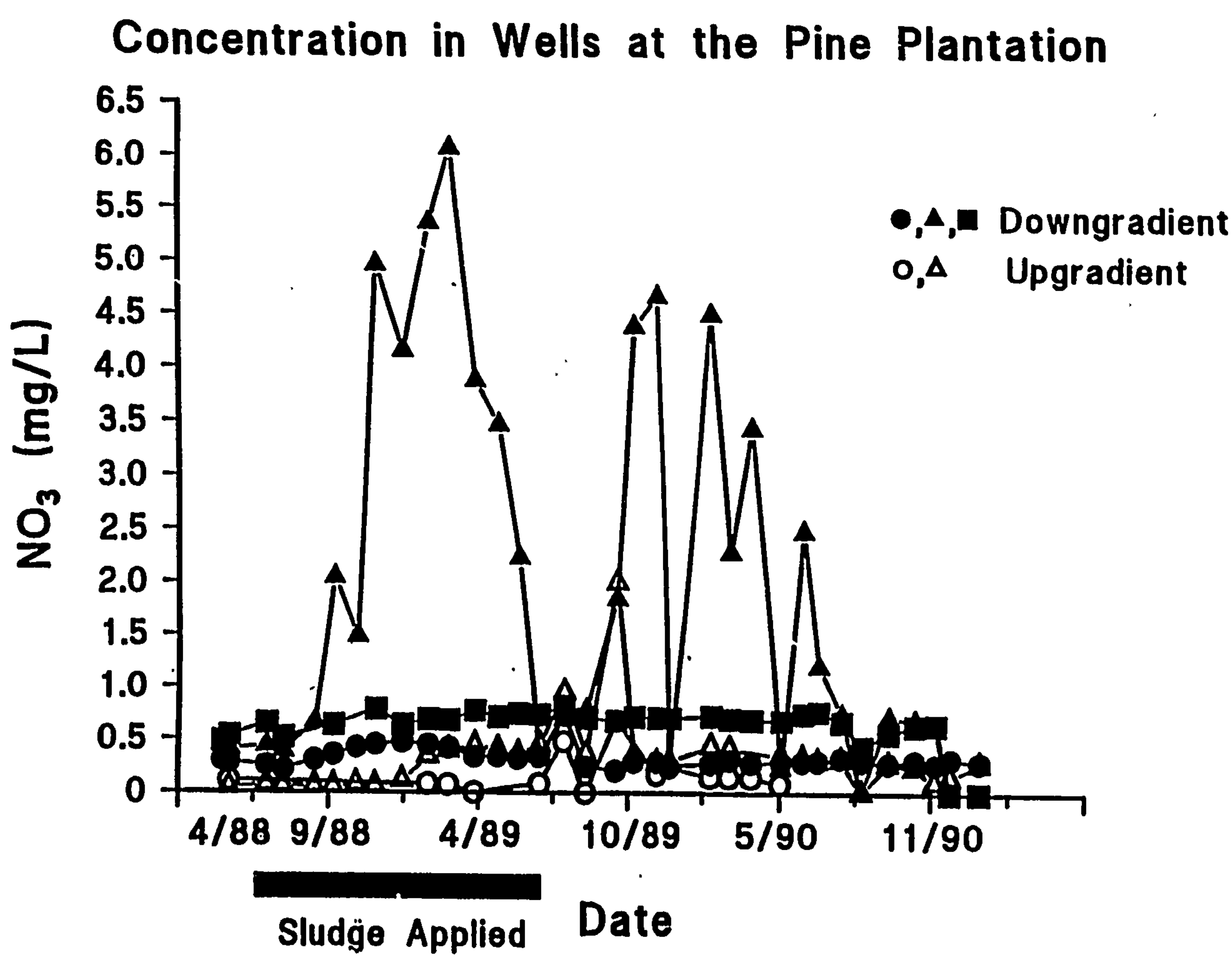

Fig. 7.1. Nitrate in wells at the Pine Plantation site before, during and after the sludge application period. Solid symbols indicate down-gradient wells: circles, well #1130; triangles, well #1131; squares, well #1132. Open symbols indicate up-gradient, or reference wells: circles, well #1133; triangles, well #1134. Note that only well #1131 showed significantly elevated nitrate levels. The drinking water standard for nitrate is 10 mg/L.

Table 8.1. Surface water chemistry and nutrients at the Cottonwood site. Values are mean, range, and number of samples analyzed for each creek. The concentrations, conductivity, etc. for the two creeks in the treatment area were also compared pairwise for those dates (storm events) when both treatment and reference samples were available, and the number of those events when concentration (or other value) was elevated are given. Values were designated as elevated if they were greater than 110% of the reference value for that storm.

The reference was taken from a stream flowing from the south side of Bear Creek Road, through a culvert and into the treatment area. The "Cottonwood South Creek" samples were taken from the same creek after it passed through a broad, gently sloping portion of the treatment area. This sampling position had water only during or after heavy rains. The "Cottonwood North Creek" samples were taken further downstream, after the creek passing through the treatment area had been joined by a creek passing through an untreated pine stand. This sampling position had water more frequently than the "South Creek" position. Some individual samples may have had inadequate volume to perform all analyses. Samples were collected during storm events from August 1989 through December 1990.

Units for fecal coliform are colonies/100mL; for conductivity, µmhos/cm; for alkalinity, meq/L; for NO_3, mg/L; for NH_4, µg/L; for total N, mg/L; for total P, mg/L; for soluble reactive phosphorus (SRP), mg/L; and for total suspended solids (TSS), mg/L. Means are the mean of values above the detection limit. "ND" indicates the number of samples, if any, below the detection limit.

Site: Reference Creek

	Mean	Range	Number of samples analyzed
Fecal Coliform	0	1300	1
Conductivity	150	58 - 412	8
Alkalinity	1.13	0.73 - 1.56	8
pH	7.75	7.2 - 8.18	8
NO_3	0.239	0.012 - 1.205	8
NH_4	28.62	17 - 40.8	8
Total N	0.589	0.312 - 0.920	7
Total P	0.042	0.012-0.072	7
SRP	0.010	0.007 - 0.017	8 (3 ND)
TSS	0.160	0.020 - 0.881	8

Site: Cottonwood North Creek (treatment)

	Mean	Range	Number of samples analyzed	Number of storms when value was elevated/ number of paired storms
Fecal Coliform		3200	1	1/1
Conductivity	88	30 - 160	10	1/8
Alkalinity	0.692	0.19 - 1.36	10	1/8
pH	6.98	6.5 - 8.2	10	
NO_3	0.236	0.005 - 1.000	10	3/8
NH_4	190.2	4.0 - 1291	10	3/8
Total N	0.800	0.34 - 2.78	9	3/7
Total P	0.184	0.020 - 0.666	9	4/7
SRP	0.163	0.005 - 0.48	10 (1 ND)	4/8
TSS	0.075	0.035 - 0.121	9	3/8

Site: Cottonwood South Creek

	Mean	Range	Number of samples analyzed	Number of storms when value was elevated/ number of paired storms
Fecal Coliform			0	
Conductivity	101	83 - 130	3	3/3
Alkalinity	0.78	0.61 - 0.96	3	0/3
pH	7.97	7.84 - 8.07	3	
NO_3	1.04	0.892 - 1.243	3	3/3
NH_4	2930	39 - 4518	3	2/3
Total N	4.43	2.15 - 6.17	3	3/3
Total P	2.26	0.69 - 3.74	3	3/3
SRP	1.48	0.69 - 2.09	3	3/3
TSS	1.92	1.03 - 3.54	3	3/3

Table 8.2. Surface water chemistry and nutrients at the Watson Road site. Values are mean, range, and number of samples analyzed for each creek. Grab samples were collected from all three creeks during or after storm events on October 18, November 28, and December 17, 1990. The concentrations, conductivity, etc. for the three creeks in the treatment area were compared to the values from the reference creek.

The reference was taken from a stream crossing Watson Road, east and upstream of the treatment area. The three treatment area samples were taken from creeks within the treatment area: W1 and W2 crossing Old County Road, and W3 crossing Watson Road inside the spray area. Some individual samples were not analyzed for total N or total P.

Units for fecal coliform are colonies/100mL; for biological oxygen demand (BOD), mg/L; for conductivity, µmhos/cm; for alkalinity, meq/L; for NO_3, mg/L; for NH_3, µg/L; for total N, mg/L; for total P, mg/L; for soluble reactive phosphorus (SRP), mg/L; and for total suspended solids (TSS), mg/L. Means are the mean of values above the detection limit. "ND" indicates the number of samples, if any, below the detection limit.

Site: Watson Road Reference Creek (WR)

	Mean	Range	Number of samples analyzed
Fecal Coliform	460		1
BOD	3		1
Conductivity	103	80 - 130	3
Alkalinity	0.91	0.38 - 1.60	3
pH	7.41	6.88 - 7.95	3
NO_3	0.01	0.008 - 0.014	3
NH_4	26.55	14.3 - 38.8	2
Total N	0.249	0.214 - 0.284	2
Total P	0.045	0.044 - 0.046	2
SRP	0.023	0.002 - 0.039	3
TSS	0.016	0.010 - 0.025	3

Site: Watson Road treatment area (W1, W2, and W3)

	Mean	Range	Number of samples analyzed	Sites with consistently higher values*
Fecal Coliform	154	13 - 355	3	
BOD	3	2 - 4	3	
Conductivity	216	140 - 290	9	W2, W3
Alkalinity	2.16	0.92 - 3.34	9	W2, W3
pH	7.64	6.68 - 8.36	9	
NO_3	0.243	0.008 - 1.322	9	W1
NH_4	28.42	15.0 - 45.0	9	
Total N	0.506	0.235 - 1.027	6	W1
Total P	0.111	0.060 - 0.135	6	
SRP	0.069	0.020 - 0.127	9	W1
TSS	0.316	0.021 - 1.178	9	W1

* The sampling locations listed were consistently higher in concentration (or other parameter) than the other treatment sampling locations and contributed significantly to the higher means for that parameter. Where no location is listed in this column, values for the three locations were comparable.

Table 8.3. Surface water chemistry and nutrients at the Rogers site. Values are mean, range, and number of samples analyzed for each creek. The concentrations, conductivity, etc. for the compositor and grab samples in the treatment area were also compared pairwise to treatment samples of the same type for those dates when both were available, and the number of those events when concentration (or other value) was elevated are given. Values were designated as elevated if they were greater than 110% of the reference value for that storm.

Samples contributing to this table were collected during or after rain events from July 1988 through May 1990, during and after the period of sludge application. Samples were take from compositors (R5 and R2 in reference and treatment areas, respectively, 7/14/88 through 3/30/89 only) and as grab samples near the location of the compositors (R4 and R1 in reference and treatment areas). In addition, as a "worst case", a grab sample was taken from a standing pool in the treatment area (R3, 7/14/88 through 2/17/89 only). Samples were not available from every sample position on each date, and that is reflected in the number of samples analyzed.

Units for Biological oxygen demand (BOD) are mg/L, fecal coliform are colonies/100mL; for conductivity, µmhos/cm; for alkalinity, meq/L; for NO_3, mg/L; for NH_4, µg/L; for total N, mg/L; for total P, mg/L; for soluble reactive phosphorus (SRP), mg/L; and for total suspended solids (TSS), mg/L. Means are the mean of values above the detection limit. "ND" indicates the number of samples, if any, below the detection limit.

Sample: Reference Grab Sample (R4)

	Mean	Range	Number of samples analyzed
BOD	<5	<5	2
Fecal Coliform	245	100- 390	2
Conductivity	129	58- 217	12
Alkalinity	2.17	0.50- 10.04	12
pH	7.63	7.01- 8.29	12
NO_3	0.284	0.020- 1.080	12
NH_4	13.67	0- 53.0	12
Total N	0.763	0.023- 1.331	12
Total P	0.146	0.01- 0.428	12
SRP	0.055	0.010- 0.139	12
TSS	0.518	0.015- 2.725	13

Sample: Reference Compositor (R5)

	Mean	Range	Number of samples analyzed
BOD	7		1
Fecal Coliform	70		1
Conductivity	100	74- 128	3
Alkalinity	2.19	0.74- 5.00	3
pH	7.78	7.39- 8.20	3
NO_3	0.42	0.128- 0.664	3
NH_4	3.43	0- 7.98	3
Total N	1.463	0.672- 2.402	3
Total P	0.288	0.100- 0.514	3
SRP	0.071	0.038- 0.094	3
TSS	0.788	0.062- 1.398	3

Sample: Treatment Grab Sample (R1)

	Mean	Range	Number of samples analyzed	Number of storms when value was elevated/ number of paired storms
BOD	<7.75	<5 - 10.5	2	0/1
Fecal Coliform	>475	350 - >600	2	0/1
Conductivity	212	74- 429	9	7/8
Alkalinity	0.96	0.61- 1.30	9	2/8
pH	7.46	7.07- 8.36	9	
NO_3	8.879	0.337- 23.13	9	7/8
NH_4	54.12	9.60- 207.8	9	7/8
Total N	9.434	1.539- 25.86	9	8/8
Total P	1.955	0.210- 5.520	9	8/8
SRP	1.544	0.190- 3.46	9	8/8
TSS	0.213	0.013- 0.538	10	4/9

Sample: Treatment Compositor (R2)

	Mean	Range	Number of samples analyzed	Number of storms when value was elevated/ number of paired storms
BOD	<5		1	0/1
Fecal Coliform	>1200		1	1/1
Conductivity	194	102- 323	5	3/3
Alkalinity	0.84	0.46- 1.26	5	0/3
pH	7.42	7.27- 7.87	5	
NO_3	5.259	1.427- 8.711	5	3/3
NH_4	316.67	70.65- 688.0	5	3/3
Total N	6.428	2.763- 9.810	5	2/3
Total P	0.761	0.167- 1.640	5	2/3
SRP	0.703	0.116- 1.640	5	3/3
TSS	0.065	0.006- 0.192	5	0/3

Sample: Standing Pool, Grab Sample (Treatment) (R3)

	Mean	Range	Number of samples analyzed
BOD	7		1
Fecal Coliform	>1200		1
Conductivity	424	85.3- 1195	4
Alkalinity	1.03	0.62- 1.18	4
pH	7.41	7.24- 7.54	4
NO_3	27.11	1.436- 96.15	4
NH_4	724.43	16.63- 2737	4
Total N	28.66	2.277- 98.82	4
Total P	2.43	1.22- 4.14	4
SRP	2.093	1.08- 3.63	4
TSS	0.194	0.075- 0.47	4

Table 8.4 Water chemistry and nutrients in surface runoff at the Pine Plantation site.
Data are presented as means (a) and as individual data from four typical storms (b) and (c). Sample locations are defined below.

Chemical parameters and units were: Conductivity, µmhos/cm; pH; Alkalinity, meq/L; NO_3, mg/L; NH_4, µg/L; Total P, mg/L; Soluble reactive phosphorus (SRP), mg/L; Biological oxygen demand (BOD) mg/L; fecal coliform, colonies/100mL; for total N, mg/L; and Total suspended solids (TSS), mg/L.

a) Mean, standard deviation and sample number for four sample locations and types: compositor samples from reference (ref) and sludge treatment (trt) plots, sampled from November 1988 through March 1989, and grab samples from the same locations, sampled from July 1988 through February 1990. Samples id's are as follows: P4, a compositor in the reference plot; P3, a grab sample from near the P4 compositor on the reference site; P2, a compositor in the treatment plot; P1, a grab sample from near the P2 compositor on the treatment site;

b) Runoff collections on two typical dates. Grab samples only were taken from various locations on the reference and treatment plots and from a creek downstream from the site (Trt, dil). Sample id's are as in a), plus the following: 1132SP, surface flow (possible spring) near well 1132 on the treatment plot; C at C, from the creek downhill from the treatment plot, at the corner where another stream enters and dilutes the runoff; P6, a sample even further down the same creek, by a rock wall and a USGS marker. Replicate samples are shown when available, designated "rep".

c) Runoff collections on two typical dates. Both compositor (Comp) and grab samples were taken from various locations on the reference and treatment plots and from a creek downstream from the site. Sample id's are as in a) and b), plus the following: P5, from a standing pool in the reference field.

Table 8.4.a: Means for four sample locations and types:

		Conduct.	pH	Alk.	NO_3 mg/L	NH_4 µg/L	TN mg/L	TP mg/L	SRP, mg/L	TSS, mg/L	BOD	Fecal Coliform
Mean P3	Reference, Grab	43.7	5.93	0.60	0.130	35.19	0.464	0.040	0.016	0.045	7.8	2350
Std		12.3	0.27	0.96	0.162	30.86	0.211	0.032	0.022	0.054		
n		7	7	7	7	7	7	7	7	7	1	1
Mean P4	Reference, Compositor	159.0	6.98	0.66	0.382	226.66	1.001	0.079	0.042	0.045		
Std		184.4	0.73	0.84	0.231	226.25	0.429	0.026	0.015	0.030		
n		4	4	4	4	4	4	4	4	4		
Mean P1	Treatment, Grab	119	6.68	0.54	6.657	831.36	8.181	1.466	0.785	1.24	8.4	6520
Std		51	0.80	0.59	4.679	1290.7	5.250	1.958	1.363	2.16	8.4	5980
n		16	16	16	16	16	16	16	16	16	2	2
Mean P2	Treatment, Compositor	257	7.76	1.34	4.612	897.7	6.186	0.539	0.373	0.616		
Std		46	0.22	0.34	3.734	1249.9	6.024	0.649	0.427	0.999		
n		4	4	4	4	4	4	4	4	4		

Table 8.4.b. Runoff collections on two typical dates; Grab samples:

DATE	Sample	TRT	Type	Cond.	pH	Alk.	NO_3 mg/L	NH_4 µg/L	TN mg/L	TP mg/L	SRP, mg/L	TSS, mg/L	BOD	Fecal Colif.
05/05/89	P3	Ref	Grab	48	6.14	2.52	0.112	89.3	0.859	0.092	0.045	0.150	7.8	2350
05/05/89	1132SP	Trt	Grab	249	7.59	2.08	4.214	7402.2	17.502	3.860	2.475	0.623	46.1	47000
05/05/89	P1	Trt	Grab	134	7.70	2.32	3.799	2576.3	12.786	5.200	1.110	4.830	16.8	12500
05/05/89	P1 rep	Trt	Grab	136	7.72	2.28	3.613	2800.4	12.982	4.500	1.040	5.522		
05/05/89	C at C	Trt, dil.	Grab	180	7.76	2.40	2.064	849.3	5.437	0.800	0.210	2.287		
05/05/89	P6	Trt, dil.	Grab	92	8.14	3.50	0.137	41.7	1.295	0.244	0.050	1.524		
06/09/89	P3	Ref	Grab	55	6.12	0.22	0.484	60.3	0.436	0.038	0.050	0.060		
06/09/89	1132SP	Trt	Grab	426	6.30	0.00	38.295	5104.2	47.100	6.760	6.260	0.142		
06/09/89	P1	Trt	Grab	237	7.21	0.50	16.585	2547.6	22.185	6.460	5.500	3.203		
06/09/89	P1 rep	Trt	Grab	237	7.18	0.52	16.625	2517.4	22.110	6.620		2.590		
06/09/89	C at C	Trt, dil.	Grab	230	7.02	0.60	14.612	1690.5	18.700	2.600	2.300	0.247		
06/09/89	P6	Trt, dil.	Grab	124	7.66	0.82	3.664	261.1	4.812	0.640	0.370	0.232		

Table 8.4.c. Runoff collections on two typical dates; compositors plus grab samples:

DATE	Sample	TRT	Type	Conduct.	pH	Alk.	NO_3 mg/L	NH_4 µg/L	TN mg/L	TP mg/L	SRP, mg/L	TSS, mg/L
11/19/88	P4	Ref	Comp	478	8.22	2.12	0.572	0.00	0.750	0.080		0.093
11/19/88	P5,pool	Ref	Grab	64	5.86	0.72	0.230	225.76	1.248	0.096	0.050	0.018
11/19/88	P2	Trt	Comp	331	7.74	1.04	2.772	495.08	3.207	0.196	0.165	0.086
11/19/88	P6	Trt, dil	Grab	255	6.96	2.50	0.607	0.00	0.756	0.017	0.001	0.004
01/12/89	P3	Ref	Grab	49.5	5.73	0.06	0.049	0.00	0.333	0.014	0.001	0.005
01/12/89	P4	Ref	Comp	57	6.74	0.22	0.031	2.85	0.432	0.119	0.063	0.014
01/12/89	P5,pool	Ref	Grab	29	6.49	0.10	0.116	0.00	0.778	0.067	0.016	0.013
01/12/89	P1	Trt	Grab	97	7.09	0.46	2.805	513.00	5.519	1.160	0.860	0.532
01/12/89	P2	Trt	Comp	251	8.10	1.92	1.457	11.86	1.653	0.101	0.079	0.007
01/12/89	P6	Trt, dil	Grab	104	7.23	0.56	2.576	204.03	3.265	0.251	0.173	0.058
01/12/89	P6 rep	Trt, dil	Grab	107	7.31	1.18	2.628	209.68	3.216	0.267	0.176	0

Table 8.5. Metals in grab samples of surface runoff at the McCoy Site for two dates after sludge application. Data listed by date and as total, soluble, or particulate fraction where data available. BMDL and < indicate values below the analytical detection limits (ICP).

	Date	Ag	Al	As	B	Ba	Be	
Total, mg/L								
UPSTREAM (C)	02/27/87	<.0084	0.780	<.017	<.013	0.069	<.00033	
DOWNSTREAM (D)	02/27/87	<.0077	3.00	<.015	<.012	0.067	<.00031	
Soluble,mg/L								
UPSTREAM (C)	02/27/87	<.05	<.2	<.01	<.08	0.040	<.002	
DOWNSTREAM (D)	02/27/87	<.05	<.2	<.01	<.08	<.053	<.002	
Total, mg/L								
UPSTREAM (C)	01/19/88	0.010	0.620	0.045	<.08	0.030	<.0003	
DOWNSTREAM (D)	01/19/88	0.009	4.700	0.039	<.08	0.051	<.0003	
Particulate, mg/L								
UPSTREAM (C)	01/19/88	0.001	0.124	0.006	0.016	0.022	0.000	
DOWNSTREAM (D)	01/19/88	0.002	0.850	0.016	0.040	0.130	0.000	
Particulate, mg/g								
UPSTREAM (C)	01/19/88	0.036	5.636	0.273	0.727	1.000	0.003	
DOWNSTREAM (D)	01/19/88	0.020	8.500	0.160	0.400	1.300	0.002	

Table 8.5 (continued)

	Date	Ca	Cd	Co	Cr	Cu	Fe	
Total, mg/L								
UPSTREAM (C)	02/27/87	17.00	BMDL	<.0017	<.0067	<.0033	0.86	
DOWNSTREAM (D)	02/27/87	20.00	BMDL	0.003	0.007	0.005	3.300	
Soluble,mg/L								
UPSTREAM (C)	02/27/87	18.00	<.005	<.01	<.04	<.02	<.03	
DOWNSTREAM (D)	02/27/87	25.00	<.005	<.01	<.04	<.02	0.089	
Total, mg/L								
UPSTREAM (C)	01/19/88	29.000	0.002	<.003	0.011	<.010	0.410	
DOWNSTREAM (D)	01/19/88	38.000	0.002	<.003	0.013	<.010	3.400	
Particulate, mg/L								
UPSTREAM (C)	01/19/88	0.220	0.000	0.001	0.007	0.001	0.200	
DOWNSTREAM (D)	01/19/88	0.700	0.001	0.010	0.001	0.625	0.500	
Particulate, mg/g								
UPSTREAM (C)	01/19/88	10.000	0.020	0.027	0.327	0.055	9.091	
DOWNSTREAM (D)	01/19/88	7.000	0.010	0.095	0.009	6.250	5.000	

Table 8.5 (continued)

	Date	Ga	K	Li	Mg	Mn	Mo	
Total, mg/L								
UPSTREAM (C)	02/27/87	<.05		<.033	5.20	0.060	<.0067	
DOWNSTREAM (D)	02/27/87	<.046		<.031	4.80	0.120	<.0062	
Soluble,mg/L								
UPSTREAM (C)	02/27/87	<.03		<.02	5.60	<.005	<.04	
DOWNSTREAM (D)	02/27/87	<.03		<.02	5.30	<.005	<.04	
Total, mg/L								
UPSTREAM (C)	01/19/88	<.3	1.300	<.2	12.000	0.026	<.04	
DOWNSTREAM (D)	01/19/88	<.3	3.000	<.2	11.000	0.065	<.04	
Particulate, mg/L								
UPSTREAM (C)	01/19/88	0.060	0.008	0.040	0.076	0.017	0.008	
DOWNSTREAM (D)	01/19/88	0.150	0.035	0.100	0.100	0.022	0.020	
Particulate, mg/g								
UPSTREAM (C)	01/19/88	2.727	0.364	1.818	3.455	0.755	0.364	
DOWNSTREAM (D)	01/19/88	1.500	0.350	1.000	1.000	0.220	0.200	

Table 8.5 (continued)

	Date	Na	Ni	P	Pb	Sb	Se	
Total, mg/L								
UPSTREAM (C)	02/27/87	3.50	<0.01	<0.05	<.033	<.033	<.033	
DOWNSTREAM (D)	02/27/87	2.30	<0.0092	0.120	<.031	<.031	<.031	
Soluble,mg/L								
UPSTREAM (C)	02/27/87	4.30	<.06	0.300	<.2	<.2	<.2	
DOWNSTREAM (D)	02/27/87	4.30	<.06	0.300	<.2	<.2	<.2	
Total, mg/L								
UPSTREAM (C)	01/19/88	11.000	<.006	<0.3	<.03	<.03	<.04	
DOWNSTREAM (D)	01/19/88	7.900	<0.006	<0.3	<.03	<.03	<.04	
Particulate, mg/L								
UPSTREAM (C)	01/19/88	0.004	0.002	0.060	0.006	0.006	0.008	
DOWNSTREAM (D)	01/19/88	0.105	0.004	0.185	0.028	0.015	0.020	
Particulate, mg/g								
UPSTREAM (C)	01/19/88	0.182	0.083	2.727	0.273	0.273	0.364	
DOWNSTREAM (D)	01/19/88	1.050	0.035	1.850	0.275	0.150	0.200	

Table 8.5 (continued)

	Date	Si	Sn	Sr	Ti	V	Zn	Zr
Total, mg/L								
UPSTREAM (C)	02/27/87	2.50	<.0084	0.037	0.013	0.004	0.010	<.0033
DOWNSTREAM (D)	02/27/87	2.40	<.0077	0.034	0.017	0.007	0.018	0.004
Soluble,mg/L								
UPSTREAM (C)	02/27/87	2.50	<.05	0.044	<.02	<.01	<.02	<.02
DOWNSTREAM (D)	02/27/87	2.40	<.05	0.045	<.02	<.01	<.02	<.02
Total, mg/L								
UPSTREAM (C)	01/19/88	3.800	<.05	0.047	0.040	0.007	0.004	<.02
DOWNSTREAM (D)	01/19/88	11.000	<.05	0.060	0.090	0.010	0.013	<.02
Particulate, mg/L								
UPSTREAM (C)	01/19/88	0.182	0.010	0.001	0.068	0.001	0.010	0.004
DOWNSTREAM (D)	01/19/88	0.155	0.025	0.003	0.075	0.002	0.015	0.010
Particulate, mg/g								
UPSTREAM (C)	01/19/88	8.273	0.455	0.045	3.091	0.036	0.445	0.182
DOWNSTREAM (D)	01/19/88	1.550	0.250	0.025	0.750	0.020	0.150	0.100

Table 8.6.a. Metal concentrations in surface runoff at the Rogers site, for two sample dates. Samples were taken from compositors in both the sludge treatment field and a reference field nearby. All samples were taken during the active sludge application period. Analysis by ICP. Concentrations in total fraction are in mg/L and in particulate fraction, mg/g.

	Date	Ag	Al	As	B	Ba	Be	Ca	Cd
Total (mg/L)									
Reference	09/12/87	<.050	2.60	<.10	<.08	<.020	<.002	>10	<.005
Treatment	09/12/87	<.050	17.00	<.10	<.08	0.14	<.002	>10	<.005
Particulate (mg/g)									
Reference	09/12/87	0.161	15.16	0.323	0.258	0.065	0.006	27.10	0.016
Treatment	09/12/87	0.027	10.22	0.054	0.043	0.065	0.001	5.914	0.003
Total (mg/L)									
Reference	01/19/88	0.011	10.000	<.03	<.08	0.054	0.0005	27.00	0.002
Treatment	01/19/88	0.013	3.300	0.034	<.08	0.040	<.0003	76.00	<.002
Particulate. (mg/g)									
Reference	01/19/88	0.010	11.951	0.095	0.195	0.124	0.001	15.12	0.006
Treatment	01/19/88	0.011	8.857	0.094	0.229	0.109	0.001	14.286	0.006

Table 8.6.a (continued)

	Date	Co	Cr	Cu	Fe	Ga	K	Li	Mg
Total (mg/L)									
Reference	09/12/87	<.010	0.190	<.020	5.20	<.30	15.00	<.20	3.50
Treatment	09/12/87	0.017	<.040	0.059	18.00	<.30	19.00	<.20	12.00
Particulate (mg/g)									
Reference	09/12/87	0.003	0.129	0.065	24.52	0.968	0.297	0.065	2.74
Treatment	09/12/87	0.005	0.024	0.017	16.67	0.204	0.204	0.108	1.56
Total (mg/L)									
Reference	01/19/88	<.003	0.021	0.013	13.00	<.3	5.70	<.2	4.60
Treatment	01/19/88	<.003	0.016	0.034	3.60	<.3	9.70	<.2	11.00
Particulate (mg/g)									
Reference	01/19/88	0.007	0.112	0.439	19.02	0.732	0.415	0.488	2.44
Treatment	01/19/88	0.009	0.126	0.109	11.71	0.857	0.629	0.571	2.029

Table 8.6.a (continued)

	Date	Mn	Mo	Na	Ni	P	Pb	Sb	Se
Total (mg/L)									
Reference	09/12/87	0.120	<.040	0.810	<.060	0.47	<.20	<.20	<.20
Treatment	09/12/87	1.500	<.040	4.60	<.06	5.00	<.20	<.20	<.20
Particulate (mg/g)									
Reference	09/12/87	0.310	0.013	1.74	0.019	0.97	0.065	0.065	0.065
Treatment	09/12/87	0.753	0.022	0.269	0.032	1.34	0.108	0.108	0.108
Total (mg/L)									
Reference	01/19/88	0.17	<.04	<.2	0.008	0.53	<.03	<.03	<.04
Treatment	01/19/88	0.21	<.04	4.40	0.007	3.30	<.03	<.03	<.04
Particulate (mg/g)									
Reference	01/19/88.	0.463	0.098	0.488	0.059	0.73	0.159	0.073	0.098
Treatment	01/19/88	0.743	0.114	0.571	0.063	3.43	0.114	0.086	0.114

Table 8.6.a (continued)

	Date	Si	Sn	Sr	Ti	V	Zn	Zr	
Total (mg/L)									
Reference	09/12/87	5.90	<.050	0.070	<.020	<.020	<.020	<.020	
Treatment	09/12/87	19.00	<.050	0.081	0.073	0.037	0.340	<.020	
Particulate (mg/g)									
Reference	09/12/87	15.81	0.161	0.039	1.35	0.065	0.677	0.065	
Treatment	09/12/87	3.33	0.027	0.011	0.274	0.017	0.226	0.011	
Total (mg/L)									
Reference	01/19/88	20.00	<.05	0.039	0.20	0.018	0.029	0.020	
Treatment	01/19/88	8.20	<.05	0.071	0.023	0.009	0.081	<0.02	
Particulate (mg/g)									
Reference	01/19/88.	15.366	0.122	0.029	1.024	0.021	0.244	0.054	
Treatment	01/19/88	8.286	0.143	0.028	1.429	0.011	0.457	0.057	

Table 8.6.b. Metal concentrations in grab samples of surface runoff at the Rogers site, on 2/27/87, taken from both the sludge treatment field (including a standing pool), and a reference field nearby. Analysis was of total sample, by ICP. Concentrations are in mg/L.

	Ag	Al	As	B	Ba	Be	Ca	Cd
Reference		10.50				0.0003	15.00	
Treatment	<0.0077	3.70	<0.015	0.014	0.054	<0.0003	25.00	<0:0008
Standing Pool		8.50			0.088	0.005	20.00	0.009
	Co	Cr	Cu	Fe	Ga	K	Li	Mg
Reference	0.004	0.012	0.005	10.30				3.00
Treatment	0.002	0.008	0.007	4.00	<0.046		<0.031	3.20
Standing Pool	0.005	0.017	0.017	10.00				4.90
	Mn	Mo	Na	Ni	P	Pb	Sb	Se
Reference	0.093		0.69		0.27			
Treatment	0.034	<0.0062	0.99	<0.0092	1.30	<0.031	<0.031	<0.031
Standing Pool	0.17		1.60	0.010	3.00			
	Si	Sn	Sr	Ti	V	Zn	Zr	
Reference	3.80		0.023	0.026	0.015	0.076	0.006	
Treatment	2.80	<0.0077	0.026	0.018	0.007	0.029	0.004	
Standing Pool	2.90		0.026	0.025	0.014	0.071	0.006	

Table 8.7 (a,b,c) Metals in surface runoff at the Pine Plantation Site, listed by sample collection date for all dates analyzed. Concentrations are in mg/L, from the total (unfiltered) samples. In addition to the metals listed, Hg was measured on 1/27/89 and both sample concentrations were <4.0 mg/L. Concentration of Ga was measured on 7/14/88 and was <0.3 mg/L in all three samples. Concentrations of Zr were measured on 7/14/88 and 1/21/90 and were <0.02 mg/L in all samples. Other samples below the minimum detection limit for the sample run are listed as BMDL or < a particular detection limit if given by the analytical lab. Metals were measured by ICP by ORNL Analytical Chemistry and/or the University of Georgia. Site sample locations ID's are as described in Table 8.4. (a) Ag through Cr, (b) Cu through P, (c) Pb through Zn.

8.7.a. Ag through Cr

Site	TRT	Date	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr
P1'	Trt grab	07/14/88	<0.006	11.00	<0.06	0.27	0.21	0.0037	44	<0.001	0.015	0.0084
P1	Trt grab	07/14/88	<0.006	9.30	<0.06	0.31	0.18	0.0031	35	<0.001	0.013	0.0081
C at C	Trt dil	07/14/88	0.0076	16.00	<0.06	0.35	0.37	0.0053	180	<0.001	0.043	0.0088
P4	Ref comp	11/19/88	<0.005	0.81	0.05	0.07	0.026	<0.001	9.3	<0.005	<0.02	<0.01
P5	Ref pool	11/19/88	<0.005	1.50	<0.03	0.05	0.16	<0.001	3.6	<0.005	<0.02	<0.01
P2	Trt grab	11/19/88	<0.005	0.86	0.06	0.12	0.069	<0.001	30.0	<0.005	<0.02	0.01
P6	Trt dil	11/19/88	<0.005	0.23	<0.03	<0.01	0.11	<0.001	31.3	<0.005	<0.02	<0.01
P4	Ref comp	01/12/89	<0.005	0.28	<0.03	0.01	0.079	<0.001	5.5	<0.005	<0.02	<0.01
P3	Ref grab	01/12/89	<0.005	0.23	<0.03	0.02	0.074	<0.001	4.4	<0.005	<0.02	<0.01
P5	Ref pool	01/12/89	<0.005	1.50	<0.03	<0.01	0.064	<0.001	2.6	<0.005	<0.02	<0.01
P2	Trt grab	01/12/89	<0.005	0.16	0.15	0.24	0.038	<0.001	24.1	<0.005	<0.02	<0.01
P1	Trt grab	01/12/89	<0.005	9.40	<0.03	0.01	0.63	<0.001	13.6	<0.005	<0.02	0.01
P6	Trt dil	01/12/89	<0.005	4.20	<0.03	0.01	0.044	<0.001	13.9	<0.005	<0.02	<0.01
P6'	Trt dil	01/12/89	<0.005	2.30	<0.03	0.01	0.04	<0.001	13.7	<0.005	<0.02	<0.01
P3	Ref grab	10/02/89		0.03		0.03			5.987	BMDL		0.0319

Table 8.7.a (continued)

Site	TRT	Date	Ag	Al	As	B	Ba	Be	Ca	Cd	Co	Cr
P1	Trt grab	10/02/89		0.42		0.025			10.91	BMDL		0.0058
P1	Trt grab	11/27/89		0.05		0.0125			8.17	BMDL		0.0075
C at C	Trt dil	11/27/89		0.07		0.0108			15.03	BMDL		BMDL
P1	Trt grab	01/04/90		0.05		0.0162			13.6	BMDL		0.0059
P3	Ref grab	01/21/90	<0.005	0.17	<0.05	<0.08	0.28	<.003	3.7	<.007	<.004	<.004
P1	Trt grab	01/21/90	<0.005	0.62	<0.05	0.11	1.2	<.003	7.7	<.007	<.004	<.004
C at C	Trt dil	01/21/90	<0.005	0.12	<0.05	<0.08	0.77	<.003	9.5	<.007	<.004	<.004
P6	Trt dil	01/21/90	<0.005	<0.03	<0.05	<0.08	1.1	<.003	17	<.007	<.004	<.004

8.7.b Cu through P.

Site	TRT	Date	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P
P1'	Trt grab	07/14/88	0.031	3.10	13	<0.2	8.8	1.5	<0.04	1.3	0.013	3.4
P1	Trt grab	07/14/88	0.028	2.70	16	<0.2	7.8	1.3	<0.04	1.4	0.011	3.7
C at C	Trt dil	07/14/88	0.040	4.40	7.8	<0.2	13.0	4.1	<0.04	0.4	0.019	0.33
P4	Ref comp	11/19/88	0.07	1.40	35	<0.005	5.0	0.15	<0.01	3.9	<0.02	
P5	Ref pool	11/19/88	<0.01	0.74	4	<0.005	1.4	0.13	<0.01	0.5	<0.02	
P2	Trt grab	11/19/88	0.02	2.00	11	0.022	5.1	0.23	0.02	10.2	<0.02	
P6	Trt dil	11/19/88	<0.01	0.20	<1	<0.005	14.1	0.008	<0.01	0.6	<0.02	
P4	Ref comp	01/12/89	<0.01	0.21	<1	<0.005	1.9	0.027	<0.01	0.5	<0.02	
P3	Ref grab	01/12/89	<0.01	0.19	<1	<0.005	1.4	0.029	<0.01	0.3	<0.02	

Table 8.7.b (continued)

Site	TRT	Date	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P
P5	Ref pool	01/12/89	<0.01	0.56	2	<0.005	1.4	0.021	<0.01	<0.2	<0.02	
P2	Trt grab	01/12/89	<0.01	0.16	14	0.028	3.7	0.021	0.03	15.5	<0.02	
P1	Trt grab	01/12/89	0.03	10.90	3	<0.005	3.2	0.46	<0.01	0.6	<0.02	
P6	Trt dil	01/12/89	<0.01	2.50	2	<0.005	3.9	0.084	<0.01	0.7	<0.02	
P6'	Trt dil	01/12/89	<0.01	2.00	2	<0.005	3.7	0.086	<0.01	0.7	<0.02	
P3	Ref grab	10/02/89	BMDL	0.009	0.504		1.92	0.035	0.0241	0.49	BMDL	0.047
P1	Trt grab	10/02/89	0.0134	0.162	1.341		3.58	0.0401	0.0229	1.21	0.0014	0.069
P1	Trt grab	11/27/89	BMDL	0.013	0.976		2.48	0.0306	BMDL	2.03	0.0056	0.068
C at C	Trt dil	11/27/89	BMDL	0.030	1.030		3.87	0.0016	BMDL	1.80	BMDL	0.002
P1	Trt grab	01/04/90	BMDL	0.015	1.723		3.72	0.0151	BMDL	2.18	BMDL	0.307
P3	Ref grab	01/21/90	<.005	0.056		<15	1.1	0.0063	<.04	<5	<.009	<.3
P1	Trt grab	01/21/90	<.005	0.110		<15	1.1	<.002	<.04	6.9	<.009	<.3
C at C	Trt dil	01/21/90	<.005	0.076		<15	1.9	0.0032	<.04	<5	<.009	<.3
P6	Trt dil	01/21/90	<.005	0.040		<15	4.7	<.002	<.04	<5	<.009	<.3

8.7.c Pb through Zn

Site	TRT	Date	Pb	Sb	Se	Si	Sn	Sr	Ti	V	Zn
P1'	Trt grab	07/14/88	0.034	<0.05	<0.05	7.22	<0.05	0.069	<0.02	0.024	0.15
P1	Trt grab	07/14/88	0.033	<0.05	<0.05	6.72	<0.05	0.058	<0.02	0.022	0.13
C at C	Trt dil	07/14/88	0.061	<0.05	<0.05	9.05	<0.05	0.240	<0.02	0.036	0.17
P4	Ref comp	11/19/88	0.06	<0.03	<0.06	1.4	0.04	0.027	0.014	<0.01	5.20
P5	Ref pool	11/19/88	<0.03	<0.03	<0.06	2.9	<0.02	0.013	0.024	<0.01	0.02
P2	Trt grab	11/19/88	<0.03	<0.03	<0.06	5.0	0.03	0.094	0.014	<0.01	1.70
P6	Trt dil	11/19/88	<0.03	<0.03	<0.06	3.5	<0.02	0.046	<0.003	<0.01	0.03
										<0.01	
P4	Ref comp	01/12/89	<0.03	<0.03	<0.06	2.7	<0.02	0.029	0.003	<0.01	1.20
P3	Ref grab	01/12/89	<0.03	<0.03	<0.06	2.6	<0.02	0.028	<0.003	<0.01	0.11
P5	Ref pool	01/12/89	<0.03	<0.03	<0.06	3.0	0.03	0.007	0.025	<0.01	0.24
P2	Trt grab	01/12/89	<0.03	<0.03	<0.06	8.7	0.03	0.076	0.003	<0.01	0.48
P1	Trt grab	01/12/89	<0.03	<0.03	<0.06	9.1	<0.02	0.033	0.11	0.02	0.11
P6	Trt dil	01/12/89	0.04	<0.03	<0.06	12.8	<0.02	0.027	0.23	<0.01	0.04
P6'	Trt dil	01/12/89	0.03	<0.03	<0.06	6.4	0.05	0.026	0.082	<0.01	0.04
P3	Ref grab	10/02/89	0.001								0.065
P1	Trt grab	10/02/89	0.0001								0.017

Table 8.7.c (continued)

Site	TRT	Date	Pb	Sb	Se	Si	Sn	Sr	Ti	V	Zn
P1	Trt grab	11/27/89	0.002								0.025
C at C	Trt dil	11/27/89	BMDL								0.014
P1	Trt grab	01/04/90	BMDL								0.028
P3	Ref grab	01/21/90	<.03	<.05	<.01	1.3	<.05	0.022	<.02	<.004	0.074
P1	Trt grab	01/21/90	<.03	<.05	<.01	1	<.05	0.036	<.02	<.004	0.049
C at C	Trt dil	01/21/90	<.03	<.05	<.01	1.6	<.05	0.033	<.02	<.004	0.032
P6	Trt dil	01/21/90	<.03	<.05	<.01	2.2	<.05	0.041	<.02	<.004	0.032

Table 8.8 Metals in surface runoff at the Cottonwood site (mg/L), listed by sample collection date. In addition to the metals shown, Cd, Cu, Mo, Ni, and Pb were always below the minimum detection limits (BMDL). Samples from 1/21/90 were also analyzed for Ag, As, Be, Co, Li, Sb, Se, Sn, Ti, V, and Zr, and were BMDL for all samples. Concentrations listed as < a value were also BMDL for that lab. Sample location ID designations are as described in Table 8.1. "Trt dil" indicates the sampling location was downstream of the sludge treatment area, subject to dilution from other water sources.

ID	TRT	Date	Al	B	Ba	Ca	Cr	Fe	K
CR'	Ref	08/01/89	0.4182	0.0212		18.25	BMDL	0.1845	5.325
CR	Ref	08/01/89	0.4068	0.0262		18.55	BMDL	0.1831	5.197
CNC'	Trt dil	08/01/89	0.0729	0.0371		25.53	BMDL	0.1461	1.806
CNC	Trt dil	08/01/89	0.1367	0.0454		25.43	BMDL	0.1698	1.915
CR	Ref	01/04/90	0.3236	0.0029		31.48	BMDL	0.1862	2.501
CNC	Trt dil	01/04/90	0.2815	0.0146		10.02	0.0177	0.2439	0.902
CR	Ref	01/21/90	0.220	<.08	0.32	9.9	<.004	0.073	
CNC'	Trt dil	01/21/90	0.300	<.08	0.37	3.5	<.004	0.140	
CNC	Trt dil	01/21/90	0.035	<.08	0.35	3.5	<.004	0.170	
CSC	Trt	01/21/90	0.700	0.085	1.00	5.6	<.004	0.170	

Table 8.8 (continued)

ID	TRT	Date	Mg	Mn	Na	P	Si	Sr	Zn
CR’	Ref	08/01/89	2.66	0.004	1.20	0.016			0.0324
CR	Ref	08/01/89	2.67	0.010	1.11	0.013			0.0386
CNC’	Trt dil	08/01/89	2.99	1.288	2.88	0.015			0.2189
CNC	Trt dil	08/01/89	2.98	1.226	2.89	BMDL			0.2220
CR	Ref	01/04/90	4.09	0.007	46.68	0.020			0.0184
CNC	Trt dil	01/04/90	1.48	0.029	2.59	0.010			0.0190
CR	Ref	01/21/90	1.00	<.002	<5.0	<0.30	0.84	0.018	0.011
CNC’	Trt dil	01/21/90	0.70	0.027	<5.0	0.47	1.7	0.017	0.120
CNC	Trt dil	01/21/90	6.90	0.030	<5.0	0.47	1.7	0.016	0.099
CSC	Trt	01/21/90	1.20	0.036	7.1	1.90	1.3	0.024	0.013

Table 8.9. Mercury in surface runoff at the Rogers site during active sludge application. In addition, both reference and treatment samples taken on 11/19/88 and 1/12/89 were below the detection limit of 0.008 ppm Hg, analyzed by the Soil Testing and Plant Analysis Laboratory at the University of Georgia, Athens.

Sample ID	Treatment, Sample type	Sample Date	Hg in soluble fraction (µg/L)	Hg in particulate fraction (µg/L basis)	Hg in particulate fraction (µg/g)
B	Reference (grab)	2/27/87	1	8	
A	Treatment (composite)	9/14/87			0.286
B	Reference (composite)	9/14/87			1.52
B	Reference (composite)	9/30/87	< 0.10	0.08	0.45
A	Treatment (composite)	11/17/87	0.3	0.02	0.112
F	Treatment (Pool)	1/4/88	2.2		2.62
B	Reference (composite)	1/4/88	0.04		0.34
A	Treatment (composite)	2/19/88	0.2		
B	Reference (composite)	2/19/88	0.1		

Table 8.10. Radionuclides in surface runoff at: Rogers, Pine Plantation, Cottonwoods and McCoy sites. Data are from grab samples except as indicated.

Site	Treatment	ID	Sample Date	^{137}Cs (pCi/L)	^{60}Co (pCi/L)	U (mg/L)?
Rogers	Treatment	R1	1/13/89	< 8.5	< 5.5	0.16
	Treatment	R1	1/29/90	< 2.66	< 2.47	0.011
	Reference	R4	1/13/89	< 10.40	< 9.0	0.09
	Reference	R4	1/29/90	< 0.04	----	< 0.0005
Pine	Treatment	P1	12/88	----	----	0.07
	Treatment	P1	1/13/89	< 2.3	< 2.3	0.03
	Treatment	P1	1/29/90	3.9	< 2.1	0.275
	Reference	P3	1/13/89	< 2.3	< 2.4	
	Reference	P3	1/29/90	< 2.5	< 1.9	0.023
	Reference	P4*	12/88	----	----	0.09
	Treatment (downstream)	P6 (rock wall)	1/29/90	< 3.0	< 2.5	0.093
	Treatment (downstream)	Creek at Corner	1/29/90	< 3.1	< 2.8	0.029
Cottonwood	Treatment	North Creek	1/29/90	1.6	< 3.0	<0.0005
	Treatment	North Creek	2/16/90	< 2.9	< 2.8	
	Treatment	South Creek	1/29/90	2.4	< 3.0	0.006
	Treatment	South Creek	2/16/90	2.2	< 2.0	
	Reference	Ref. Creek	1/29/90	< 2.2	< 2.7	0.122
Rogers	Treatment	Pool	3/10/88	----	4.9	
	Treatment	Weir	3/10/88	< 5.0	< 5.0	
	Treatment	A*	2/4/88	< 2.7	< 5.4	
	Reference	B*	2/4/88	< 2.7	< 2.7	
	Reference	F*	2/4/88	< 5.4	< 5.4	
McCoy	Reference	Upstream	3/10/88	< 3.7	< 2.7	
	Treatment	Downstream*	3/10/88	< 2.7	< 2.7	
	Treatment	Downstream	3/10/88	< 5.0	< 3.7	

* These samples taken from compositors.

Table 8.11 Biological oxygen demand (mg/L) and fecal coliform bacteria (colonies/100 mL)in surface runoff from the Cottonwood, Pine Plantation, and Rogers site. Data are arranged by site, sample treatment type or area (reference, Ref; or sludge treated, Trt) and date. "Trt" samples were in or downstream from the application areas, "dil" means flow has been potentially diluted. "Grab" or "Comp" indicate grab samples or sample from compositors. If not labelled, samples were grab samples. Sample IDs are further described in legends for previous tables in this section, and A, B, and ' designate replicate samples. Some of this data also appears in Tables 8.1 through 8.3.

Sample ID	Site	TRT		Fecal Coliform	BOD
CR	Cottonwood	Ref	01/04/90	30	4
CR	Cottonwood	Ref	01/30/90	3	<2
CR	Cottonwood	Ref	05/02/90	5200	3
CSC	Cottonwood	Trt	01/30/90	40	>15
CSC	Cottonwood	Trt	05/02/90	8300	3
CNC	Cottonwood	Trt dil	09/22/89	2260	<4
CNC	Cottonwood	Trt dil	01/04/90	140	<2
CNC	Cottonwood	Trt dil	01/30/90	520	2
CNC	Cottonwood	Trt dil	02/22/90	380	<2
CNC	Cottonwood	Trt dil	05/02/90	6200	3
P3A	Pine	Ref grab	06/09/89	330	<5
P3B	Pine	Ref grab	06/09/89	300	<5
P3	Pine	Ref grab	01/30/90	10	4
P3	Pine	Ref grab	10/02/90	<100	<4
1132SPA	Pine	Trt	06/09/89	24000	13.2
1132SPB	Pine	Trt	06/09/89	26000	12.7

Table 8.11 (continued)

P1A	Pine	Trt grab	06/09/89	13000	12.2
P1B	Pine	Trt grab	06/09/89	15000	10.8
P1A	Pine	Trt grab	09/22/89	260000	12
P1B	Pine	Trt grab	09/22/89	250000	12
P1	Pine	Trt grab	01/04/90	260	<2
P1	Pine	Trt grab	01/30/90	800	5
P1	Pine	Trt grab	02/22/90	2300	<2
P1	Pine	Trt grab	10/02/90	500	<4
P1	Pine	Trt grab	11/27/90	28	<2
C AT C	Pine	Trt dil	01/30/90	673	4
C AT C	Pine	Trt dil	02/22/90	1950	<2
C AT C	Pine	Trt dil	11/27/90	13	<2
P6	Pine	Trt dil	09/22/89	11400	5
P6	Pine	Trt dil	01/04/90	10	<2
P6	Pine	Trt dil	01/30/90	150	3
R1	Rogers	Trt Grab	01/04/90	330	4
R1	Rogers	Trt Grab	01/30/90	270	2
R1	Rogers	Trt Grab	02/22/90	650	2
R1	Rogers	Trt Grab	05/02/90	>57000	7
R1A	Rogers	Trt Grab	02/17/89	>600	<5
R1B	Rogers	Trt Grab	02/17/89	100	<5
R2	Rogers	Trt Comp	07/14/88	>1200	<5
R2'	Rogers	Trt Comp	07/14/88	>1200	
R3	Rogers	Trt Pool	07/14/88	>1200	7
R4	Rogers	Ref Grab	09/22/89	41000	2
R4	Rogers	Ref Grab	01/04/90	180	3
R4	Rogers	Ref Grab	01/30/90	33	<2
R4	Rogers	Ref Grab	02/22/90	120	<2
R4	Rogers	Ref Grab	05/02/90	>51666700	5
R4	Rogers	Ref Grab	10/02/90	800	<2
R4	Rogers	Ref Grab	11/27/90	700	<2
R4A	Rogers	Ref Grab	02/17/89	260	<5
R4B	Rogers	Ref Grab	02/17/89	520	
R5	Rogers	Ref Comp	07/14/88	22	7
R5'	Rogers	Ref Comp	07/14/88	118	

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