Metals Data for Pennsylvania Soils

by

Edward J. Ciolkosz,
Richard C. Stehouwer,
and
Mary Kay Amistadi

Agronomy Series Number 140

Agronomy Department
The Pennsylvania State University
University Park, PA 16802

June 1998

Contents

CHAPTER 1

Introduction

In recent years, a great concern has developed in the effect of metals on the environment and human health. In particular, the threshold amounts of metals that impact the environment and health. As a part of this concern, a significant amount of research has been done on the background levels of these metals in the environment, in particular, in the soil. Many of these studies have not been published or are obscure and not readily available. To partially rectify this situation for Pennsylvania soils, this publication has been produced. This publication is a series of chapters of published and unpublished data, and little attempt has been made to synthesize the data from the various chapters, other than the comments given in the following section.

Materials and Methods

The soil samples used in the studies in Chapters 3 and 5 were from the Penn State Soil Characterization Laboratory's collection of soil samples and have been analyzed by that laboratory for basic physical and chemical properties (Ciolkosz, 1998). The soil samples used in the study in Chapter 2 were collected and analyzed by the USDA-SCS (now USDA-NRCS) Soil Survey staff members. The soil samples used in the Chapter 4 study were sent in to the Penn State Environmental Chemistry Laboratory, and with the exception of county identification, very little is known about these samples other than they are mainly surface (A) horizon samples. Some effort was made by lab staff to exclude data from known contaminated samples from the data set, but it appears that some data from contaminated samples is included. The samples used in Chapter 6 were collected by John Washington as a part of his M.S. thesis study, and the samples used in Chapter 7 were collected by USCS personnel.

The methods used to analyze soil samples is a major concern when data is evaluated, merged, or folded into a database. For example, total analysis cannot be compared directly with extraction analysis in which a soil residue remains after the soil samples have been extracted. In addition, different extraction analysis cannot be compared unless it is proven that the different extractants and/or methods provide identical data. In many cases, different extractants and/or methods provide data that is not identical, thus not comparable. The methods used in Chapters 4 and 5 were the same, thus comparable; and the method used in Chapter 6 also gave comparable results to the data in Chapters 4 and 5. It is uncertain if the method used in Chapter 2 is comparable, but cursory evaluation of the data indicates similar orders of magnitude in the data. In general, the cadmium data in Chapter 3 appears an order of magnitude lower; and the zinc data appears two orders of magnitude lower than that noted in the other studies. The data in Chapter 7 is for total analysis. This method analyzes the total amount of the elements in the sample, and thus, is not directly comparable with the other extraction methods. Total analysis is a standard type of analysis done in geologic sciences; and significant data has been gathered using this methodology for stream sediments (Rose and Keith 1971; Keith et al., 1967), and only limited data are available for Pennsylvania soils (McNeal and Rose, 1974). Additional stream sediment data is available from surveys of the National Uranium Evaluation program (see data in depository libraries). The stream sediment approach is an attempt to get average data for various watersheds.

References

Ciolkosz, E. J. 1998. Pennsylvania State University Soil Characterization Laboratory Database. Agronomy Department. Pennsylvania State Univ., Univ. Park, PA.

Keith, M. L. 1967. Trace metals in stream sediment of southeastern Pennsylvania, Part 1. Pennsylvania State Univ. Earth and Mineral Sciences Experiment Station, Bull. 82. Copy does not include map. A complete copy is in the PSU Library.

McNeal, J. M. and A. W. Rose. 1974. The geochemistry of mercury in sedimentary rocks and soils in Pennsylvania. Geochemica et Cosmochimica Acta, 38:1759-1784.

Rose, A. W. and M. L. Keith. 1971. Trace elements in stream sediment of southeastern Pennsylvania. Parts 2, 3, and 4. Pennsylvania State Univ. Earth and Mineral Sciences Experiment Station, Bull. 86.

CHAPTER 2

SCS (NRCS) Cadmium (Cd)-Lead (Pb) Study

Introduction

An extensive study of metals in soils and crops was conducted in the United States in the late 1970's by the USDA, FDA, and USEPA (Holmgren et al., 1993; White et al., 1997). These studies included soils and crop data on metals from Pennsylvania, but only summary data was published. The complete data is very useful for many purposes, in particular, determining the background level of metals in various kinds of Pennsylvania soil. Thus, the objective of this chapter is to present the complete data from this study for Pennsylvania soils and crops.

Material and Methods

The soils chosen for study were developed from red alluvium (Barbour and Linden) and red glacial till (Oquaga and Wellsboro) in the central and northeastern part of the state. Only the surface horizon (Ap) and the tomatoes growing on plants in the area in which the soil was sampled were collected for analysis. The soils were sampled by soil scientists of the USDA-SCS (now the USDA-NRCS) and analyzed by the USDA-SCS National Soil Survey Laboratory in Lincoln, NE (See Table 1 for the data). All except five samples of the soil were a composite of five subsamples from within a three by four meter area. The five noncomposite samples (Table 1, 097014R) were the five individual samples that made up the composite 097014X sample (Table 1). The texture of the samples was determined in the field by the "feel method." In this method, a soil scientist rubs the soil material between his fingers which have been calibrated with known textures, and a judgement is made as to the texture of the sample. Reaction (pH) was determined in a 1:1 (soil:water) sample with a pH meter. Organic carbon was determined by the Walkley-

Black method. Cation exchange capacity (CEC) was determined by direct distillation of ammonium ion adsorbed from pH 7 normal ammonium acetate solution. The metals were determined as follows: soil samples were digested with concentrated Ultrex nitric acid in teflon bombs overnight at 150°C; cadmium was determined by atomic absorption with standard additions utilizing a graphite furnace; lead was determined by anodic stripping voltammeter with standard additions. All other metals were determined simultaneously with one pass through a DC plasma spectrograph. Additional details on these methods are available in Holmgren et al. (1993).

Results

The Pennsylvania data from this study (Tables 1 and 2) is too limited to draw any general conclusions about metals in Pennsylvania soils, but the soils data can be used in combination with other Pennsylvania data to draw a better picture of the values and range of metals in Pennsylvania soils.

References

Holmgren, G. G. S., M. W. Meyer, R. L. Chaney, and R. B. Daniels. 1993. Cadmium, lead, zinc, copper, and nickel in agricultural soils of the United States of America. J. Environ. Qual. 22:335-348.

White, J. G., R. M. Welch, and W. A. Norvell. 1997. Soil zinc map of the USA using geostatistics and geographic information systems. Soil Sci. Soc. Am. J. 61:185-194.

Table 1. Soils data for Cd-Pb Pennsylvania soils study. The first numbers under soil number are the federal (FIPS) county number (081 = Lycoming, 097 = Northumberland, 109 = Snyder, 069 = Lackawanna, and 131 = Wyoming).

Soil			Parts Per Million						Percent	Meq/100g	
Series	Number	Texture+	Cd	Pb	Zn	Cu	Ni	pH	Organic Carbon	CEC+	L*D*I*N[8]P[8]K[8]
Barbour	081036X	L	0.110	13	55.4	16.3	17.1	5.7	0.47	9.3	0 5 N A C 0
Barbour	081040X	L	0.130	16	83.9	23.1	26.0	5.7	0.85	7.0	0 5 N 8 8 8
Barbour	097015X	FSL	0.150	11	108.0	22.1	33.8	6.4	0.64	6.8	0 5 Y 9 1 1
Barbour	097016X	FSL	0.160	10	80.4	19.4	22.9	6.5	0.73	4.9	0 5 Y 9 1 1
Barbour	097027X	SL	0.150	19	71.0	22.5	21.8	6.7	0.79	5.2	0 5 Y 7 7 A
Barbour	097028X	L	0.180	17	79.1	21.6	22.3	6.5	1.06	8.0	0 5 Y 7 7 A
Barbour	109021X	FSL	0.390	28	130.0	31.9	41.6	6.2	1.89	9.9	0 5 Y 6 8 1
Barbour	109023X	SIL	0.260	24	135.0	29.3	46.8	6.2	1.65	11.6	0 5 Y 6 8 1
Barbour	109024X	SL	0.290	13	70.2	42.7	24.0	6.1	0.90	7.0	0 5 Y 9 2 2
Barbour	109025X	SL	0.130	13	65.5	41.6	22.5	5.7	0.74	5.7	0 5 Y 9 2 2
Linden	081037X	L	0.240	23	113.0	22.9	35.7	5.8	1.55	11.0	0 5 N 8 8 8
Linden	081038X	L	0.250	19	112.0	25.4	32.4	5.7	1.23	9.1	0 5 N 8 8 8
Linden	081039X	L	0.260	24	108.0	25.2	38.0	5.1	1.36	10.1	0 5 N 8 8 8
Linden	097014R	SIL	0.160	14	107.0	22.0	31.6	6.3	0.81	7.4	0 5 Y 9 1 1
Linden	097014R	SIL	0.170	15	104.0	23.0	30.2	6.3	1.00	8.0	0 5 Y 9 1 1
Linden	097014R	SIL	0.160	14	111.0	22.6	30.8	6.4	0.91	7.9	0 5 Y 9 1 1
Linden	097014R	SIL	0.190	16	116.0	23.6	30.9	6.6	1.06	8.6	0 5 Y 9 1 1
Linden	097014R	SIL	0.180	15	102.0	18.0	30.1	6.6	1.02	8.2	0 5 Y 9 1 1
Linden	097014X	SIL	0.180	15	99.0	20.7	30.2	6.6	1.00	8.8	0 5 Y 9 1 1
Linden	097017X	FSL	0.130	15	80.8	24.9	31.0	7.3	0.59	5.0	0 5 Y 9 1 1
Linden	097018X	SL	0.160	13	70.8	21.7	20.4	6.6	0.92	4.9	0 5 Y 8 2 2
Linden	097019X	SL	0.160	15	67.8	19.8	20.2	6.2	0.94	6.7	0 5 Y 8 2 2
Linden	109020X	SIL	0.230	21	107.0	25.6	38.4	6.3	1.28	9.0	0 5 Y 6 8 1
Linden	109022X	SIL	0.250	24	126.0	27.5	44.3	6.2	1.59	11.7	0 5 Y 6 8 1
Linden	109026X	SIL	0.130	19	96.9	46.7	33.9	6.5	0.83	8.2	0 5 Y 9 2 2
Oquaga	069032X	SIL	0.160	16	62.3	24.1	23.2	6.5	1.85	9.5	0 5 N A A A
Oquaga	069033X	L	0.140	13	61.2	25.1	24.2	5.3	1.71	10.0	0 5 N A A A
Oquaga	069034X	SIL	0.160	15	72.8	14.8	28.4	5.1	1.99	10.6	0 5 N A A A
Oquaga	069035X	SIL	0.230	130	88.9	78.9	19.6	5.4	2.12	11.6	0 5 N A A A
Oquaga	079002X	SIL	0.230	23	77.3	15.9	18.8	6.0	1.66	9.8	0 5 N A B B
Oquaga	079003X	SIL	0.200	17	57.7	15.1	18.0	5.9	1.47	11.8	0 6 N A B B
Oquaga	079005X	SIL	0.200	17	68.7	14.9	19.4	6.2	1.68	10.7	0 5 N B C C
Oquaga	079006X	SIL	0.260	28	96.4	190.0	18.9	5.4	2.38	12.2	0 5 N B C C
Oquaga	079008X	SIL	0.220	20	71.1	36.4	18.9	5.5	1.90	10.3	0 5 N B C C
Oquaga	131030X	SIL	0.200	21	77.1	37.7	20.3	4.7	1.85	8.8	0 5 N A A A
Wellsboro	069009X	SIL	0.140	15	74.4	23.5	21.1	6.4	1.44	9.5	0 4 N 4 8 A
Wellsboro	069010X	SIL	0.150	41	94.0	41.3	20.0	7.0	2.10	9.7	0 4 N 4 8 A
Wellsboro	069011X	SIL	0.200	48	106.0	43.2	19.3	7.0	1.91	9.9	0 4 N 8 8 A
Wellsboro	069012X	SIL	0.270	32	111.0	31.6	24.6	6.7	2.72	15.5	3 4 N A A A
Wellsboro	079001X	SIL	0.270	14	82.2	16.2	19.3	6.1	1.76	11.1	0 4 N A B B
Wellsboro	079004X	L	0.210	16	84.8	19.6	22.3	5.8	1.19	8.2	0 4 N B C C
Wellsboro	079007X	SIL	0.280	31	85.7	62.3	19.7	4.9	2.76	14.4	0 4 N B C C
Wellsboro	079013X	SIL	0.180	21	72.7	83.7	15.9	5.7	1.60	7.8	0 4 N B C C
Wellsboro	131029X	SIL	0.093	16	66.6	17.9	21.3	5.2	0.90	6.0	0 4 N A A A
Wellsboro	131031X	SIL	0.220	19	72.7	31.3	30.3	5.2	0.22	6.2	0 4 N A A A

+L = loam, FSL = fine sandy loam, SL = sandy loam, and SIL = silt loam.
*L = lime added (tons/acre) *D = soil drainage class (4 - moderately well, 5 - well, and 6 - somewhat excessive).
*I = irrigation (Y = yes, N = no).
[8]N (Nitrogen), [8]P (Phosphorous), and [8]K (Potassium) fertilizer added (maximum yearly application within the last 5 years); 1 = 10 lbs, 5 = 50 lbs, 7 = 70 lbs, etc.; A = 100, B = 200 lbs, C = 300 lbs.
CEC+ = Cation Exchange Capacity.

Table 2. Cadmium (Cd), Lead (Pb), and other metals in tomatoes in Pennsylvania.*

		Parts Per Million Dry Weight												
Soil Series	Soil Numbe	Ca	Cd	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	Zn
Wellsboro	069009X	1200	0.160	11.00	61.0	38000	2100	24.0	< 0.100	< 270	< 0.330	4600	0.017	24.0
Wellsboro	069010X	1800	0.120	9.90	38.0	32000	1700	14.0	0.190	< 270	< 0.340	3300	0.084	17.0
Wellsboro	069011X	1600	0.160	13.00	44.0	40000	1800	17.0	< 0.100	< 270	0.470	3900	0.240	22.0
Wellsboro	069012X	1800	0.200	11.00	43.0	38000	1700	23.0	< 0.100	310	0.780	4000	0.130	23.0
Oquaga	069032X	1200	0.320	13.00	58.0	38000	1800	14.0	0.590	< 270	< 0.340	3600	0.050	19.0
Oquaga	069033X	1100	0.310	13.00	53.0	41000	1800	15.0	0.110	< 270	0.830	3600	0.039	22.0
Oquaga	069034X	990	0.210	13.00	55.0	38000	1700	24.0	0.100	< 270	0.950	3100	0.025	22.0
Oquaga	069035X	1200	0.110	12.00	50.0	37000	1500	12.0	< 0.100	< 270	0.720	4400	0.100	23.0
Wellsboro	079001X	1500	0.130	9.20	45.0	36000	1500	22.0	< 0.100	< 270	0.690	4300	0.027	26.0
Oquaga	079002X	1400	0.170	8.30	41.0	38000	1600	21.0	< 0.099	< 270	0.440	4200	0.041	26.0
Oquaga	079003X	1100	0.150	9.30	42.0	37000	1700	22.0	< 0.100	< 270	< 0.340	3700	0.034	26.0
Wellsboro	079004X	1500	0.210	12.00	56.0	41000	1900	21.0	0.100	< 270	0.740	3600	0.034	30.0
Oquaga	079005X	1600	0.230	11.00	59.0	41000	1900	20.0	0.170	< 270	0.950	4000	0.038	32.0
Oquaga	079006X	1200	0.130	13.00	41.0	45000	1900	50.0	< 0.099	< 260	1.200	5300	0.031	25.0
Wellsboro	079007X	1500	0.250	13.00	46.0	36000	1700	50.0	< 0.100	< 270	1.100	3900	0.045	24.0
Oquaga	079008X	1000	0.180	11.00	36.0	39000	1600	19.0	0.110	< 260	0.330	4400	0.027	23.0
Wellsboro	079013X	1300	0.093	13.00	40.0	36000	1800	30.0	< 0.100	< 270	0.330	3600	0.054	23.0
Barbour	081036X	1900	0.200	6.30	50.0	33000	1400	38.0	< 0.100	< 270	0.900	4200	0.037	29.0
Linden	081037X	1500	0.210	8.60	50.0	43000	1700	19.0	< 0.098	< 260	1.000	4700	0.018	20.0
Linden	081038X	1500	0.190	11.00	51.0	42000	1700	17.0	< 0.100	< 270	1.200	4800	0.034	23.0
Linden	081039X	1400	0.250	11.00	55.0	37000	1700	33.0	< 0.099	< 260	2.400	3900	0.099	27.0
Barbour	081040X	1900	0.180	7.90	50.0	36000	1700	21.0	< 0.099	< 260	0.610	4600	0.067	22.0
Linden	097014X	1700	0.250	7.20	46.0	31000	1800	17.0	0.280	< 280	0.390	4200	0.047	20.0
Barbour	097015X	1300	0.290	9.70	57.0	38000	2100	20.0	0.650	290	0.550	5200	0.023	25.0
Barbour	097016X	1100	0.130	8.60	41.0	42000	1900	14.0	0.580	280	< 0.350	5000	0.027	24.0
Linden	097017X	1600	0.200	7.70	60.0	38000	1800	14.0	0.640	< 280	< 0.340	4700	0.020	12.0
Linden	097018X	1300	0.160	6.80	44.0	34000	1500	16.0	0.290	< 280	0.610	3500	0.015	20.0
Linden	097019X	1400	0.130	8.80	42.0	38000	2000	15.0	0.250	< 280	< 0.350	4500	0.033	20.0
Barbour	097027X	1200	0.100	9.40	46.0	40000	1700	15.0	0.320	< 280	< 0.350	4500	0.028	22.0
Barbour	097028X	1200	0.190	9.20	48.0	42000	1800	17.0	< 0.099	< 260	0.620	3800	0.041	22.0
Linden	109020X	2000	0.170	13.00	61.0	36000	1800	18.0	< 0.100	300	1.300	4500	0.028	29.0
Barbour	109021X	2200	0.210	15.00	60.0	42000	1900	19.0	< 0.100	270	1.900	4700	0.036	32.0
Linden	109022X	1900	0.180	12.00	58.0	40000	1800	23.0	< 0.100	320	1.000	4500	0.020	28.0
Barbour	109023X	2600	0.220	13.00	68.0	39000	1900	22.0	< 0.100	330	1.300	4400	0.040	32.0
Barbour	109024X	1900	0.160	12.00	64.0	36000	1900	24.0	< 0.100	270	0.670	3900	0.150	26.0
Barbour	109025X	1700	0.130	13.00	61.0	38000	1800	21.0	< 0.100	290	0.590	4300	0.050	28.0
Linden	109026X	1800	0.170	11.00	59.0	35000	1800	21.0	< 0.099	< 260	0.530	3500	0.023	23.0
Wellsboro	131029X	1000	0.190	12.00	66.0	35000	1400	18.0	< 0.100	< 270	0.830	3900	0.017	27.0
Oquaga	131030X	700	0.150	14.00	63.0	36000	1400	26.0	< 0.100	< 270	1.500	4100	0.034	29.0
Wellsboro	131031X	1200	0.140	15.00	60.0	40000	1900	20.0	< 0.100	270	0.790	4800	0.038	29.0

*Samples were analyzed by the USEPA Laboratory in Cincinnati, Ohio.

CHAPTER 3

Pepperman's Cadmium (Cd)-Zinc (Zn) Study

Introduction

Robert Pepperman conducted a study on cadmium and lead in Pennsylvania soils developed from sandstone, shale, and limestone parent materials (Pepperman, 1981). These data to the authors' knowledge have not been published, and the soil samples used were a part of the library of characterized Pennsylvania Soils (Ciolkosz, 1998). Because of these reasons, the data and Pepperman's results and conclusions are present here.

Materials and Methods

All horizons of fifteen Pennsylvania soil profiles derived from either sandstone, limestone, or shale residuum parent material were selected from the Penn State Soil Characterization Library of soil samples (Ciolkosz, 1998). The fine earth (< 2 mm) soil material was analyzed for extractable cadmium (Cd) and zinc (Zn) using the Baker (DTPA-TEA, pH 7.3) Soil Test (Baker, 1974). See Pepperman (1981) for details of the analysis. The data are presented in Table 1.

Results and Conclusions

Results of the soil analyses indicate that several generalizations can be made concerning the distribution of the two metals within the soil profile. In most profiles, cadmium and zinc concentrations were highest at the surface and decreased with depth and indicated a recycling of the two elements, additions of the metals via fertilizer and/or pesticides, or both. Soil horizons which contained significant clay accumulations also tended to have higher amounts of the two metals, especially zinc. A similar relationship between horizons with iron and/or manganese coatings and extractable zinc was noted. Finally, an increase in the amount of extractable zinc occurred in the gleyed horizons of one of the soils analyzed.

For the fifteen soils sampled, the influence of parent material on background levels of cadmium and zinc, as reflected by the extractable metal from the lowest most horizon, proved nonsignificant. A more intensive study of soils within a smaller region is necessary to determine if a relationship between the parent material and the soil levels of extractable cadmium and zinc exists.

Six soil physical and chemical characteristics served as independent variables in a step-wise regression analysis of the soil properties which influence cadmium and zinc extractability by DTPA-TEA. When cadmium was used as the dependent variable, zinc was also included as an independent variable in the regression and vice versa. In the 15 Ap horizons tested, extractable cadmium was significantly correlated with organic matter and base saturation at the 5 percent and 1 percent levels, respectively. Extractable zinc in the Ap horizons of the fifteen soils was correlated at the 1 percent level with four variables; organic matter, pH, cation exchange capacity, and base saturation.

References

Baker, D. E. 1974. Determination of the relative availabilities of hydrogen, calcium, magnesium, potassium, sodium, phosphorous, sulfur, iron, manganese, zinc, copper, aluminum, and other metals by the small exchange approach to soil testing. In Handbook on Reference Methods for Soil Testing. The Council on Soil Testing and Plant Analysis. Athens, GA.

Ciolkosz, E. J. 1998. Pennsylvania State University Soil Characterization Laboratory Database. Agronomy Department, Pennsylvania State Univ., Univ. Park, PA.

Pepperman, R. E. 1981. Background levels of cadmium and zinc in several Pennsylvania soils. M.S. Thesis. Pennsylvania State Univ., Univ. Park, PA.

Table 1. Cadmium (Cd), lead (Pb), and selected characterization data used in this study.

Soil and Drainage Class	Soil Number*	Horizon	Depth in cm	pH	Percent: Organic Carbon	Percent: Sand	Percent: Silt	Percent: Clay	Parts Per Million: Cd	Parts Per Million: Zn
				Residual Acid Sandstone						
Clymer	032-055-01	Ap	0 - 20	4.8	1.39	49.7	40.2	10.1	0.0860	1.20
(well drained)	032-055-02	Bt1	20 - 38	4.9	0.16	45.5	37.0	17.5	0.0095	0.60
	032-055-03	Bt2	38 - 61	4.8	0.06	47.5	38.3	14.2	0.0060	0.70
	032-055-04	BC	61 - 91	4.8	0.02	53.0	33.8	13.2	0.0035	0.55
	032-055-05	C	91 - 107	4.6	0.04	65.5	25.5	9.0	0.0300	0.50
Hazleton	026-010-01	Ap	0 - 23	6.7	2.50	47.7	35.3	17.0	0.2330	0.75
(well drained)	026-010-02	BA	23 - 38	6.6	0.48	49.2	33.1	17.7	0.0300	0.80
	026-010-03	Bw	38 - 66	5.7	0.17	60.8	29.7	9.5	0.0190	0.40
	026-010-04	BC	66 - 86	4.9	0.09	62.9	29.9	7.2	0.0035	0.65
	026-010-05	C	86 - 145	4.9	0.05	70.7	18.8	10.5	0.0045	0.55
Lansdale	046-001-01	Ap	0 - 25	5.1	0.91	25.3	63.1	11.6	0.0635	1.30
(well drained)	046-001-02	Bw	25 - 41	5.6	0.42	40.4	42.1	17.5	0.0115	0.50
	046-001-03	BC	41 - 51	5.9	0.25	48.7	37.4	13.9	0.0450	0.70
	046-001-04	C1	51 - 66	5.7	0.10	71.7	19.4	8.9	0.0180	0.50
	046-001-05	C2	66 - 91	5.0	0.10	64.5	28.6	6.9	0.1300	0.75
	046-001-06	C3	91 - 107	4.8	0.08	78.5	17.6	3.9	0.0055	0.55
				Residual Calcareous Sandstone						
Vanderlip	031-002-01	Ap1	0 - 8	4.1	4.51	83.4	12.9	3.7	0.1410	6.15
(well drained)	031-002-02	Ap2	8 - 20	4.9	0.79	77.3	17.9	4.8	0.0630	1.45
	031-002-03	E	20 - 43	4.9	0.35	80.1	14.7	5.2	0.0410	0.85
	031-002-04	EB	43 - 66	5.1	0.09	84.8	9.9	5.3	0.0445	1.00
	031-002-05	BEt	66 - 97	4.9	0.02	89.5	6.2	4.3	0.0370	1.15
	031-002-06	Bt1	97 - 122	5.1	0.05	90.2	5.9	3.9	0.0495	1.50
	031-002-07	Bt2	122 - 137	5.1	0.02	79.5	16.0	4.5	0.0410	2.40
	031-002-08	Bt3	137 - 152	5.2	0.02	90.2	5.9	3.9	0.0375	1.30
	031-002-09	Bt4	152 - 170	5.2	0.04	83.8	6.3	9.9	0.0345	0.95
	031-002-10	Bt5	170 - 178	5.1	0.03	78.2	11.5	10.3	0.0265	1.10
	031-002-11	BC	178 - 211	5.0	0.04	70.2	18.0	11.8	0.0170	1.30
	031-002-12	C	211 - 226	5.1	0.03	79.8	7.1	13.1	0.0200	1.10
				Residual Brown Shale						
Gilpin	033-006-01	Ap	0 - 18	7.0	2.46	30.3	52.7	17.0	0.2625	1.30
(well drained)	033-006-02	BA	18 - 33	6.7	0.67	34.6	48.8	16.6	0.0470	0.45
	033-006-03	Bt	33 - 48	6.5	0.57	34.0	51.1	14.9	0.0610	1.15
	033-006-04	BC	48 - 69	5.1	0.75	40.3	45.3	14.4	0.0280	0.65
	033-006-05	C	69 - 102	5.0	0.61	47.2	46.8	6.0	0.0616	1.00
				Residual Red Shale						
Leck Kill	022-004-01	Ap	0 - 25	6.8	1.14	44.5	36.0	19.5	0.0715	0.85
(well drained)	022-004-02	Bw1	25 - 36	5.1	0.27	49.0	24.1	26.9	0.0180	1.00
	022-004-03	Bw2	36 - 46	4.8	0.13	45.6	35.5	18.9	0.0065	0.80
	022-004-04	BC	46 - 64	4.6	0.15	44.7	34.1	21.2	0.0085	0.80
	022-004-05	C	64 - 117	4.7	0.08	42.2	34.0	23.8	0.0095	0.85
	022-004-06	R	117 - 165	4.6	--	45.8	29.8	24.4	Red shale	
Penn	067-001-01	Ap	0 - 23	7.7	1.13	25.3	60.7	14.0	0.0685	1.45
(well drained)	067-001-02	BA	23 - 36	4.7	0.36	26.4	57.6	16.0	0.0565	1.40
	067-001-03	Bt1	36 - 53	6.4	0.17	17.6	64.1	18.3	0.0395	1.20
	067-001-04	Bt2	53 - 61	5.0	0.07	20.0	60.3	19.7	0.0675	2.30
	067-001-05	C1	61 - 76	5.5	0.04	18.5	60.8	20.7	0.0675	2.05
	067-001-06	C2	76 - 124	7.2	0.01	25.0	59.0	16.0	0.0580	1.45
Readington	046-012-01	Ap	0 - 20	6.0	1.02	14.9	70.0	15.1	0.0815	1.35
(moderately well	046-012-02	AB	20 - 28	6.1	0.67	12.9	65.3	21.8	0.0615	0.80
drained)	046-012-03	BA	28 - 38	5.7	0.22	10.6	65.8	23.6	0.0335	0.55
	046-012-04	Bt1	38 - 51	5.1	0.14	11.2	62.7	26.1	0.0165	0.55
	046-012-05	Bx1	51 - 74	4.7	0.02	14.4	58.8	26.8	0.0260	0.60
	046-012-06	Bx2	74 - 84	4.5	0.02	20.6	41.7	37.7	0.0240	1.00
	046-012-07	Bx3	84 - 102	4.8	0.01	16.6	57.8	25.6	0.0185	1.60
	046-012-08	Bx4	102 - 112	4.8	0.01	12.3	65.7	22.0	0.0185	2.55
Reaville	046-016-01	Ap	0 - 20	4.7	0.89	12.4	68.5	19.1	0.0525	3.95
(somewhat poorly	046-016-02	BA	20 - 30	4.5	0.10	13.0	58.9	28.1	0.0220	1.80
drained)	046-016-03	Bt1	30 - 38	4.4	0.10	14.0	57.0	29.0	0.0180	3.65
	046-016-04	Bt2	38 - 48	4.4	0.09	11.6	58.7	29.7	0.0185	1.30
	046-016-05	C1	48 - 66	4.5	0.05	19.1	55.5	25.4	0.0335	2.65
	046-016-06	C2	66 - 81	4.0	0.05	26.7	51.7	21.6		

Table 1. Cont. Cadmium (Cd), lead (Pb), and selected characterization data used in this study.

Soil and Drainage Class	Soil Number*	Horizon	Depth in cm	pH	Percent Organic Carbon	Percent Sand	Percent Silt	Percent Clay	Parts Per Million Cd	Parts Per Million Zn
			Residual Metamorphosed Shale							
Brecknock	001-015-01	Ap	0 - 23	6.7	1.23	23.1	58.4	18.5	0.0625	0.90
(well drained)	001-015-02	Bt1	23 - 36	6.7	0.27	20.2	51.2	28.6	0.0270	0.50
	001-015-03	Bt2	36 - 56	5.1	0.21	26.2	50.7	23.1	0.0135	0.35
	001-015-04	BC	56 - 71	4.9	0.12	35.9	42.3	21.8	0.0110	0.55
	001-015-05	C	71 - 97	5.0	0.12	44.4	35.5	20.1	0.0200	0.40
	001-015-06	R	97 - 118	Phyllite						
			Residual Limestone							
Hagerstown	014-005-01	Ap	0 - 23	5.7	1.53	6.0	70.0	24.0	0.1620	1.60
(well drained)	014-005-02	Bt1	23 - 43	5.1	0.26	2.5	48.8	48.7	0.0210	1.40
	014-005-03	Bt2	43 - 66	5.2	0.25	1.8	34.9	63.3	0.0210	0.95
	014-005-04	Bt3	66 - 79	4.9	0.17	1.7	32.5	65.8	0.0180	4.45
	014-005-05	Bt4	79 - 107	6.5	0.14	1.4	35.5	63.1	0.0470	1.60
	014-005-06	BC	107 - 135	7.6	0.12	5.7	54.2	40.1	0.0480	2.10
	014-005-07	C	135 - 173	7.5	0.10	8.7	53.1	38.2	0.0465	1.10
	014-005-08	R	173 - 198	Limestone						
			Residual Shaley Limestone							
Ryder	006-009-01	Ap	0 - 18	6.1	1.48	16.2	56.5	27.3	0.0795	1.15
(well drained)	006-009-02	Bt1	18 - 28	6.3	0.21	15.6	55.6	28.8	0.0195	0.45
	006-009-03	Bt2	28 - 43	5.5	0.15	15.9	57.8	26.3	0.0225	0.65
	006-009-04	BC	43 - 53	5.2	0.13	16.2	57.7	26.1	0.0195	0.70
	006-009-05	C	53 - 84	5.1	0.13	17.0	58.9	24.1	0.0310	0.95
	006-009-06	R	84 - 99	Shaley limestone						
Duffield	028-012-01	Ap	0 - 25	7.4	0.90	24.3	59.5	16.2	0.0775	0.95
(well drained)	028-012-02	BA	25 - 51	6.5	0.13	20.9	55.3	23.8	0.0445	0.85
	028-012-03	Bt1	51 - 74	6.3	0.15	32.1	41.5	26.4	0.0260	0.65
	028-012-04	Bt2	74 - 102	6.3	0.10	29.6	44.8	25.6	0.0180	0.80
	028-012-05	BC	102 - 142	6.3	0.13	14.9	49.2	35.9	0.0110	0.80
	028-012-06	C	142 - 241	6.0	0.17	24.2	33.7	42.1	0.0115	1.05
			Cherty Limestone							
Hublersburg	014-012-01	Ap	0 - 23	6.2	1.37	21.8	56.8	21.4	0.0940	1.30
(well drained)	014-012-02	Bt1	23 - 38	6.7	0.73	10.7	39.9	49.4	0.0230	0.40
	014-012-03	Bt2	38 - 66	5.2	0.17	8.6	33.5	57.9	0.0090	0.35
	014-012-04	Bt3	66 - 94	5.0	0.10	10.5	31.8	57.7	0.0047	0.40
	014-012-05	BC1	94 - 117	5.1	0.10	5.5	33.7	60.8	0.0060	0.40
	014-012-06	BC2	117 - 147	5.0	0.09	4.6	43.0	52.4	0.0130	0.55
	014-012-07	BC3	147 - 193	5.3	0.08	4.9	52.9	42.2	0.0140	0.90
	014-012-08	BC4	193 - 231	5.0	0.09	2.6	36.3	61.1	0.0095	0.65
	014-012-09	C	231 - 262	6.0	0.09	6.0	54.3	39.7	0.0845	0.95
			Very Cherty Limestone							
Elliber	050-007-01	Ap	0 - 20	6.7	2.40	38.9	48.9	12.2	0.2900	3.55
(well drained)	050-007-02	E	20 - 38	7.0	0.58	38.9	46.9	14.2	0.0690	2.10
	050-007-03	Bw	38 - 56	7.1	0.22	33.7	49.7	16.6	0.0555	1.50
	050-007-04	Bt1	56 - 79	6.9	0.13	17.2	50.4	32.4	0.0510	1.15
	050-007-05	Bt2	79 - 109	5.0	0.10	13.9	48.3	37.8	0.0280	1.00
	050-007-06	C1	109 - 140	4.8	0.08	36.5	33.0	30.5	0.0365	1.30
	050-007-07	2C2	140 - 183	4.9	0.07	37.6	31.7	30.7	0.1335	1.90
	050-007-08	3C3	183 - 208	4.7	0.07	6.4	47.3	46.3	0.0925	3.10

*Penn State Soil Characterization Laboratory Number.

CHAPTER 4

Penn State Environmental Chemistry Laboratory Data

Introduction

During the 1980's a large number of samples (the bulk of which were soil samples) were analyzed for metals in the Environmental Chemistry Laboratory in the Penn State Agronomy Department supervised by Dr. Dale Baker. Some of these data were published in various forms. A summary of these data were produced and presented by Amistadi and Baker (1990) but never published. Thus, the intent of this chapter is to present these data. In addition, data from two Pennsylvania soils (Gilpin and Hagerstown) are included. These soils were part of an extensive study of soils and sludges (NE-96) in the Northeast United States (NERRP, 1985), and the data were published by Baker and Wolf (1984). These data are included because soil characterization data for these soils is a part of the Penn State soil characterization data base (Ciolkosz, 1998).

Materials and Methods

Over 8,000 samples were analyzed from 60 of the 67 counties of Pennsylvania. These samples were primarily from the surface soil horizon. Research and known contaminated samples were eliminated from the data set. The data are presented in an increasing value distribution array by county (Tables 1-5). The method used for analysis of the soil samples was the USEPA Acid Digestion of Sediments, Sludges, and Soils Method 3050 (USEPA, 1986). See Chapter 5 of this publication for more details of this method.

Results

The data in Table 1 indicates a wide range of values from county to county. Because of the uncertainty of the origin of the samples, it must be assumed that the extreme values indicate an unknown contamination of these samples. The data in Tables 6 and 7 present additional Pennsylvania data and are presented as additional background data.

References

Amistadi, M. K. and D. E. Baker. 1990. Summary of database for chemical elements in soils involved with land application of sludges in Pennsylvania. Agronomy Abstracts (San Antonio, TX). p. 32.

Baker, D. E. and A. M. Wolf. 1984. Soil chemistry, soil mineralogy, and the disposal of solid wastes. In: S. K. Majumdar and E. Willard Miller (editors). Solid and liquid wastes, management, methods, and socioeconomic considerations. Pennsylvania Academy of Science. pp. 238-253.

Ciolkosz, E. J. 1998. Pennsylvania State University Soil Characterization Laboratory Database. Agronomy Department. Pennsylvania State Univ., Univ. Park, PA.

NERRP (Northeast Regional Research Publication). 1985. Criteria and recommendations for land application of sludges in the Northeast. PA Ag. Expt. Station Bull. 851.

USEPA, United States Environmental Protection Agency. 1986. Acid digestion of sediment, sludge, and soils (Method 3050). In: Test methods for evaluating solid waste. SW-846. USEPA. Washington, DC.

Table 1. Distribution of Cadmium (Cd) values according to percentage class for Pennsylvania by county. Values are parts per million.

County Number and Name		Number of Samples	Maximum 100%	90%	75%	Median 50%	25%	10%	Minimum 0%	Mean
1	Adams	114	14.60	0.22	0.13	0.10	0.07	0.04	0.01	0.61
2	Allegheny	70	80.60	20.10	20.10	0.72	0.17	0.06	0.04	7.60
3	Armstrong	25	0.44	0.42	0.37	0.21	0.03	0.03	0.03	0.19
4	Beaver	457	66.60	11.30	4.74	2.13	1.09	0.54	0.01	4.61
5	Bedford	18	0.34	0.32	0.20	0.17	0.12	0.07	0.06	0.17
6	Berks	302	94.40	0.31	0.23	0.17	0.10	0.06	0.01	0.50
7	Blair	9	0.22	0.22	0.18	0.12	0.08	0.04	0.04	0.12
8	Bradford	27	0.26	0.21	0.16	0.11	0.08	0.07	0.07	0.13
9	Bucks	230	17.60	0.67	0.26	0.14	0.08	0.02	0.01	0.50
10	Butler	54	1.80	1.53	0.96	0.57	0.47	0.26	0.11	0.76
11	Cambria	110	1.60	0.22	0.13	0.07	0.22	0.02	0.01	0.13
12	Cameron	6	0.25	0.25	0.25	0.17	0.09	0.09	0.09	0.17
13	Carbon	9	54.70	54.70	25.80	2.13	0.89	0.04	0.04	12.91
14	Centre	200	102.10	8.82	0.24	0.16	0.09	0.06	0.01	6.11
15	Chester	393	0.65	0.27	0.19	0.14	0.10	0.06	0.01	0.16
16	Clarion	39	2.86	2.86	2.86	0.10	0.05	0.03	0.01	0.97
17	Clearfield	47	0.43	0.29	0.25	0.22	0.15	0.10	0.06	0.20
18	Clinton	2	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
19	Columbia	60	2.26	0.28	0.19	0.13	0.10	0.08	0.05	0.22
20	Crawford	6	0.35	0.35	0.35	0.25	0.15	0.07	0.07	0.24
21	Cumberland	485	1.97	0.26	0.18	0.14	0.09	0.07	0.01	0.16
22	Dauphin	274	1.57	0.30	0.18	0.14	0.07	0.03	0.01	0.18
23	Delaware	20	3.17	3.17	2.51	1.38	0.42	0.20	0.17	1.54
24	Elk	141	152.00	31.50	14.60	4.82	1.31	0.32	0.08	13.93
25	Erie	32	6.35	2.59	0.27	0.17	0.11	0.07	0.06	0.75
26	Fayette	--	--	--	--	--	--	--	--	--
27	Forest	--	--	--	--	--	--	--	--	--
28	Franklin	158	17.60	0.19	0.14	0.07	0.06	0.06	0.01	0.29
29	Fulton	--	--	--	--	--	--	--	--	--
30	Greene	71	0.41	0.39	0.29	0.16	0.13	0.06	0.05	0.20
31	Huntingdon	42	0.74	0.31	0.22	0.15	0.12	0.10	0.07	0.19
32	Indiana	39	0.50	0.37	0.28	0.24	0.21	0.12	0.05	0.24
33	Jefferson	23	37.90	0.67	0.33	0.20	0.15	0.11	0.05	1.88
34	Juniata	8	1.63	1.63	1.26	0.14	0.07	0.05	0.05	0.49
35	Lackawanna	8	0.26	0.26	0.25	0.19	0.03	0.02	0.02	0.15
36	Lancaster	528	25.30	0.38	0.25	0.16	0.11	0.07	0.01	0.28
37	Lawrence	2	0.60	0.60	0.60	0.37	0.14	0.14	0.14	0.37
38	Lebanon	242	1.02	0.23	0.20	0.15	0.11	0.06	0.01	0.16
39	Lehigh	30	1.65	1.27	0.84	0.43	0.23	0.12	0.08	0.53
40	Luzerne	29	15.90	0.67	0.28	0.19	0.06	0.01	0.01	0.79
41	Lycoming	44	8.75	1.75	0.20	0.14	0.08	0.06	0.04	0.67
42	McKean	--	--	--	--	--	--	--	--	--
43	Mercer	--	--	--	--	--	--	--	--	--
44	Mifflin	29	0.37	0.25	0.22	0.18	0.13	0.10	0.06	0.18
45	Monroe	10	10.30	7.57	1.69	1.28	0.05	0.05	0.03	3.98
46	Montgomery	489	37.90	1.53	0.33	0.20	0.14	0.09	0.04	0.98
47	Montour	46	0.35	0.27	0.24	0.19	0.16	0.12	0.08	0.19
48	Northampton	55	1.77	0.58	0.30	0.23	0.16	0.06	0.02	0.29
49	Northumberland	98	1.53	0.17	0.14	0.08	0.03	0.02	0.02	0.10
50	Perry	27	0.73	0.26	0.17	0.15	0.11	0.05	0.01	0.16
51	Philadelphia	81	94.40	0.97	0.39	0.27	0.19	0.11	0.01	1.86
52	Pike	--	--	--	--	--	--	--	--	--
53	Potter	4	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.12
54	Schuylkill	29	0.42	0.15	0.11	0.08	0.08	0.08	0.08	0.11
55	Snyder	76	0.40	0.29	0.22	0.13	0.09	0.05	0.02	0.15
56	Somerset	47	4.92	2.40	0.37	0.04	0.04	0.03	0.03	0.55
57	Sullivan	--	--	--	--	--	--	--	--	--
58	Susquehanna	13	37.90	22.90	0.48	0.37	0.15	0.11	0.09	3.19
59	Tioga	--	--	--	--	--	--	--	--	--
60	Union	37	0.37	0.21	0.13	0.09	0.08	0.07	0.05	0.12
61	Venango	8	0.88	0.88	0.18	0.04	0.04	0.03	0.03	0.17
62	Warren	33	0.58	0.40	0.33	0.29	0.21	0.18	0.17	0.29
63	Washington	22	1.97	1.75	0.39	0.15	0.10	0.01	0.01	0.49
64	Wayne	24	0.51	0.24	0.19	0.16	0.08	0.05	0.01	0.16
65	Westmoreland	224	85.90	0.74	0.53	0.41	0.27	0.19	0.04	0.91
66	Wyoming	--	--	--	--	--	--	--	--	--
67	York	507	8.34	0.45	0.20	0.14	0.09	0.05	0.01	0.29

Table 2. Distribution of Copper (Cu) values according to percentage class for Pennsylvania by county. Values are parts per million.

County Number	and Name	Number of Samples	Maximum 100%	90%	75%	Median 50%	25%	10%	Minimum 0%	Mean
1	Adams	114	88.00	25.80	17.55	11.75	7.55	5.05	1.60	14.82
2	Allegheny	70	1710.00	43.30	36.70	21.70	14.30	10.30	5.50	59.50
3	Armstrong	25	32.30	19.10	13.90	9.90	6.10	6.10	6.10	10.66
4	Beaver	457	640.00	48.50	34.90	22.80	15.50	12.20	7.11	33.20
5	Bedford	18	29.70	28.30	24.00	13.80	10.90	6.80	5.00	16.40
6	Berks	302	195.00	32.40	24.80	17.50	13.40	8.30	3.50	20.62
7	Blair	9	22.40	22.40	19.10	10.10	6.20	3.90	3.90	12.82
8	Bradford	27	32.30	18.00	13.80	10.70	4.90	4.68	4.50	10.73
9	Bucks	230	4690.00	42.20	20.70	14.40	12.90	12.90	5.60	49.90
10	Butler	54	88.00	31.80	24.20	18.10	12.80	11.10	6.30	20.26
11	Cambria	110	196.00	49.00	25.70	20.80	16.00	7.51	3.60	26.56
12	Cameron	6	20.90	20.90	20.90	13.80	6.70	6.70	6.70	13.80
13	Carbon	9	2620.00	2620.00	1255.00	101.00	19.00	15.10	15.10	673.86
14	Centre	200	142.00	39.00	16.50	10.50	6.33	5.40	1.91	16.96
15	Chester	393	90.00	30.80	22.40	16.40	12.00	6.74	1.20	18.31
16	Clarion	39	24.40	19.90	10.90	8.10	6.50	6.20	4.90	9.80
17	Clearfield	47	56.10	30.00	22.90	15.70	11.50	8.46	4.30	18.17
18	Clinton	2	11.10	11.10	11.10	10.40	9.70	9.70	9.70	10.40
19	Columbia	60	34.30	20.40	15.90	12.90	9.70	7.64	4.20	13.40
20	Crawford	6	25.30	25.30	24.80	17.10	10.10	9.40	9.40	17.30
21	Cumberland	485	168.00	36.30	25.70	15.10	11.10	7.82	2.40	19.35
22	Dauphin	274	250.00	34.60	22.20	14.60	9.68	6.35	3.40	18.89
23	Delaware	20	116.00	81.10	51.90	28.80	23.70	17.00	11.70	39.31
24	Elk	141	232.00	75.60	32.60	17.10	11.10	8.90	6.00	33.02
25	Erie	32	131.00	34.00	28.90	14.70	7.05	5.56	4.70	22.98
26	Fayette	--	--	--	--	--	0	0	0	--
27	Forest	--	--	--	--	--	--	--	--	--
28	Franklin	158	62.00	22.40	15.30	11.00	6.50	5.10	3.20	12.83
29	Fulton	--	--	--	--	--	--	--	--	--
30	Greene	71	28.70	27.50	18.20	14.40	10.00	6.52	5.90	15.06
31	Huntingdon	42	33.50	23.90	14.60	11.10	9.00	6.62	4.70	13.13
32	Indiana	39	55.70	35.70	19.60	13.90	12.70	10.80	6.20	18.35
33	Jefferson	23	51.80	37.90	29.20	15.90	10.10	7.36	4.70	20.13
34	Juniata	8	13.60	13.60	12.60	8.50	4.90	3.70	3.70	8.61
35	Lackawanna	8	35.20	35.20	32.30	18.00	11.80	6.70	6.70	20.94
36	Lancaster	528	117.00	39.00	29.90	21.00	14.00	9.29	4.20	23.45
37	Lawrence	2	26.40	26.40	26.40	17.70	9.00	9.00	9.00	17.70
38	Lebanon	242	54.40	39.20	31.30	23.20	16.60	8.80	5.60	24.02
39	Lehigh	30	218.00	176.00	109.00	28.30	15.20	12.20	11.70	57.64
40	Luzerne	29	62.30	32.30	29.90	20.30	14.30	10.10	10.10	21.68
41	Lycoming	44	26.80	25.10	13.70	10.40	5.65	4.70	4.00	11.34
42	McKean	--	--	--	--	--	--	--	--	--
43	Mercer	--	--	--	--	--	--	--	--	--
44	Mifflin	29	39.30	28.30	18.70	14.00	7.80	6.00	5.00	15.08
45	Monroe	10	81.00	75.10	22.10	10.20	5.40	5.40	5.40	18.93
46	Montgomery	489	272.00	27.30	21.00	16.90	13.30	9.40	3.20	21.22
47	Montour	46	48.90	26.80	17.40	13.00	11.50	9.10	6.60	16.05
48	Northampton	55	88.00	60.20	19.60	15.20	11.00	8.00	6.70	21.19
49	Northumberland	98	31.00	18.30	11.50	10.20	6.50	5.10	3.20	10.69
50	Perry	27	48.20	23.40	16.20	11.50	9.30	7.30	3.80	13.98
51	Philadelphia	81	251.00	44.80	36.10	26.20	18.60	12.80	3.90	30.90
52	Pike	--	--	--	--	--	--	--	--	--
53	Potter	4	13.30	13.30	12.60	8.80	5.50	5.00	5.00	8.98
54	Schuylkill	29	40.00	21.90	18.50	10.10	10.10	10.10	6.40	14.26
55	Snyder	76	27.40	20.50	17.90	14.60	10.30	7.47	4.70	14.16
56	Somerset	47	193.00	115.00	22.50	12.40	6.20	6.20	6.20	29.17
57	Sullivan	--	--	--	--	--	--	--	--	--
58	Susquehanna	13	59.00	52.40	31.20	19.60	13.40	11.40	10.90	24.05
59	Tioga	--	--	--	--	--	--	--	--	--
60	Union	37	40.40	32.20	14.10	6.90	5.90	5.30	4.50	12.24
61	Venango	8	129.00	129.00	7.40	6.40	6.30	6.10	6.10	21.86
62	Warren	33	65.00	37.90	29.90	22.80	11.20	9.20	8.00	22.94
63	Washington	22	31.80	30.50	25.00	15.10	9.13	0.20	0.20	15.36
64	Wayne	24	24.50	16.40	14.10	8.60	5.48	4.20	3.80	10.12
65	Westmoreland	224	730.00	24.80	20.30	15.80	12.30	8.30	5.30	23.94
66	Wyoming	--	--	--	--	--	--	--	--	--
67	York	507	153.00	33.70	23.30	14.90	9.40	6.10	1.20	18.20

Table 3. Distribution of Lead (Pb) values according to percentage class for Pennsylvania by county. Values are parts per million.

County Number	and Name	Number of Samples	Maximum 100%	90%	75%	Median 50%	25%	10%	Minimum 0%	Mean
1	Adams	114	237.00	47.35	24.50	18.95	14.20	10.05	6.30	24.92
2	Allegheny	70	1000.00	164.00	164.00	26.20	16.80	13.90	9.10	77.03
3	Armstrong	25	30.70	25.90	23.20	20.90	10.10	10.10	10.10	17.52
4	Beaver	457	2600.00	215.00	91.50	49.50	31.10	23.20	16.30	103.24
5	Bedford	18	35.30	34.70	25.20	18.90	16.00	9.95	7.70	20.37
6	Berks	302	910.00	38.00	29.90	25.20	19.30	11.10	8.30	33.76
7	Blair	9	27.10	27.10	24.90	20.60	11.40	5.70	5.70	18.36
8	Bradford	27	26.60	21.30	19.40	16.70	9.80	8.80	8.30	15.31
9	Bucks	230	245.00	34.50	26.80	20.40	15.40	12.40	12.40	26.54
10	Butler	54	34.70	34.70	31.40	24.80	22.10	12.60	11.00	25.34
11	Cambria	110	226.00	44.80	25.60	21.40	17.40	13.00	0.30	30.38
12	Cameron	6	23.70	23.70	23.70	20.10	16.50	16.50	16.50	20.10
13	Carbon	9	830.00	830.00	462.00	177.00	72.30	9.50	9.50	279.23
14	Centre	200	740.00	65.80	26.90	19.80	11.60	9.60	4.41	46.20
15	Chester	393	293.00	27.90	24.40	19.60	14.40	9.70	4.80	20.18
16	Clarion	39	47.60	23.30	18.70	14.10	10.20	10.20	7.80	15.62
17	Clearfield	47	42.10	27.80	25.30	22.40	18.80	8.54	7.90	21.51
18	Clinton	2	10.40	10.40	10.40	9.90	9.40	9.40	9.40	9.90
19	Columbia	60	83.00	28.30	21.20	17.30	13.40	10.70	7.60	20.13
20	Crawford	6	27.30	27.30	25.10	19.60	13.30	8.40	8.40	19.03
21	Cumberland	485	123.00	31.20	26.00	21.50	16.40	11.90	5.90	22.34
22	Dauphin	274	112.00	33.40	26.00	20.70	15.40	9.50	5.10	22.12
23	Delaware	20	198.00	194.40	104.00	53.60	35.80	26.00	25.40	76.80
24	Elk	141	282.00	164.00	32.50	19.40	14.90	9.74	7.20	48.22
25	Erie	32	109.00	53.40	30.40	18.70	9.33	7.59	7.10	26.55
26	Fayette	--	--	--	--	--	--	--	--	--
27	Forest	--	--	--	--	--	--	--	--	--
28	Franklin	158	172.00	29.90	20.10	10.10	7.40	5.89	5.10	16.66
29	Fulton	--	--	--	--	--	--	--	--	--
30	Greene	71	25.60	19.50	18.60	17.80	6.20	5.90	5.60	13.57
31	Huntingdon	42	36.70	34.20	24.50	20.70	18.00	15.10	13.10	22.12
32	Indiana	39	30.60	28.50	24.40	23.70	22.30	19.70	14.30	23.58
33	Jefferson	23	484.00	227.40	27.10	21.90	20.50	15.40	9.80	58.27
34	Juniata	8	36.70	36.70	32.30	18.50	10.50	7.10	7.10	20.30
35	Lackawanna	8	246.00	246.00	194.00	26.60	17.50	11.60	11.60	79.04
36	Lancaster	528	177.00	31.00	26.80	21.90	17.50	10.50	5.60	22.74
37	Lawrence	2	42.80	42.80	42.80	30.30	17.80	17.80	17.80	30.30
38	Lebanon	242	1425.00	33.90	28.50	23.20	17.50	14.90	7.30	29.59
39	Lehigh	30	219.00	177.00	109.00	33.40	21.80	19.40	15.40	67.40
40	Luzerne	29	83.00	74.00	37.10	26.60	20.70	18.50	14.00	32.07
41	Lycoming	44	50.50	26.90	19.50	14.20	8.70	7.55	6.00	16.40
42	McKean	--	--	--	--	--	--	--	--	--
43	Mercer	--	--	--	--	--	--	--	--	--
44	Mifflin	29	54.60	48.50	30.80	26.30	19.70	13.80	9.10	26.49
45	Monroe	10	82.00	78.90	51.10	15.40	15.40	15.40	15.40	32.77
46	Montgomery	489	469.00	54.10	28.10	25.50	21.80	18.60	8.20	31.29
47	Montour	46	44.10	26.30	21.00	19.90	18.10	16.10	14.30	20.98
48	Northampton	55	42.70	37.80	26.80	23.20	13.80	10.40	6.60	22.19
49	Northumberland	98	34.70	17.80	15.30	14.20	8.20	6.70	6.10	13.36
50	Perry	27	26.20	22.60	20.30	19.10	14.30	9.20	6.20	17.64
51	Philadelphia	81	950.00	84.20	38.70	30.80	25.90	19.70	10.10	59.13
52	Pike	--	--	--	--	--	--	--	--	--
53	Potter	4	20.00	20.00	18.70	14.50	9.38	7.80	7.80	14.18
54	Schuylkill	29	36.00	24.20	20.60	20.60	20.40	9.80	9.60	19.91
55	Snyder	76	28.10	24.60	21.50	17.90	13.80	9.60	7.50	17.56
56	Somerset	47	119.00	95.60	31.30	12.00	9.90	9.90	9.60	28.52
57	Sullivan	--	--	--	--	--	--	--	--	--
58	Susquehanna	13	129.00	114.00	29.80	24.50	15.50	12.60	12.40	35.70
59	Tioga	--	--	--	--	--	--	--	--	--
60	Union	37	26.50	19.10	13.80	10.20	8.15	7.02	6.00	11.88
61	Venango	8	71.00	71.00	11.90	10.60	10.10	9.90	9.90	18.24
62	Warren	33	38.30	29.30	24.40	21.30	19.40	18.40	17.90	22.69
63	Washington	22	112.00	37.10	33.50	25.40	10.20	0.30	0.30	24.20
64	Wayne	24	27.00	27.00	21.00	16.50	12.40	8.60	5.70	16.82
65	Westmoreland	224	96.00	40.90	30.00	25.30	19.40	14.10	10.30	28.23
66	Wyoming	--	--	--	--	--	--	--	--	--
67	York	507	171.00	31.20	24.70	19.10	12.10	8.50	5.10	22.18

Table 4. Distribution of Zinc (Zn) values according to percentage class for Pennsylvania by county. Values are parts per million.

County Number and Name		Number of Samples	Maximum 100%	90%	75%	Median 50%	25%	10%	Minimum 0%	Mean
1	Adams	114	550.00	70.50	56.00	45.50	29.10	25.00	14.00	62.26
2	Allegheny	70	1600.00	720.00	338.00	81.50	46.00	22.70	17.00	240.20
3	Armstrong	25	102.00	93.00	71.50	56.00	17.70	17.70	17.70	47.96
4	Beaver	457	2700.00	600.00	300.00	178.00	102.00	71.80	29.60	274.18
5	Bedford	18	330.00	165.00	73.50	51.00	34.00	32.10	14.70	73.76
6	Berks	302	3050.00	114.00	85.30	61.00	46.80	33.00	19.20	79.08
7	Blair	9	97.00	97.00	83.00	47.00	38.50	22.20	22.20	56.94
8	Bradford	27	117.00	89.20	63.00	56.00	31.20	28.00	26.80	52.75
9	Bucks	230	730.00	108.00	58.30	55.00	52.00	40.10	31.00	76.54
10	Butler	54	127.00	117.00	96.80	77.00	53.30	30.00	15.60	75.20
11	Cambria	110	220.00	95.70	70.00	52.00	30.80	22.40	8.00	56.88
12	Cameron	6	64.00	64.00	64.00	53.50	43.00	43.00	43.00	53.50
13	Carbon	9	7000.00	7000.00	4300.00	1200.00	161.50	23.80	23.80	2155.00
14	Centre	200	5400.00	886.00	69.80	35.00	24.00	18.20	7.01	315.30
15	Chester	393	220.00	99.60	73.00	54.00	38.90	26.30	7.44	59.27
16	Clarion	39	144.00	122.00	122.00	44.00	36.00	27.60	13.00	66.98
17	Clearfield	47	97.00	82.80	67.00	52.00	38.00	26.60	20.60	52.98
18	Clinton	2	27.70	27.70	27.70	26.90	26.10	26.10	26.10	26.90
19	Columbia	60	180.00	76.90	60.50	46.00	33.25	20.90	12.30	51.61
20	Crawford	6	94.00	94.00	86.50	60.00	33.00	33.00	33.00	60.67
21	Cumberland	485	730.00	114.00	87.00	59.00	44.00	29.30	9.20	74.00
22	Dauphin	274	440.00	96.00	72.00	53.00	38.00	24.60	13.50	59.62
23	Delaware	20	400.00	336.00	251.00	191.00	124.00	70.40	58.70	193.88
24	Elk	141	380.00	240.00	84.00	48.00	28.50	22.90	10.50	82.44
25	Erie	32	660.00	155.00	99.90	55.70	34.40	27.10	25.10	104.29
26	Fayette	--	--	--	--	--	--	--	--	--
27	Forest	--	--	--	--	--	--	--	--	--
28	Franklin	158	730.00	97.60	65.30	42.50	31.20	20.80	12.90	55.86
29	Fulton	--	--	--	--	--	--	--	--	--
30	Greene	71	69.00	61.80	56.00	40.00	17.50	14.60	12.40	37.29
31	Huntingdon	42	197.00	70.50	49.50	40.50	33.00	29.30	24.00	46.77
32	Indiana	39	148.00	91.00	82.00	69.00	62.00	44.00	33.00	71.00
33	Jefferson	23	1970.00	167.20	91.00	63.70	47.20	43.00	26.70	154.59
34	Juniata	8	120.00	120.00	104.00	47.00	23.80	13.60	13.60	57.83
35	Lackawanna	8	84.00	84.00	59.00	55.00	44.00	2.10	2.10	50.51
36	Lancaster	528	190.00	97.00	73.00	55.00	40.00	26.00	18.10	58.97
37	Lawrence	2	144.00	144.00	144.00	95.50	47.00	47.00	47.00	95.50
38	Lebanon	242	207.00	110.00	86.30	68.00	54.70	35.20	18.70	71.34
39	Lehigh	30	2110.00	231.00	188.00	119.00	82.80	63.70	53.00	195.60
40	Luzerne	29	510.00	172.00	74.00	59.00	44.00	40.00	40.00	79.55
41	Lycoming	44	157.00	67.00	58.00	34.50	23.00	18.80	17.50	45.87
42	McKean	--	--	--	--	--	--	--	--	--
43	Mercer	--	--	--	--	--	--	--	--	--
44	Mifflin	29	86.40	77.50	69.60	47.00	31.50	21.50	19.00	50.32
45	Monroe	10	420.00	420.00	420.00	70.40	58.50	22.70	22.70	186.70
46	Montgomery	489	1970.00	144.00	67.00	56.00	47.00	41.00	16.00	89.70
47	Montour	46	173.00	92.20	69.60	58.00	48.50	40.00	34.00	62.29
48	Northampton	55	146.00	133.00	87.00	59.00	48.10	37.90	31.00	72.63
49	Northumberland	98	117.00	64.00	51.00	39.50	26.90	18.80	7.30	41.41
50	Perry	27	59.30	55.50	53.00	47.00	31.00	16.90	15.10	41.39
51	Philadelphia	81	3050.00	141.00	87.00	69.00	54.50	40.20	27.00	130.70
52	Pike	--	--	--	--	--	--	--	--	--
53	Potter	4	39.00	39.00	37.50	32.00	30.80	30.70	30.70	33.43
54	Schuylkill	29	79.00	64.00	46.00	46.00	40.90	28.20	26.00	45.59
55	Snyder	76	151.00	101.00	87.00	58.00	39.80	26.90	18.20	64.08
56	Somerset	47	370.00	254.00	89.00	45.00	15.00	15.00	15.00	79.47
57	Sullivan	--	--	--	--	--	--	--	--	--
58	Susquehanna	13	1970.00	1224.00	106.00	66.30	52.90	44.50	39.10	217.17
59	Tioga	--	--	--	--	--	--	--	--	--
60	Union	37	72.00	64.20	51.50	27.80	22.50	21.10	18.40	35.51
61	Venango	8	149.00	149.00	18.80	16.70	15.50	15.00	15.00	33.18
62	Warren	33	130.00	93.60	82.00	66.00	54.50	47.80	42.00	70.33
63	Washington	22	159.00	134.00	69.00	39.60	28.00	0.20	0.20	53.44
64	Wayne	24	72.00	67.00	65.50	51.00	34.80	20.40	17.30	48.30
65	Westmoreland	224	1850.00	123.00	89.00	72.00	60.00	40.70	24.00	88.39
66	Wyoming	--	--	--	--	--	--	--	--	--
67	York	507	400.00	89.00	63.00	44.00	30.60	21.10	7.40	53.14

Table 5. Nickel and chronium data for Pennsylvania by county.

County Number and Name		Number of Samples	Nickel (Ni) Maximum	Nickel (Ni) Minimum	Nickel (Ni) Mean	Nickel (Ni) Median	Chromium (Cr) Maximum	Chromium (Cr) Minimum	Chromium (Cr) Mean	Chromium (Cr) Median
1	Adams	114	48.10	4.30	17.83	16.50	226.00	4.40	28.20	19.10
2	Allegheny	70	251.00	5.60	22.68	20.50	105.00	9.10	18.26	16.85
3	Armstrong	25	28.60	6.30	12.70	13.30	24.30	6.90	12.80	11.40
4	Beaver	457	185.00	2.90	22.76	20.40	347.00	3.30	23.58	17.80
5	Bedford	18	27.30	7.30	17.80	16.95	22.90	7.00	13.30	12.50
6	Berks	302	320.00	6.00	23.06	22.10	47.40	6.60	17.13	16.30
7	Blair	9	30.60	6.40	18.14	19.40	18.00	4.10	11.60	10.90
8	Bradford	27	25.00	5.90	13.70	14.40	13.70	7.00	9.80	9.60
9	Bucks	230	100.00	6.90	20.67	18.35	2020.00	5.80	33.73	16.40
10	Butler	54	29.00	7.80	19.82	21.55	35.80	6.70	18.42	18.35
11	Cambria	110	40.20	0.30	18.60	19.50	41.40	1.80	9.38	8.60
12	Cameron	6	20.70	11.10	15.90	15.90	11.50	8.30	9.90	9.90
13	Carbon	9	72.00	6.90	28.97	24.80	63.00	5.30	22.99	19.50
14	Centre	200	66.00	2.20	14.00	11.30	170.00	3.40	15.01	11.85
15	Chester	393	730.00	1.90	21.33	16.70	168.00	3.80	21.22	19.30
16	Clarion	39	22.60	5.10	15.71	14.90	36.30	8.10	17.16	16.30
17	Clearfield	47	33.10	6.60	16.52	16.50	27.80	3.00	15.53	16.30
18	Clinton	2	7.80	7.30	7.55	7.55	11.30	9.40	10.35	10.35
19	Columbia	60	22.70	4.20	13.19	12.60	38.40	6.30	14.72	14.95
20	Crawford	6	34.40	10.70	22.68	24.55	29.50	6.40	17.87	18.15
21	Cumberland	485	63.00	2.50	18.66	18.10	89.00	3.30	18.04	17.50
22	Dauphin	274	37.30	3.40	16.56	17.00	121.00	3.30	17.57	15.10
23	Delaware	20	32.80	17.50	25.08	23.45	72.00	9.60	31.08	19.55
24	Elk	141	36.80	2.40	11.15	10.10	27.00	5.10	13.58	13.00
25	Erie	32	41.80	6.50	15.20	11.20	46.20	5.80	11.56	7.90
26	Fayette	--	--	--	--	--	--	--	--	--
27	Forest	--	--	--	--	--	--	--	--	--
28	Franklin	158	38.50	3.80	13.69	9.95	38.90	4.90	12.47	9.10
29	Fulton	--	--	--	--	--	--	--	--	--
30	Greene	71	25.50	8.20	16.24	16.90	57.00	4.00	21.58	15.40
31	Huntingdon	42	43.50	7.40	17.65	16.70	28.50	7.70	14.55	14.45
32	Indiana	39	31.30	9.10	20.68	21.00	26.60	6.90	16.24	15.70
33	Jefferson	23	41.80	6.60	20.27	17.20	26.80	8.80	17.87	16.90
34	Juniata	8	18.10	6.70	12.78	13.35	19.00	6.40	13.19	13.25
35	Lackawanna	8	40.30	2.70	17.46	17.10	16.30	4.80	11.85	11.60
36	Lancaster	528	1740.00	3.60	37.81	20.00	372.00	6.10	27.57	18.50
37	Lawrence	2	17.00	14.00	15.50	15.50	21.20	11.90	16.55	16.55
38	Lebanon	242	69.30	7.00	22.77	22.35	41.30	7.00	21.32	21.55
39	Lehigh	30	50.30	9.80	19.71	18.60	3440.00	4.80	142.70	21.20
40	Luzerne	29	25.20	12.10	16.29	16.60	25.20	7.20	12.95	11.60
41	Lycoming	44	36.70	4.70	12.52	12.15	46.20	5.80	13.56	12.05
42	McKean	--	--	--	--	--	--	--	--	--
43	Mercer	--	--	--	--	--	--	--	--	--
44	Mifflin	29	36.80	7.20	20.13	21.50	35.00	7.00	20.67	19.30
45	Monroe	10	32.40	10.00	12.73	10.70	115.00	10.00	23.42	12.30
46	Montgomery	489	57.10	5.30	18.45	18.50	89.00	5.20	17.46	18.00
47	Montour	46	36.00	9.70	18.93	18.45	32.60	7.10	14.05	12.55
48	Northampton	55	30.60	9.30	18.09	16.00	29.30	6.90	13.66	11.10
49	Northumberland	98	25.70	5.80	15.77	15.50	21.20	4.50	11.23	8.50
50	Perry	27	23.60	6.50	14.94	13.40	24.80	6.10	13.64	15.00
51	Philadelphia	81	40.10	6.70	15.53	14.60	103.00	6.10	20.46	17.20
52	Pike	--	--	--	--	--	--	--	--	--
53	Potter	4	13.40	8.40	11.08	11.25	12.60	6.30	9.68	9.90
54	Schuylkill	29	25.10	4.80	16.50	19.40	14.50	3.30	9.46	10.90
55	Snyder	76	30.70	5.20	18.22	17.60	15.90	5.10	8.90	8.20
56	Somerset	47	42.30	5.90	13.30	9.00	111.00	6.40	22.66	13.00
57	Sullivan	--	--	--	--	--	--	--	--	--
58	Susquehanna	13	37.90	0.09	3.19	0.37	28.30	6.40	15.85	14.00
59	Tioga	--	--	--	--	--	--	--	--	--
60	Union	37	0.37	0.05	0.12	0.09	26.50	7.30	13.77	10.50
61	Venango	8	0.88	0.03	0.17	0.04	19.80	5.90	8.08	6.40
62	Warren	33	0.58	0.17	0.29	0.29	45.20	11.20	15.72	14.90
63	Washington	22	1.97	0.08	0.49	0.15	51.50	0.10	19.96	13.75
64	Wayne	24	0.51	0.01	0.16	0.15	24.40	5.80	12.87	13.50
65	Westmoreland	224	85.90	0.04	0.91	0.41	620.00	4.90	21.06	18.35
66	Wyoming	--	--	--	--	--	--	--	--	--
67	York	507	8.34	0.01	0.29	0.14	90.00	1.80	13.36	12.90

Table 6. Metal composition of a Gilpin and Hagerstown soil (from Baker and Wolf, 1984).

Soil Series		Parts per million							
Soil Number		Cr	Mn	Co	Zn	Ni	Cu	Pb	Cd
Gilpin	Ap	68.1	633.2	45.5	127.2	52.7	24.6	46.3	0.43
002-024	Bt	75.3	239.7	24.0	105.7	61.9	60.9	58.8	0.52
Hagerstown	Ap	110.1	3129.7	94.3	60.4	25.4	28.0	40.0	0.23
014-023	Bt	130.7	461.3	91.7	60.4	65.8	40.8	40.0	0.31

Table 7. Total elemental analysis of a Gilpin and Hagerstown soil (from Baker and Wolf, 1984).

		Percent									
Soil Series										Ignition	
Soil Number		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	Loss	Total
Gilpin	Ap	76.51	10.16	4.07	0.07	0.70	0.57	1.58	0.16	6.10	99.9
002-024	Bt	75.54	11.24	5.90	0.01	0.98	0.51	1.96	0.09	4.89	101
Hagerstown	Ap	77.03	9.50	4.72	0.10	0.61	0.40	1.64	0.23	6.13	100
014-023	Bt	71.10	12.28	6.87	0.01	1.15	0.15	2.18	0.07	5.53	99.8

CHAPTER 5

Metals in Pennsylvania Soils*

Introduction

The content of metals in soils has been studied for many years. The objective of early studies was to characterize and investigate the genesis of soils. Recent interest in metals in soils revolves around the ability of soils to supply certain elements to plants and the potential toxic effect of these elements on humans and animals (Risser and Baker, 1990). In addition, many of these elements are pollutants that have or could be added to soils in the form of sewage sludge or other materials. Baseline data on the naturally-occurring levels of metals in soils is needed to provide a better understanding of the interactions of these metals in soils. In Pennsylvania, this type of baseline data is not available. Because of this shortcoming, a study was initiated to characterize the metal content of an array of Pennsylvania soils developed from a number of parent materials.

Materials and Methods

Two hundred and ten (210) samples representing 67 soil profiles were selected from the Penn State University Soil Characterization Laboratory library of soil samples (Ciolkosz and Thurman, 1993). These samples were collected and analyzed for basic soil characteristics and properties over a number of years as a part of an inventory of Pennsylvania's soil resources. A surface horizon (A) and two or three subsoil horizons (B or C) were selected from each profile (Table 1).

---

* Reprinted with added data (Table 4) from Ciolkosz et al., 1993. Metals in Pennsylvania Soils. Penn State Agronomy Series 128, Penn State Univ., Univ. Park, PA.

The U.S. EPA Acid Digestion of Sediments, Sludges, and Soils Method 3050 was used to analyze the soils (USEPA, 1986). The Pennsylvania Department of Environment Resources recommends this method for sludge and soil analysis in their Municipal Waste Management program (PADER, 1988). Additional information on sludges is given in NERRP (1985). With this method, the fine earth (< 2 mm) soil sample material is digested in nitric acid, hydrogen peroxide, and hydrochloric acid, and the extract is analyzed by atomic absorption spectroscopy.

The following elements were analyzed according to Method 3050: Aluminum (Al), Cadmium (Cd), Calcium (Ca), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Magnesium (Mg), Manganese (Mn), Nickel (Ni), Potassium (K), Sodium (Na), Zinc (Zn). Total Phosphorous (P) was determined on the sample extracts using the vanadomolybate method of Olsen and Sommers (1982). Additional soil characterization data obtained as a part of the Pennsylvania State University Soil Characterization program (Ciolkosz and Thurman, 1993; Thurman et al., 1992) includes pH (1:1 soil to water); percentages of sand, silt, and clay (pipette method); and percent Fe_2O_3 (Citrate-Bicarbonate-Dithionite, CBD, method). Many of these samples have also been used in a study on the amorphous material in Pennsylvania soils (Ciolkosz et al., 1989). Additional data on metals in Pennsylvania soils are provided in studies by Ciolkosz et al (1993a, 1993b).

Results and Discussion

The data for Fe, Al, Mn, Ca, Mg, Na, and K are given in Table 1, and the data for Cu, Zn, Ni, Pb, Cd, Cr, and P are given in Table 2. Table 3 summarizes the median, minimum, and maximum values of each element for the surface and subsurface horizons by parent material origin. This study does not provide a representative sampling of all soils in Pennsylvania and does not lend itself to extrapolating baseline data in all cases. For instance, while baseline estimates of elemental extractions for soils forming from limestone residuum may be possible, such estimates may not be reliable for soils forming in other parent materials which have fewer samples.

Most of the values for the extracted elements do not follow a normal distribution (Table 3). The data are predominantly skewed toward the low end of the range, with a few high values. This is especially true in the subsurface horizons. The surface horizons show evidence of additions of many of the elements. Mechanisms for additions probably include application by humans (as in the case of agricultural activities), atmospheric deposition, biocycling, or a combination of processes. Some general differences in parent materials are evident. Specific trends are noted in the discussion that follows.

An examination of the data shows, with some exceptions, the following trends:

1. Iron (Fe): The nitric acid-hydrogen peroxide-hydrochloric acid method extracts more Fe than the CBD method. The content of extracted Fe is greatest in the subsurface (Bt > Bx > Bw) and least in the surface (A) horizons. The largest quantity of extracted Fe occurs in soils developed from crystalline rock and calcareous shale parent materials. Some limestone-derived soils, particularly those with high clay contents, also had high concentrations. The lowest quantities of extracted Fe occur in soils of glacial till and sandstone parent materials.
2. Aluminum (Al): The extracted Al content is generally high but usually lower than the extracted Fe content. The highest concentrations usually occur in the upper B horizons. The greatest content of extracted Al typically is found in soils derived from crystalline rock and limestone parent materials, and the lowest content usually occurs in sandstone residuum soils.
3. Manganese (Mn): The maximum extracted Mn contents are in the surface (A) horizons; the lowest occur in the upper B horizons. In some cases, extracted Mn concentrations

increase below the B horizon. Poorly drained soils frequently show slightly different trends. The upper B horizons of some limestone and basic crystalline rock soils show high concentrations of Mn. This may be associated with black coatings observed in these soils.

4. Calcium (Ca): The highest contents of extracted Ca occur in soils derived from limestone, red calcareous shale, and basic crystalline parent materials. Soils of acidic parent materials have the lower extracted Ca contents. Surface enrichment of Ca is evident, particularly in the Ap horizons. In soils of calcareous parent materials, the extracted Ca content increases below the B horizon.

5. Magnesium (Mg): The extracted Mg content generally increases with depth in all soils except those forming from crystalline rock parent materials. In these soils, the Mg content either decreases with depth or reaches a maximum in the upper B horizon. Soils forming in limestone residuum have the greatest extracted Mg content; pre-Wisconsinan till, acid crystalline rock, and sandstone soils have the lowest contents of Mg.

6. Sodium (Na): The greatest concentrations of extracted Na occur in soils derived from basic crystalline rock parent materials. In these soils, the Na content increases with depth. No consistent trend in extracted Na is evident in any of the other soils.

7. Potassium (K): Extracted K content is generally greater in the shale and limestone residuum and colluvial soils and lowest in the crystalline, sandstone, and pre-Wisconsinan till soils. No consistent trend with depth is evident.

8. Phosphorus (P): Total P is typically greatest in the surface (A) horizons and is lowest in the subsurface (generally the Bt horizon).

9. Copper (Cu): The content of extracted Cu generally increases with depth (lowest in the A horizons). Soils forming in basic crystalline rock and red calcareous shale parent materials tend to have the greatest amounts of extracted Cu.

10. Zinc (Zn): Extracted Zn content tends to be greater in soils forming in Wisconsinan till and gray (acid and calcareous) shale parent materials and lower in soils forming in pre-

Wisconsinan till, crystalline rock, and sandstone parent materials. No regular trend with depth is evident.

11. Nickel (Ni): The content of extracted Ni generally increases with depth. Soils forming in basic crystalline rock parent materials tend to have the greatest amounts of extracted Ni while soils forming in acid crystalline rock, sandstone, and pre-Wisconsinan till parent materials have the lowest contents.

12. Lead (Pb): The greatest contents of extracted Pb are usually found in the surface horizons (A). Soils forming in limestone and red calcareous shale parent materials generally have greater extracted Pb contents while soils forming in crystalline rock and pre-Wisconsinan till parent materials have lower contents.

13. Cadmium (Cd): The content of extracted Cd tends to be greatest in the surface horizons (A) and lowest in the B horizons. Soils forming in calcareous parent materials generally have greater extracted Cd contents in the subsurface than soils forming in other parent materials.

14. Chromium (Cr): The B horizons typically have a greater content of extracted Cr than do the A or C horizons. Extracted Cr is generally greater in soils forming in basic crystalline rock parent materials.

The data from Tables 1 and 2 are summarized in Table 4 which presents a state-wide distribution of element concentrations in surface and subsurface soil horizons. These distributions give an indication of the range and distribution of extractable element concentrations in Pennsylvania soils. Because not all soil types are represented in this data set, and because limestone derived soils are over represented relative to soils of other parent materials, the actual state-wide distributions may differ from those presented here. Surface horizons tended to have higher concentrations of Fe, Ca, Cd, Mn, P, Pb, and Zn than subsurface horizons. Subsurface horizons tended to have larger concentrations of Al, Cr, Cu, K, Mg, and Ni. As was noted in

Table 3, the data are skewed toward the low end of the range and do not follow a normal distribution. For all elements the mean was larger than the median (50^{th} percentile), and in many cases the maximum value was much larger than the 90^{th} percentile value, indicating the presence of a few high concentration samples. Concentrations greater than the 90^{th} percentile are likely due to human activities and should be considered to be above the normal range for non-contaminated soils.

References

Ciolkosz, E. J., R. C. Cronce, and R. R. Dobos. 1989. Amorphous material in Pennsylvania soils. Pennsylvania State Univ. Agronomy Series No. 105.

Ciolkosz, E. J. and N. C. Thurman. 1993. Pennsylvania State University Soil Characterization Laboratory Database. Agronomy Dept. Pennsylvania State Univ., Univ. Park, PA.

Ciolkosz, E. J., A. W. Rose, W. J. Waltman, and N. C. Thurman. 1993a. Total elemental analysis of Pennsylvania soils. Pennsylvania State Univ. Agronomy Series No. 126.

Ciolkosz, E. J., W. J. Waltman, and N. C. Thurman. 1993b. Iron and aluminum in Pennsylvania soils. Pennsylvania State Univ. Agronomy Series No. 127.

NERRP, Northeast Regional Research Publication. 1985. Criteria and recommendations for land application of sludges in the Northeast. PA Ag. Expt. Station Bull. 851.

Olsen, S. R. and L. E. Sommers. 1982. Phosphorus. In A. L. Page, R. H. Miller, and D. R. Keeney (editors). Methods of Soil Analysis (Part 2): Chemical and Microbiological Properties (2nd edition). Agronomy 9:403-430.

PADER, Pennsylvania Department of Environmental Resources. 1988. Rules and Regulations--Municipal Waste Management. Pennsylvania Bulletin 18 (No. 15) part II. Commonwealth of Pennsylvania Legislative Reference Bureau. Capital Bldg., Harrisburg, PA. p. 1754.

Risser, J. A. and D. E. Baker. 1990. Testing soils for toxic metals. In R. L. Westerland (editor) Soil Sci. Soc. Amer. Book Series No. 3:275-298.

Thurman, N. C., E. J. Ciolkosz, and R. R. Dobos. 1992. Pennsylvania State University Soil Characterization Methods Manual. Pennsylvania State University Agronomy Series No. 117.

USEPA, United States Environmental Protection Agency. 1986. Acid digestion of sediment, sludge, and soils (Method 3050). In Test methods for evaluating solid waste. SW-846. USEPA. Washington, DC.

Table 1. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent: Sand	Silt	Clay	Fe_2O_3[1]	Fe_2O_3[2]	Fe	Parts Per Million: Al	Mn	Ca	Mg	Na	K
Grayish-Brown Wisconsinan Glacial Till																
Bath	008-011-01	Ap	0-18	5.5	28.2	56.8	15.0	1.5	1.14	0.80	1.55	495	1120	2450	45.7	717
(Well	008-011-03	Bw2	30-43	5.0	36.6	50.3	13.1	1.6	1.86	1.30	1.95	340	257	3275	57.7	1125
drained)	008-011-06	Bx3	69-107	5.0	40.9	45.6	13.5	1.7	2.43	1.70	1.60	585	355	3600	60.8	1700
Bath	008-099-02	A	0-5	4.3	42.3	46.8	10.9	1.2	2.06	1.44	1.04	407	245	1600	44.2	635
(Well	008-099-05	Bw2	36-51	4.4	38.3	47.3	14.4	1.6	2.17	1.52	1.29	337	3	3075	49.2	868
drained)	008-099-09	Bx4	135-180	5.0	22.3	56.4	21.3	2.0	2.93	2.05	1.35	672	667	3925	62.7	1215
	008-099-12	Bx7	285-361	5.2	36.0	48.8	15.2	1.6	3.00	2.10	1.40	697	705	3950	81.7	1600
Volusia	008-014-01	Ap	0-20	6.9	24.4	53.7	21.9	1.6	1.72	1.20	1.60	695	1560	2525	52.0	1200
(Somewhat	008-014-03	E2	28-36	6.7	24.9	53.8	21.3	1.8	2.00	1.40	1.37	225	462	2825	42.0	940
poorly drained)	008-014-06	Bxg3	74-97	5.0	24.5	48.0	27.5	2.1	2.93	2.05	1.68	615	462	3550	63.5	1375
Chippewa	008-016-01	Ap	0-15	5.6	11.6	63.4	25.0	2.2	2.60	1.82	1.82	1325	1250	2900	89.7	1100
(Very poorly	008-016-03	Eg	30-43	5.5	14.2	60.7	25.1	2.4	3.69	2.58	2.12	893	660	3325	89.5	1200
drained)	008-016-06	Bxg3	94-130	6.3	20.0	69.2	10.8	1.4	2.57	1.80	1.27	772	1147	3700	67.5	725
Red Wisconsinan Glacial Till																
Lackawanna	045-080-01	Ap	0-18	5.3	42.3	45.6	12.1	1.4	2.69	1.88	1.24	132	42	1295	35.2	495
(Well	045-080-03	Bw2	36-51	5.7	44.4	43.9	11.7	1.1	3.03	2.12	1.40	322	80	2725	49.7	777
drained)	045-080-05	Bx1	71-109	5.6	51.7	37.6	10.7	1.3	2.53	1.77	0.90	540	70	2400	38.0	520
Morris	058-003-01	Ap	0-18	5.7	34.1	44.9	21.0	1.7	3.15	2.20	2.52	857	1350	3025	92.5	1900
(Somewhat	058-003-03	BA	28-43	6.0	45.9	42.3	11.8	1.2	3.19	2.23	1.60	787	250	3100	60.3	1525
poorly drained)	058-003-07	Bx4	79-117	6.6	41.5	45.2	13.3	1.2	3.55	2.48	1.50	662	840	3600	78.0	2000
Norwich	058-021-01	A	0-20	5.0	18.5	36.7	44.8	3.2	4.86	3.40	3.30	2350	2372	2950	76.0	1675
(Poorly	058-021-03	Bwg	25-64	5.2	21.1	47.0	31.9	1.4	3.03	2.12	2.30	280	1623	3075	63.2	1250
drained)	058-021-05	2Bxg2	76-91	5.7	22.5	49.8	27.7	1.7	3.75	2.62	1.24	930	1312	3650	48.2	1212

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent						Parts Per Million					
					Sand	Silt	Clay	Fe_2O_3 [1]	Fe_2O_3 [2]	Fe	Al	Mn	Ca	Mg	Na	K
Pre-Wisconsinan Glacial Till																
Allenwood	013-061-01	Ap	0-18	5.7	26.2	56.7	17.1	2.0	1.12	0.78	1.70	227	517	667	56.5	1025
(Well	013-061-04	Bt2	61-84	5.2	31.2	32.2	36.6	3.9	3.96	2.77	2.58	355	115	340	58.2	1075
drained)	013-061-07	Bt5	155-190	5.2	45.6	37.9	16.5	2.9	2.25	1.57	0.99	627	32	177	34.5	335
Watson	055-002-01	Ap	0-23	6.0	26.5	52.5	21.0	2.5	2.97	2.08	1.16	317	720	582	51.7	860
(Moderately	055-002-03	Bt2	46-56	4.8	28.6	28.9	42.5	3.8	4.68	3.27	1.70	18	140	472	52.2	730
well drained)	055-002-05	Bx2	89-114	4.5	42.3	30.7	27.0	2.2	2.83	1.98	2.05	15	60	760	85.2	1375
Acid Grayish-brown Shale and Sandstone Colluvium and Limestone Colluvium																
Laidig	014-031-03	A	0-8	4.6	34.2	49.7	16.1	1.3	2.43	1.70	1.98	4250	80	1325	44.7	1175
(Well	014-031-06	Bt2	51-58	4.9	42.8	37.4	19.8	2.9	4.62	3.23	2.60	237	120	2425	49.5	2650
drained)	014-031-10	Bx1	102-150	4.9	43.3	36.1	20.6	3.1	5.18	3.62	2.73	955	167	3100	68.8	3200
Murrill	014-088-01	Ap1	0-13	6.1	7.6	69.8	22.6	1.9	3.18	2.23	1.52	1325	1352	1475	48.2	807
(Well	014-088-04	Bt2	40-55	5.5	6.6	60.7	32.7	3.3	5.36	3.75	2.33	410	1415	2425	71.2	1600
drained)	014-088-07	Bt5	110-143	4.8	13.7	62.1	24.2	2.7	5.14	3.60	1.57	1225	510	1500	52.2	1210
	014-088-10	BCt	215-304	5.2	16.6	41.8	41.6	3.5	5.36	3.75	2.00	1090	1952	1115	57.7	1050
Andover	018-013-01	Ap	0-23	6.0	29.6	46.6	23.8	2.3	3.50	2.45	2.08	3975	1385	2100	62.7	1475
(Poorly	018-013-03	Bt	36-46	6.1	33.5	42.4	24.1	3.6	4.72	3.30	2.05	257	295	2275	60.5	2000
drained)	018-013-06	Bxg3	81-97	5.1	41.0	39.5	19.5	3.0	4.58	3.20	2.08	235	42	2300	80.2	2025
Brown Wisconsinan Loess																
Duncannon	009-005-01	Ap	0-25	5.4	8.6	74.0	17.4	1.6	2.43	1.70	1.90	843	542	1875	59.5	101
(Well	009-005-03	Bt1	43-61	6.0	7.9	69.9	22.2	3.0	4.58	3.20	3.05	225	355	3000	111.7	1700
drained)	009-005-05	BC	86-114	6.2	6.6	83.0	10.4	2.5	3.90	2.73	2.05	365	200	3250	90.2	1400
Lawrenceville	009-003-01	Ap	0-28	6.3	11.6	73.0	15.4	1.4	2.25	1.57	1.82	665	745	2000	87.2	113
(Moderately	009-003-03	Bt2	48-64	6.4	8.6	73.4	18.0	2.0	3.50	2.45	2.25	117	495	2575	82.0	1275
well drained)	009-003-05	Bx2	86-102	5.4	12.0	73.4	14.6	2.6	3.82	2.67	1.62	428	295	2550	78.0	1300

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Sand	Silt	Clay	Fe_2O_3[1]	Fe_2O_3[2]	Fe	Al	Mn	Ca	Mg	Na	K
					Percent						Parts Per Million					
Doylestown	009-011-01	Ap	0-18	5.5	4.5	73.7	21.8	2.5	3.72	2.60	2.35	428	785	1950	110.5	1162
(Poorly	009-011-02	Btg	18-38	5.5	2.9	61.7	35.4	3.1	4.58	3.20	3.60	72	622	2650	124.5	1525
drained)	009-011-04	Bxtg2	46-69	5.2	7.4	76.0	16.6	2.3	4.05	2.83	2.02	435	407	3550	124.7	1525
							Residual Acid Sandstone									
Clymer	014-083-03	E	0-8	3.8	68.1	30.3	1.6	0.3	0.53	0.37	0.30	10	80	63	17.2	470
(Well	014-083-07	Bw2	43-71	4.6	59.8	29.8	10.4	1.3	1.50	1.05	0.80	100	3	688	44.7	822
drained)	014-083-09	Bt2	94-122	4.6	54.1	23.9	22.0	2.8	4.43	3.10	0.86	455	8	210	36.2	877
	014-083-11	C1	137-168	4.8	69.3	30.3	0.4	1.2	2.04	1.43	0.88	467	92	55	31.3	870
Hazleton	017-012-02	A	0-5	4.8	26.6	52.3	21.1	2.4	2.43	1.70	1.68	1300	582	1825	82.5	1525
(Well	017-012-05	Bt2	33-61	4.8	37.3	43.4	19.3	2.4	4.36	3.05	2.27	810	275	3675	68.5	1675
drained)	017-012-08	Bt5	104-127	5.0	45.1	41.1	13.8	2.2	3.96	2.77	1.65	1032	315	4350	44.7	1107
Cookport	017-015-02	BA	5-15	4.8	31.1	47.4	21.5	3.0	5.92	4.14	1.57	79	100	1157	40.2	690
(Moderately	017-015-04	Bt2	25-38	4.9	35.0	44.8	20.2	2.7	2.25	1.58	1.60	106	95	1600	47.5	805
well	017-015-07	Bx3	84-119	5.2	35.5	43.7	20.8	2.8	4.22	3.25	0.93	712	162	1387	46.0	770
drained)																
Cookport	014-082-01	A	0-8	3.4	48.6	41.9	9.5	0.5	0.96	0.67	0.33	262	247	197	45.2	450
(Somewhat	014-082-04	Bw2	41-61	4.6	42.9	42.2	14.9	1.8	2.62	1.83	1.09	79	30	1145	44.2	882
poorly	014-082-07	Bx3	104-132	4.8	67.2	19.1	13.7	2.3	3.28	2.30	0.67	247	57	267	35.0	800
drained)	014-082-10	Bx6	203-243	4.9	70.0	21.1	8.9	1.5	2.33	1.63	0.51	165	110	460	41.5	805
Nolo	017-019-02	A	0-10	4.2	27.2	63.2	9.6	0.3	0.50	0.35	1.29	10	240	225	52.5	1005
(Poorly	017-019-04	Btg	28-36	4.7	37.5	43.2	19.3	3.1	3.64	2.55	1.11	39	55	990	50.0	818
drained)	017-019-06	Bxg2	79-124	5.3	47.3	37.2	15.5	1.8	2.61	1.33	1.83	217	497	712	56.5	537
							Residual Acid Gray Shales									
Bedington	006-012-02	A	0-5	4.2	36.0	44.5	19.5	2.0	3.00	2.10	1.95	1825	370	1475	48.0	1105
(Well	006-012-05	Bt2	30-58	4.4	44.0	37.9	18.1	2.9	3.46	2.42	2.25	285	3	2775	46.2	1400
drained)	006-012-08	Bt5	119-150	4.6	43.3	21.7	35.0	4.8	5.08	3.55	2.55	790	40	2525	53.2	2350
	006-012-10	Ct	178-208	.	.	.	.	.	5.43	3.80	2.52	1225	22	3675	53.5	1700

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent Sand	Silt	Clay	Fe_2O_3 [1]	Fe_2O_3 [2]	Fe	Parts Per Million Al	Mn	Ca	Mg	Na	K
Gilpin	032-054-01	Ap	0-23	6.6	41.6	52.5	5.9	1.7	3.86	2.70	2.27	1225	1120	2725	69.0	1245
(Well	032-054-03	Bt	36-58	5.3	27.3	50.1	22.6	2.1	4.29	3.00	2.67	325	190	3725	77.7	1575
drained)	032-054-05	C	66-76	5.0	25.9	53.3	20.8	2.4	4.53	3.17	2.30	220	115	3875	75.0	1625
Rayne	056-002-04	Bt3	66-97	4.8	29.9	29.5	40.6	5.5	6.15	4.30	2.27	125	63	1050	71.7	2075
(Well	056-002-07	C1	168-208	4.8	47.4	28.5	24.1	3.5	4.36	3.05	2.23	645	25	1650	59.5	1525
drained)																
Wharton	032-053-01	Ap	0-25	6.2	17.3	69.7	13.0	2.7	1.60	1.12	1.90	1750	1550	1875	58.5	835
(Moderately	032-053-04	Bt2	48-61	4.9	10.3	62.5	27.2	3.8	2.86	2.00	2.52	342	360	3150	74.5	1600
well	032-053-06	C	91-137	4.9	21.7	56.7	21.6	3.1	3.36	2.35	2.10	675	155	3425	58.0	1050
drained)																
Cavode	010-039-01	Ap	0-28	5.3	20.1	52.3	27.6	2.6	3.90	2.73	1.37	957	755	852	54.2	920
(Somewhat	010-039-04	Btg2	53-69	4.9	3.6	40.1	56.3	3.1	4.64	3.25	1.43	20	455	770	83.5	1475
poorly	010-039-07	2Btg5	104-130	4.8	30.9	46.1	23.0	2.3	5.04	3.53	1.62	770	428	1775	75.5	1800
drained)																
Cavode	032-059-01	Ap	0-28	5.2	22.8	61.5	15.7	2.3	2.72	1.90	2.17	2075	530	1270	69.0	1825
(Somewhat	032-059-03	Bt1	41-53	4.9	12.4	48.4	39.2	2.7	4.10	2.87	3.25	160	500	2725	89.2	2750
poorly	032-059-06	Cg	119-145	4.9	28.3	50.6	21.1	1.5	2.83	1.98	1.45	255	105	2700	66.0	2500
drained)																
						Residual Calcareous Red Shales										
Upshur	002-023-01	Ap	0-20	4.8	13.6	66.2	20.2	3.4	5.61	3.93	1.80	1450	927	1925	110.0	2700
(Well	002-023-03	Bt2	41-64	4.5	0.9	32.2	66.9	3.6	5.83	4.08	2.33	35	1517	2575	113.5	2750
drained)	002-023-07	C1	117-142	6.1	2.2	66.4	31.4	5.5	7.93	5.55	1.50	180	6375	3100	147.5	2800
Vandergrift	004-001-01	Ap	0-18	5.0	9.2	60.9	29.9	1.9	1.79	1.25	1.37	1775	900	1192	67.7	1475
(Moderately	004-001-04	Bt3	41-58	5.1	3.3	27.9	68.8	2.7	5.86	4.10	2.00	44	1867	1525	127.5	2600
well	004-001-08	C1	147-180	8.2	3.1	63.9	33.0	1.7	2.72	1.90	1.39	170	4795	2500	115.3	2100
drained)																

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent Sand	Silt	Clay	Fe_2O_3[1]	Fe_2O_3[2]	Fe	Parts Per Million Al	Mn	Ca	Mg	Na	K
Residual Calcareous Gray Shales																
Westmoreland	063-043-01	Ap	0-25	7.1	12.8	71.6	15.6	2.4	3.25	2.27	1.57	2400	1873	2350	55.7	1070
(Well	063-043-04	Bt2	53-74	4.6	21.0	48.6	30.4	3.4	5.93	4.15	2.05	1275	367	2925	53.7	2025
drained)	063-043-07	C	127-147	4.7	41.5	46.5	12.0	2.5	4.98	3.48	1.73	675	577	4425	80.2	2350
Dormont	002-007-02	Ap	0-18	4.7	9.7	68.6	21.7	3.1	4.32	3.02	1.43	2125	252	1377	56.3	1325
(Moderately	002-007-05	Bt2	38-48	5.3	11.5	59.2	29.3	4.5	5.08	3.55	1.50	557	855	2075	60.8	1400
well drained)	002-007-08	Bw1	79-102	4.8	29.5	51.1	19.4	3.3	3.96	2.77	1.27	620	420	3075	51.5	1375
Library	063-045-01	Ap	0-25	5.7	9.1	68.8	22.1	2.6	4.18	2.92	1.31	1295	1637	1775	64.2	1475
(Somewhat	063-045-04	Btg1	48-61	6.0	9.0	58.3	32.7	3.7	4.48	3.13	1.85	850	1570	2075	84.7	1625
poorly drained)	063-045-08	C1	124-132	6.8	5.0	39.5	55.5	2.1	2.76	1.93	1.35	1295	2805	1925	109.5	1900
Residual Limestones																
Duffield	014-074-01	A	0-18	5.3	6.8	75.9	17.3	1.2	2.22	1.55	1.31	2575	1567	1532	36.2	1475
(Well	014-074-05	Bt2	71-94	4.9	3.5	57.2	39.3	3.3	4.29	3.00	2.89	547	470	6275	46.7	2950
drained)	014-074-11	3C1	193-211	5.3	8.7	51.8	39.5	3.6	4.86	3.40	2.75	627	267	7125	57.0	3625
Duffield	036-017-01	Ap	0-18	5.8	11.7	69.9	18.4	2.0	2.29	1.60	1.11	1370	925	1600	35.7	660
(Well	036-017-03	Bt1	30-56	6.4	10.9	54.7	34.4	4.7	4.82	3.37	1.35	395	620	1022	31.7	610
drained)	036-017-06	C	102-132	6.6	31.1	40.1	28.8	1.6	4.36	3.05	2.23	237	852	4450	41.0	1600
Hagerstown	014-005-01	Ap	0-23	5.7	6.0	70.0	24.0	3.2	3.43	2.40	1.11	1137	900	1807	32.2	1342
(Well	014-005-04	Bt3	66-79	4.9	1.7	32.5	65.8	5.1	5.29	3.70	1.95	642	1392	3075	45.0	2375
drained)	014-005-07	C	135-173	7.5	8.7	53.1	38.2	3.7	3.96	2.77	1.74	567	34450	11425	80.0	2650
Hagerstown	014-007-01	Ap	0-25	6.1	16.5	72.2	11.3	3.0	2.53	1.77	1.17	1625	1915	1277	38.7	940
(Well	014-007-05	Bt2	79-109	4.8	2.2	36.0	61.8	4.7	4.40	3.08	2.21	415	722	1510	46.2	2375
drained)	014-007-07	BC1	142-183	5.2	1.9	29.5	68.6	3.4	4.68	3.27	2.44	435	767	1785	49.7	1950
Hagerstown	014-014-01	Ap	0-30	6.7	1.5	87.2	11.3	1.8	2.22	1.55	1.19	1500	1495	1252	48.0	772
(Well	014-014-04	Bt1	51-76	6.9	0.8	46.2	53.0	4.3	5.22	3.65	2.21	740	4875	1347	56.7	1342
drained)	014-014-05	Bt2	76-102	7.5	1.0	41.6	57.4	3.9	4.86	3.40	2.47	640	9225	1640	73.0	1250

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent						Parts Per Million					
					Sand	Silt	Clay	Fe_2O_3 [1]	Fe_2O_3 [2]	Fe	Al	Mn	Ca	Mg	Na	K
Hagerstown	014-066-01	A	0-8	5.5	4.7	77.2	18.1	1.5	4.48	3.13	0.78	430	220	441	38.0	1007
(Well	014-066-05	Bt2	53-76	4.8	5.4	44.4	50.2	4.4	4.58	3.20	2.38	620	2950	1842	39.5	1325
drained)	014-066-08	3C	112-178	7.5	3.3	65.2	31.5	3.6	5.25	3.67	2.94	672	30525	18475	82.0	2200
Hagerstown	014-067-01	A	0-10	5.4	3.4	79.1	17.5	1.5	2.54	1.78	1.10	1825	3675	2300	43.0	1045
(Well	014-067-05	Bt2	53-76	4.8	2.9	40.7	56.4	4.5	6.40	4.48	3.68	275	1277	8175	61.5	5225
drained)	014-067-08	3C2	137-155	7.9	9.0	56.0	35.0	1.6	2.61	1.83	0.95	177	132775	78600	195.0	1200
Hagerstown	014-068-01	A	0-8	5.8	8.1	75.3	16.6	1.2	1.64	1.15	0.85	2350	5350	6025	44.5	1110
(Well	014-068-05	Bt2	61-84	5.8	20.2	45.9	33.9	2.3	2.69	1.88	3.20	242	870	28050	63.2	8450
drained)	014-068-08	3Cr1	140-160	6.6	19.2	51.4	29.4	2.2	2.47	1.73	3.01	192	2267	33500	89.2	7675
Hagerstown	014-069-01	A	0-10	5.8	4.5	75.2	20.3	1.5	1.57	1.10	1.24	2475	3600	1962	45.7	1200
(Well	014-069-05	Bt2	53-69	5.1	3.5	38.6	57.9	4.4	5.76	4.03	3.49	325	1002	6100	64.2	4000
drained)	014-069-08	3C	99-147	8.0	5.4	57.2	37.4	2.0	2.97	2.08	1.32	225	117525	62225	150.0	1775
Hagerstown	014-070-01	A	0-8	5.3	10.8	73.9	15.3	1.0	2.65	1.85	1.25	3075	7125	2825	97.0	693
(Well	014-070-06	3Bt3	66-89	5.3	7.4	51.0	41.6	3.2	4.68	3.27	2.97	335	695	3425	49.7	2025
drained)	014-070-09	3Bt6	160-183	5.7	1.7	43.9	54.4	3.8	5.08	3.55	4.18	367	977	9800	63.0	4125
Hagerstown	014-071-01	A	0-8	5.0	9.2	73.4	17.4	1.4	2.47	1.73	1.22	2650	625	1110	51.2	772
(Well	014-071-05	Bt2	61-86	5.3	2.7	41.0	56.3	4.4	5.89	4.12	3.15	305	537	3375	40.2	232
drained)	014-071-07	3C	112-142	6.9	3.2	50.1	46.7	4.4	5.36	3.75	2.73	387	3700	6575	68.0	2650
Hagerstown	014-072-01	A	0-8	5.4	9.4	74.6	16.0	1.2	2.29	1.60	1.26	3125	1748	1302	39.2	655
(Well	014-072-05	Bt2	46-79	5.1	2.9	54.2	42.9	3.1	3.65	2.55	2.44	300	503	3750	38.0	1825
drained)	014-072-09	3BC	145-157	6.9	2.5	77.0	20.5	3.6	4.18	2.92	3.56	327	2467	13725	107.5	5125
Hagerstown	014-073-01	A	0-8	5.4	9.8	73.8	16.4	1.2	2.12	1.48	1.37	2900	1180	21700	78.5	877
(Well	014-073-05	Bt2	61-86	5.6	10.4	48.3	41.3	2.9	3.43	2.40	2.62	295	397	13275	42.7	3200
drained)	014-073-08	3C1	140-165	6.6	18.3	45.1	36.6	3.8	4.36	3.05	2.19	385	1692	5975	56.7	1750
Hagerstown	014-075-01	A	0-10	6.6	10.3	73.2	16.5	1.2	3.07	2.15	1.25	3475	2700	1365	33.7	970
(Well	014-075-05	3Bt2	61-86	5.4	3.8	38.4	57.8	4.1	4.76	3.33	3.37	340	820	6500	40.0	3100
drained)	014-075-08	3Bt5	150-160	7.5	4.3	42.6	53.1	3.8	4.26	2.98	3.15	247	3000	10725	43.8	2925

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent						Parts Per Million					
					Sand	Silt	Clay	Fe_2O_3[1]	Fe_2O_3[2]	Fe	Al	Mn	Ca	Mg	Na	K
Hagerstown	014-080-01	A	0-8	4.9	19.2	73.4	7.4	1.5	2.72	1.90	1.32	5150	2023	1177	32.7	672
(Well	014-080-05	Bt2	61-89	4.6	9.1	26.3	64.6	5.5	5.58	3.90	2.66	470	630	1165	36.2	1475
drained)	014-080-09	BC	183-254	4.9	4.1	45.5	50.4	4.2	3.86	2.70	1.53	295	370	1045	34.5	5100
Hagerstown	018-009-01	Ap	0-18	6.2	15.8	62.5	21.7	3.1	3.25	2.27	1.15	932	1095	1102	39.7	732
(Well	018-009-04	Bt3	38-53	6.0	4.9	19.2	75.9	8.4	7.82	5.47	4.01	197	1510	2102	56.7	1925
drained)	018-009-06	BC	71-81	6.2	9.1	29.3	61.6	6.3	7.94	5.55	3.30	457	1767	2215	52.0	1750
Hagerstown	018-010-01	Ap	0-15	6.0	19.3	64.1	16.6	2.1	2.60	1.82	1.34	1037	692	732	28.0	667
(Well	018-010-05	Bt2	53-71	5.3	11.8	56.0	32.2	2.7	3.60	2.52	1.39	365	428	827	32.2	652
drained)	018-010-08	BC2	112-137	5.2	6.6	40.8	52.6	4.8	4.86	3.40	1.61	135	410	685	30.7	755
Hagerstown	022-006-01	Ap	0-23	6.5	21.6	62.2	16.2	3.2	3.55	2.48	1.82	1800	1890	1892	55.5	1085
(Well	022-006-05	Bt3	74-89	7.0	9.5	14.3	76.2	4.2	7.65	5.35	3.13	790	1750	1482	67.7	1075
drained)	022-006-08	BC	147-152	6.7	2.8	19.2	78.0	5.0	7.55	5.28	3.61	855	2335	5475	74.5	1975
Hagerstown	022-007-01	Ap	0-18	6.6	15.3	65.3	19.4	2.6	3.60	2.52	1.89	1277	1810	1975	42.7	840
(Well	022-007-05	Bt3	64-71	6.8	26.9	42.3	30.8	4.8	5.69	3.98	2.36	1575	1022	1375	41.7	1025
drained)	022-007-09	BC	142-163	6.2	6.9	33.3	59.8	5.5	6.86	4.80	3.77	557	1067	4875	62.0	2350
Hagerstown	036-014-01	Ap	0-20	7.0	14.2	63.2	22.6	2.5	3.29	2.30	1.91	1187	1882	1540	41.7	955
(Well	036-014-04	Bt2	56-84	5.5	6.7	35.3	58.0	.	5.15	3.60	2.22	240	1662	895	43.2	690
drained)	036-014-08	Bt6	163-190	4.9	8.3	59.4	32.3	.	3.46	2.42	2.16	637	330	962	32.0	705
Hagerstown	036-015-01	Ap	0-18	6.0	12.9	68.5	18.6	2.0	3.04	2.13	1.73	1222	962	1425	38.5	697
(Well	036-015-04	Bt2	58-84	6.8	9.7	31.2	59.1	4.5	7.07	4.95	3.41	217	1827	1112	52.7	972
drained)	036-015-07	BCt2	157-203	5.1	18.0	32.1	49.9	4.2	7.00	4.90	2.59	220	807	970	37.7	960
Hagerstown	036-019-01	Ap	0-25	6.0	11.2	64.3	24.5	3.2	5.48	3.83	1.69	1082	745	1252	34.7	922
(Well	036-019-04	Bt3	71-86	5.3	7.6	43.6	48.8	4.7	7.58	5.30	2.64	395	627	1257	34.7	797
drained)	036-019-07	C1	142-168	5.1	9.0	47.7	43.3		6.79	4.75	2.06	340	210	1217	30.2	655
Clarksburg	014-081-01	A	0-8	5.0	12.2	69.8	18.0	1.7	2.47	1.73	1.24	3925	1087	1475	49.7	835
(Moderately	014-081-04	Bt	36-69	4.6	9.1	64.6	26.3	3.1	4.71	3.30	1.65	447	492	2825	63.2	1375
well	014-081-06	Bx2	104-140	5.0	23.5	57.5	19.0	2.7	4.97	3.48	1.45	685	665	2525	60.5	1775
drained)	014-081-10	2C3	223-259	4.7	20.8	44.0	35.2	2.8	4.29	3.00	1.75	877	467	1750	60.0	2375

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent						Parts Per Million					
					Sand	Silt	Clay	Fe_2O_3 [1]	Fe_2O_3 [2]	Fe	Al	Mn	Ca	Mg	Na	K
Residual Acid Crystalline Rocks																
Chester	036-049-01	A	0-8	4.1	41.0	41.6	17.4	2.8	3.07	2.15	1.10	55	372	542	49.7	647
(Well	036-049-04	Bw1	36-56	4.5	47.2	33.7	19.1	4.0	5.48	3.83	2.15	61	117	905	31.3	712
drained)	036-049-08	3C2	135-152	5.4	79.2	18.4	2.4	3.9	5.53	3.87	0.63	128	110	28	18.2	330
	036-049-12	3C3	244-386	5.4	75.3	22.3	2.4	3.6	4.72	3.30	0.40	94	112	25	23.2	480
Chester	036-052-01	A	0-8	4.5	26.2	54.5	19.3	2.9	3.57	2.50	2.35	745	38	680	68.0	680
(Well	036-052-04	Bt1	33-48	5.0	27.7	41.4	30.9	6.1	6.48	4.53	3.40	84	20	975	63.2	1050
drained)	036-052-07	2Bt4	97-119	5.8	52.6	21.1	26.3	6.5	8.62	6.03	4.67	31	13	262	45.5	445
	036-052-08	2Bt5	119-160	5.8	49.9	23.8	26.3	6.0	8.18	5.72	4.78	40	742	487	58.7	475
Chester	067-008-01	Ap	0-20	5.1	31.6	46.0	22.4	4.0	5.15	3.60	2.52	1202	1052	1040	57.0	777
(Well	067-008-04	Bt2	53-66	6.9	37.6	30.8	31.6	5.7	7.55	5.28	3.90	440	1207	927	69.0	890
drained)	067-008-06	C	171-86	6.1	53.8	16.5	29.7	6.2	8.29	5.80	3.87	802	592	557	50.7	570
Chester	036-050-01	A	0-5	4.8	32.7	50.8	16.5	2.4	3.25	2.27	1.82	725	390	955	41.0	607
(Well	036-050-04	Bt	30-66	5.2	38.1	40.1	21.8	3.9	5.51	3.85	2.48	188	125	1290	40.0	977
drained)	036-050-08	3Bt	157-203	5.7	41.4	29.1	29.5	4.8	6.26	4.38	3.50	95	22	672	43.0	797
	036-050-14	9C	328-338	5.6	43.6	22.2	34.2	5.9	7.91	5.53	3.77	205	5	720	63.2	1002
Glenelg	006-011-02	A	0-12	4.3	45.3	35.5	19.2	2.3	3.54	2.48	2.40	1142	335	852	49.7	375
(Well	006-011-05	Bt2	46-66	4.4	48.4	31.0	20.6	2.8	5.90	4.13	4.20	130	208	1230	55.2	780
drained)	006-011-08	C1	124-160	4.6	69.1	19.6	11.3	1.9	4.26	2.98	3.35	242	82	445	43.2	592
	006-011-11	C4	246-322	4.3	60.2	31.8	8.0	3.2	5.83	4.08	2.45	352	5	1340	56.0	1070
Glenelg	036-027-01	Ap	0-25	7.3	51.6	34.2	14.2	2.3	3.03	2.12	1.01	685	737	882	32.0	685
(Well	036-027-02	Bt1	25-48	7.3	35.1	41.0	23.9	3.9	4.26	2.98	1.77	277	1265	1192	39.7	922
drained)	036-027-05	C1	84-107	7.1	61.0	35.3	3.7		4.76	3.33	0.50	397	20	630	24.0	185
Manor	036-028-01	Ap	10-13	6.9	38.1	45.4	16.5	2.9	4.15	2.90	1.88	805	1255	2625	53.0	930
(Well	036-028-03	Bw	25-51	6.5	46.5	41.4	12.1	2.5	4.29	3.00	1.35	547	297	2375	27.0	405
drained)	036-028-06	C1	84-94	7.2	59.7	36.0	4.3	2.0	2.97	2.08	0.67	1032	52	1875	23.5	117

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 1. Cont. Selected soil characterization data and major elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent						Parts Per Million					
					Sand	Silt	Clay	Fe_2O_3[1]	Fe_2O_3[2]	Fe	Al	Mn	Ca	Mg	Na	K
							Residual Basic Crystalline Rocks									
Neshaminy	009-051-01	Ap	0-18	6.6	20.2	57.4	22.4	5.3	6.84	4.78	4.22	1357	1462	2175	101.0	557
(Well	009-051-03	Bt2	33-58	6.6	29.0	37.2	33.8	7.7	11.40	7.97	6.62	1220	1492	1900	120.0	552
drained)	009-051-05	C	91-163	6.6	50.6	21.4	28.0	6.0	6.58	4.60	6.95	902	2100	2275	145.0	357
Neshaminy	046-013-01	Ap	0-15	5.9	25.4	57.2	17.4	6.1	8.79	6.15	4.80	1450	1410	2750	110.7	525
(Well	046-013-05	Bt2	41-51	6.6	38.2	34.0	27.8	5.3	8.69	6.08	3.55	1092	1192	5375	122.7	322
drained)	046-013-08	C1	84-99	7.0	60.4	25.2	14.4	3.1	5.76	4.03	5.30	680	2075	4050	445.0	720
Mount Lucas	001-016-01	Ap	0-20	6.5	19.7	68.1	12.2	2.1	1.79	1.25	1.50	1235	1652	2100	100.5	337
(Moderately	001-016-04	Bt2	46-61	6.6	43.8	31.5	24.7	1.9	3.75	2.62	3.40	597	4688	7325	575.0	405
well drained)	001-016-06	C	71-99	6.9	79.7	14.1	6.2	0.6	1.39	0.97	3.00	285	10782	6075	2050.0	335
Watchung	009-012-01	Ap	0-20	6.4	9.2	76.6	14.2	1.7	2.06	1.44	1.17	375	1047	1112	61.8	202
(Poorly	009-012-04	Btg3	53-71	7.0	14.8	55.3	29.9	2.6	4.15	2.90	2.33	150	2580	2875	65.0	382
drained)	009-012-06	Bx2	99-135	6.9	26.9	64.4	8.7	4.6	6.03	4.22	3.73	732	3508	2550	220.0	395
Watchung	009-013-01	Ap	0-18	6.3	5.6	70.0	24.4	2.3	1.89	1.32	2.30	460	1777	1650	90.0	492
(Poorly	009-013-04	Btg2	53-71	6.8	19.7	57.6	22.7	5.5	5.72	4.00	3.37	820	1625	2275	110.0	455
drained)	009-013-06	Bxg2	104-127	5.5	32.7	43.4	23.9	6.8	8.98	6.28	5.72	1145	1492	1725	165.0	478
							Gray Acid Floodplain									
Pope	014-084-01	A	0-10	4.3	34.7	46.8	18.5	2.0	3.33	2.33	1.16	585	557	1475	56.5	1325
(Well	014-084-05	Bw3	61-86	4.1	30.2	47.6	22.2	2.4	4.14	2.90	1.24	485	217	1825	53.5	932
drained)	014-084-08	2C1	114-142	4.9	51.9	31.3	16.8	3.1	5.69	3.98	1.30	522	547	1875	57.5	1150

1 - Fe_2O_3 data from Ciolkosz and Thurman (1992) by the CBD method. 2 - Fe_2O_3 data calculated from the Fe data (Fe x 1.43).

Table 2. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
					Grayish-Brown Wisconsinan Glacial Till									
Bath	008-011-01	Ap	0-18	5.5	28.2	56.8	15.0	11.7	54.7	13.5	18.2	0.175	14.2	572.5
(Well	008-011-03	Bw2	30-43	5.0	36.6	50.3	13.1	15.5	51.2	17.2	15.5	0.100	18.0	527.5
drained)	008-011-06	Bx3	69-107	5.0	40.9	45.6	13.5	22.0	54.2	19.7	16.5	0.150	16.2	427.5
Bath	008-099-02	A	0-5	4.3	42.3	46.8	10.9	9.5	50.0	15.5	44.0	0.300	12.5	457.5
(Well	008-099-05	Bw2	36-51	4.4	38.3	47.3	14.4	24.5	55.0	18.0	12.0	0.100	14.7	350.0
drained)	008-099-09	Bx4	135-180	5.0	22.3	56.4	21.3	25.5	75.0	26.0	15.7	0.125	20.0	475.0
	008-099-12	Bx7	285-361	5.2	36.0	48.8	15.2	25.7	72.5	25.2	17.2	0.175	18.5	532.5
Volusia	008-014-01	Ap	0-20	6.9	24.4	53.7	21.9	12.7	58.0	14.5	22.5	0.100	14.5	645.0
(Somewhat	008-014-03	E2	28-36	6.7	24.9	53.8	21.3	14.2	50.0	17.0	16.0	0.075	14.7	237.5
poorly	008-014-06	Bxg3	74-97	5.0	24.5	48.0	27.5	22.5	65.0	22.5	18.8	0.100	15.7	442.5
drained)														
Chippewa	008-016-01	Ap	0-15	5.6	11.6	63.4	25.0	12.2	90.0	16.0	24.5	0.275	18.5	572.5
(Very	008-016-03	Eg	30-43	5.5	14.2	60.7	25.1	9.5	90.0	17.0	18.0	0.050	23.0	392.5
poorly	008-016-06	Bxg3	94-130	6.3	20.0	69.2	10.8	24.5	60.0	22.7	14.0	0.150	14.5	467.5
drained)														
					Red Wisconsinan Glacial Till									
Lackawanna	045-080-01	Ap	0-18	5.3	42.3	45.6	12.1	8.5	44.5	8.2	9.5	0.325	12.5	137.5
(Well	045-080-03	Bw2	36-51	5.7	44.4	43.9	11.7	18.0	42.7	14.7	4.5	0.200	15.0	82.5
drained)	045-080-05	Bx1	71-109	5.6	51.7	37.6	10.7	16.5	39.5	13.8	2.7	0.175	10.2	56.3
Morris	058-003-01	Ap	0-18	5.7	34.1	44.9	21.0	11.5	98.2	12.5	15.7	0.500	22.2	592.5
(Somewhat	058-003-03	BA	28-43	6.0	45.9	42.3	11.8	8.2	55.2	13.0	8.0	0.200	16.5	122.5
poorly	058-003-07	Bx4	79-117	6.6	41.5	45.2	13.3	15.0	59.5	17.0	12.2	0.300	16.7	375.0
drained)														
Norwich	058-021-01	A	0-20	5.0	18.5	36.7	44.8	16.2	162.7	15.0	47.5	0.700	27.3	658.7
(Poorly	058-021-03	Bwg	25-64	5.2	21.1	47.0	31.9	17.5	54.7	14.0	18.5	0.175	22.5	281.3
drained)	058-021-05	2Bxg2	76-91	5.7	22.5	49.8	27.7	22.2	78.5	22.5	42.2	0.175	15.7	272.5

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent Sand	Percent Silt	Percent Clay	Parts Per Million Cu	Zn	Ni	Pb	Cd	Cr	P
						Pre-Wisconsinan Glacial Till								
Allenwood	013-061-01	Ap	0-18	5.7	26.2	56.7	17.1	12.2	95.0	6.5	18.5	0.525	16.0	412.5
(Well	013-061-04	Bt2	61-84	5.2	31.2	32.2	36.6	31.3	39.2	14.0	15.5	0.025	25.7	355.0
drained)	013-061-07	Bt5	155-190	5.2	45.6	37.9	16.5	16.5	18.5	4.7	13.0	0.025	18.0	247.5
Watson	055-002-01	Ap	0-23	6.0	26.5	52.5	21.0	12.0	28.0	5.7	11.7	0.200	15.2	250.0
(Moderately	055-002-03	Bt2	46-56	4.8	28.6	28.9	42.5	10.5	17.7	5.5	5.2	0.125	15.7	32.5
well	055-002-05	Bx2	89-114	4.5	42.3	30.7	27.0	10.2	19.5	8.8	6.3	0.125	17.5	72.5
drained)														
						Acid Grayish-brown Shale and Sandstone Colluvium and Limestone Colluvium								
Laidig	014-031-03	A	0-8	4.6	34.2	49.7	16.1	8.5	48.7	9.7	8.0	0.175	15.2	322.5
(Well	014-031-06	Bt2	51-58	4.9	42.8	37.4	19.8	35.5	66.2	23.0	7.7	0.075	27.3	180.0
drained)	014-031-10	Bx1	102-150	4.9	43.3	36.1	20.6	42.5	63.5	27.8	9.5	0.150	28.7	440.0
Murrill	014-088-01	Ap1	0-13	6.1	7.6	69.8	22.6	14.7	48.7	13.8	20.5	0.150	19.2	620.0
(Well	014-088-04	Bt2	40-55	5.5	6.6	60.7	32.7	27.8	140.0	18.8	17.7	0.075	31.3	345.0
drained)	014-088-07	Bt5	110-143	4.8	13.7	62.1	24.2	19.5	49.5	17.2	21.7	0.100	33.2	302.5
	014-088-10	BCt	215-304	5.2	16.6	41.8	41.6	22.2	40.2	16.0	23.5	0.175	35.2	177.5
Andover	018-013-01	Ap	0-23	6.0	29.6	46.6	23.8	15.0	64.5	20.0	20.0	0.275	17.5	327.5
(Poorly	018-013-03	Bt	36-46	6.1	33.5	42.4	24.1	21.5	39.2	14.5	7.0	0.200	25.7	87.5
drained)	018-013-06	Bxg3	81-97	5.1	41.0	39.5	19.5	28.7	48.7	20.5	12.2	0.200	25.7	232.5
						Brown Wisconsinan Loess								
Duncannon	009-005-01	Ap	0-25	5.4	8.6	74.0	17.4	12.5	55.5	11.2	21.2	0.200	21.7	395.0
(Well	009-005-03	Bt1	43-61	6.0	7.9	69.9	22.2	21.2	44.2	15.2	18.2	0.050	41.0	213.8
drained)	009-005-05	BC	86-114	6.2	6.6	83.0	10.4	13.8	37.5	12.5	8.5	0.050	29.7	255.0
Lawrenceville	009-003-01	Ap	0-28	6.3	11.6	73.0	15.4	11.7	47.0	10.5	16.0	0.175	22.0	377.5
(Moderately	009-003-03	Bt2	48-64	6.4	8.6	73.4	18.0	25.2	38.5	10.7	11.0	0.075	33.5	225.0
well	009-003-05	Bx2	86-102	5.4	12.0	73.4	14.6	18.0	39.5	13.0	9.5	0.100	26.5	362.5
drained)														

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
Doylestown	009-011-01	Ap	0-18	5.5	4.5	73.7	21.8	11.0	52.2	10.5	23.0	0.175	34.0	267.5
(Poorly	009-011-02	Btg	18-38	5.5	2.9	61.7	35.4	16.2	41.2	12.0	13.5	0.125	53.5	83.7
drained)	009-011-04	Bxtg2	46-69	5.2	7.4	76.0	16.6	20.0	60.0	15.5	12.2	0.125	39.5	352.5
Residual Acid Sandstone														
Clymer	014-083-03	E	0-8	3.8	68.1	30.3	1.6	3.8	7.2	0.5	2.2	0.025	1.3	67.5
(Well	014-083-07	Bw2	43-71	4.6	59.8	29.8	10.4	23.0	24.0	5.2	10.7	0.025	8.0	110.0
drained)	014-083-09	Bt2	94-122	4.6	54.1	23.9	22.0	23.2	33.5	5.7	20.5	0.025	15.7	155.0
	014-083-11	C1	137-168	4.8	69.3	30.3	0.4	6.5	11.5	1.3	9.2	0.025	2.7	92.5
Hazleton	017-012-02	A	0-5	4.8	26.6	52.3	21.1	18.0	87.5	12.7	26.5	0.325	22.2	795.0
(Well	017-012-05	Bt2	33-61	4.8	37.3	43.4	19.3	26.5	90.0	29.2	18.0	0.025	33.2	357.5
drained)	017-012-08	Bt5	104-127	5.0	45.1	41.1	13.8	30.5	92.5	31.0	19.0	0.025	29.5	377.5
Cookport	017-015-02	BA	5-15	4.8	31.1	47.4	21.5	9.0	35.0	6.5	8.8	0.075	17.5	250.0
(Moderately	017-015-04	Bt2	25-38	4.9	35.0	44.8	20.2	10.2	53.2	9.2	9.5	0.125	13.0	360.0
well drained)	017-015-07	Bx3	84-119	5.2	35.5	43.7	20.8	20.5	53.5	16.0	13.0	0.125	14.2	382.5
Cookport	014-082-01	A	0-8	3.4	48.6	41.9	9.5	29.7	37.7	4.2	83.2	0.400	7.5	450.0
(Somewhat	014-082-04	Bw2	41-61	4.6	42.9	42.2	14.9	22.5	38.0	7.2	13.5	0.025	15.7	130.0
poorly	014-082-07	Bx3	104-132	4.8	67.2	19.1	13.7	13.2	40.5	7.5	18.2	0.025	9.5	147.5
drained)	014-082-10	Bx6	203-243	4.9	70.0	21.1	8.9	25.2	43.2	6.8	10.2	0.025	7.0	160.0
Nolo	017-019-02	A	0-10	4.2	27.2	63.2	9.6	4.7	12.0	0.8	6.0	0.200	2.2	255.0
(Poorly	017-019-04	Btg	28-36	4.7	37.5	43.2	19.3	7.5	18.8	4.5	10.7	0.025	10.7	117.5
drained)	017-019-06	Bxg2	79-124	5.3	47.3	37.2	15.5	13.8	25.7	7.2	13.0	0.125	11.5	147.5
Residual Acid Gray Shales														
Bedington	006-012-02	A	0-5	4.2	36.0	44.5	19.5	17.2	112.5	14.0	85.2	0.525	19.5	627.5
(Well	006-012-05	Bt2	30-58	4.4	44.0	37.9	18.1	25.0	95.0	25.2	17.2	0.025	28.7	392.5
drained)	006-012-08	Bt5	119-150	4.6	43.3	21.7	35.0	35.2	92.5	24.0	28.2	0.025	32.5	497.5
	006-012-10	Ct	178-208	.	.	.	.	38.5	117.5	39.0	39.5	0.050	32.0	540.0

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
Gilpin	032-054-01	Ap	0-23	6.6	41.6	52.5	5.9	16.7	86.5	21.2	17.0	0.325	30.0	612.5
(Well	032-054-03	Bt	36-58	5.3	27.3	50.1	22.6	19.5	75.7	24.5	10.7	0.175	36.5	155.0
drained)	032-054-05	C	66-76	5.0	25.9	53.3	20.8	24.7	67.5	26.0	13.5	0.150	37.0	295.0
Rayne	056-002-04	Bt3	66-97	4.8	29.9	29.5	40.6	19.7	43.8	10.7	14.0	0.200	32.0	195.0
(Well	056-002-07	C1	168-208	4.8	47.4	28.5	24.1	16.5	58.7	18.0	16.2	0.175	25.2	372.5
drained)														
Wharton	032-053-01	Ap	0-25	6.2	17.3	69.7	13.0	12.2	77.5	17.5	19.7	0.300	21.2	422.5
(Moderately	032-053-04	Bt2	48-61	4.9	10.3	62.5	27.2	24.2	67.5	23.2	14.5	0.050	37.7	267.5
well	032-053-06	C	91-137	4.9	21.7	56.7	21.6	28.7	82.5	30.5	16.5	0.050	31.5	470.0
drained)														
Cavode	010-039-01	Ap	0-28	5.3	20.1	52.3	27.6	25.7	82.5	12.7	24.7	0.375	16.7	432.5
(Somewhat	010-039-04	Btg2	53-69	4.9	3.6	40.1	56.3	25.0	37.2	8.8	15.2	0.025	25.7	110.0
poorly	010-039-07	2Btg5	104-130	4.8	30.9	46.1	23.0	20.0	102.5	26.2	19.0	0.100	21.0	110.0
drained)														
Cavode	032-059-01	Ap	0-28	5.2	22.8	61.5	15.7	11.5	84.7	15.0	18.5	0.400	22.0	320.0
(Somewhat	032-059-03	Bt1	41-53	4.9	12.4	48.4	39.2	91.0	252.5	16.7	12.2	0.250	40.0	136.2
poorly	032-059-06	Cg	119-145	4.9	28.3	50.6	21.1	27.8	88.5	20.5	13.0	0.325	23.7	100.0
drained)														
Residual Calcareous Red Shales														
Upshur	002-023-01	Ap	0-20	4.8	13.6	66.2	20.2	16.5	58.0	18.0	35.0	0.275	38.2	252.5
(Well	002-023-03	Bt2	41-64	4.5	0.9	32.2	66.9	22.5	35.5	17.7	23.2	0.125	49.0	37.5
drained)	002-023-07	C1	117-142	6.1	2.2	66.4	31.4	66.7	57.7	47.7	21.2	0.200	40.7	1697.5
Vandergrift	004-001-01	Ap	0-18	5.0	9.2	60.9	29.9	24.0	77.5	16.0	33.5	0.525	23.2	322.5
(Moderately	004-001-04	Bt3	41-58	5.1	3.3	27.9	68.8	66.5	38.5	21.5	38.5	0.075	51.5	162.5
well	004-001-08	C1	147-180	8.2	3.1	63.9	33.0	68.0	68.2	43.2	21.5	0.200	29.0	126.2
drained)														

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
						Residual Calcareous Gray Shales								
Westmoreland	063-043-01	Ap	0-25	7.1	12.8	71.6	15.6	17.7	65.5	15.7	19.7	0.450	19.2	215.0
(Well	063-043-04	Bt2	53-74	4.6	21.0	48.6	30.4	22.5	67.0	20.0	14.5	0.200	28.2	130.0
drained)	063-043-07	C	127-147	4.7	41.5	46.5	12.0	21.5	85.2	26.2	14.5	0.200	32.7	257.5
Dormont	002-007-02	Ap	0-18	4.7	9.7	68.6	21.7	16.5	85.7	17.0	28.2	0.650	22.7	512.5
(Moderately	002-007-05	Bt2	38-48	5.3	11.5	59.2	29.3	29.5	66.2	19.5	17.2	0.350	22.5	272.5
well	002-007-08	Bw1	79-102	4.8	29.5	51.1	19.4	45.0	90.0	23.0	13.0	0.325	21.2	241.2
drained)														
Library	063-045-01	Ap	0-25	5.7	9.1	68.8	22.1	19.0	86.5	16.0	24.5	0.400	22.0	322.5
(Somewhat	063-045-04	Btg1	48-61	6.0	9.0	58.3	32.7	24.5	52.2	21.7	17.0	0.100	23.2	123.7
poorly	063-045-08	C1	124-132	6.8	5.0	39.5	55.5	45.5	62.7	34.2	18.2	0.250	19.2	105.0
drained)														
						Residual Limestones								
Duffield	014-074-01	A	0-18	5.3	6.8	75.9	17.3	14.0	85.0	13.0	34.5	0.325	25.0	601.2
(Well	014-074-05	Bt2	71-94	4.9	3.5	57.2	39.3	20.7	36.7	24.5	14.7	0.050	54.2	175.0
drained)	014-074-11	3C1	193-211	5.3	8.7	51.8	39.5	20.7	28.7	29.7	14.2	0.325	62.5	108.0
Duffield	036-017-01	Ap	0-18	5.8	11.7	69.9	18.4	14.2	48.0	12.0	20.7	0.225	26.0	402.5
(Well	036-017-03	Bt1	30-56	6.4	10.9	54.7	34.4	22.7	54.7	17.5	14.5	0.050	17.7	252.5
drained)	036-017-06	C	102-132	6.6	31.1	40.1	28.8	23.7	49.7	22.7	14.5	0.075	20.5	477.5
Hagerstown	014-005-01	Ap	0-23	5.7	6.0	70.0	24.0	13.8	40.5	15.5	17.5	0.125	20.7	450.0
(Well	014-005-04	Bt3	66-79	4.9	1.7	32.5	65.8	27.3	51.0	35.7	18.8	0.125	25.5	233.7
drained)	014-005-07	C	135-173	7.5	8.7	53.1	38.2	23.0	47.5	27.5	17.2	0.150	26.2	335.0
Hagerstown	014-007-01	Ap	0-25	6.1	16.5	72.2	11.3	18.5	48.0	13.5	24.0	0.250	22.5	477.5
(Well	014-007-05	Bt2	79-109	4.8	2.2	36.0	61.8	32.5	75.0	27.0	22.5	0.150	29.2	152.5
drained)	014-007-07	BC1	142-183	5.2	1.9	29.5	68.6	34.0	82.5	32.2	23.7	0.150	34.5	168.7
Hagerstown	014-014-01	Ap	0-30	6.7	1.5	87.2	11.3	11.5	40.7	12.0	19.0	0.225	19.7	495.0
(Well	014-014-04	Bt1	51-76	6.9	0.8	46.2	53.0	20.2	43.2	20.2	23.0	0.225	38.2	260.0
drained)	014-014-05	Bt2	76-102	7.5	1.0	41.6	57.4	20.5	43.8	20.5	21.0	0.225	34.7	240.0

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
Hagerstown	014-066-01	A	0-8	5.5	4.7	77.2	18.1	18.2	34.0	10.0	16.7	0.050	13.0	351.2
(Well	014-066-05	Bt2	53-76	4.8	5.4	44.4	50.2	21.0	39.0	24.0	20.2	0.025	45.7	217.5
drained)	014-066-08	3C	112-178	7.5	3.3	65.2	31.5	26.7	67.5	39.0	18.5	0.075	53.0	227.5
Hagerstown	014-067-01	A	0-10	5.4	3.4	79.1	17.5	15.2	65.0	14.2	21.5	0.225	23.0	601.2
(Well	014-067-05	Bt2	53-76	4.8	2.9	40.7	56.4	24.5	40.2	43.2	14.7	0.050	74.0	257.5
drained)	014-067-08	3C2	137-155	7.9	9.0	56.0	35.0	12.0	15.5	23.0	12.7	0.025	28.5	201.3
Hagerstown	014-068-01	A	0-8	5.8	8.1	75.3	16.6	19.2	125.0	11.2	43.8	0.600	35.7	485.0
(Well	014-068-05	Bt2	61-84	5.8	20.2	45.9	33.9	20.2	32.0	37.2	9.7	0.075	73.7	231.2
drained)	014-068-08	3Cr1	140-160	6.6	19.2	51.4	29.4	26.2	36.0	36.7	12.0	0.025	82.7	342.5
Hagerstown	014-069-01	A	0-10	5.8	4.5	75.2	20.3	19.2	100.0	16.2	32.0	0.450	29.7	585.0
(Well	014-069-05	Bt2	53-69	5.1	3.5	38.6	57.9	27.0	49.7	44.5	16.2	0.150	71.5	248.7
drained)	014-069-08	3C	99-147	8.0	5.4	57.2	37.4	19.7	24.5	31.5	14.5	0.050	35.5	260.0
Hagerstown	014-070-01	A	0-8	5.3	10.8	73.9	15.3	18.8	117.5	12.2	39.7	0.550	35.0	633.7
(Well	014-070-06	3Bt3	66-89	5.3	7.4	51.0	41.6	19.2	29.0	20.7	19.0	0.050	61.5	151.2
drained)	014-070-09	3Bt6	160-183	5.7	1.7	43.9	54.4	23.2	42.0	33.7	14.2	0.050	70.5	175.0
Hagerstown	014-071-01	A	0-8	5.0	9.2	73.4	17.4	23.2	80.0	12.5	40.2	0.425	26.0	495.0
(Well	014-071-05	Bt2	61-86	5.3	2.7	41.0	56.3	26.2	36.2	32.5	21.5	0.025	68.2	112.5
drained)	014-071-07	3C	112-142	6.9	3.2	50.1	46.7	22.5	40.2	38.5	15.5	0.050	66.7	196.2
Hagerstown	014-072-01	A	0-8	5.4	9.4	74.6	16.0	19.7	125.0	12.0	42.5	0.550	27.5	523.7
(Well	014-072-05	Bt2	46-79	5.1	2.9	54.2	42.9	20.7	45.5	19.5	15.2	0.100	45.0	103.8
drained)	014-072-09	3BC	145-157	6.9	2.5	77.0	20.5	24.5	47.5	31.0	15.2	0.125	55.2	157.5
Hagerstown	014-073-01	A	0-8	5.4	9.8	73.8	16.4	14.0	77.5	12.7	24.5	0.225	21.5	433.8
(Well	014-073-05	Bt2	61-86	5.6	10.4	48.3	41.3	17.7	23.5	23.7	9.7	0.050	56.0	151.2
drained)	014-073-08	3C1	140-165	6.6	18.3	45.1	36.6	21.0	25.7	29.2	15.0	0.000	58.0	220.0
Hagerstown	014-075-01	A	0-10	6.6	10.3	73.2	16.5	18.5	127.5	11.0	46.5	0.675	37.2	544.0
(Well	014-075-05	3Bt2	61-86	5.4	3.8	38.4	57.8	22.7	37.0	25.5	17.5	0.850	55.0	93.8
drained)	014-075-08	3Bt5	150-160	7.5	4.3	42.6	53.1	20.7	32.2	26.0	14.7	0.200	54.7	105.0

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
Hagerstown	014-080-01	A	0-8	4.9	19.2	73.4	7.4	16.7	75.0	12.5	77.5	0.600	19.5	486.2
(Well	014-080-05	Bt2	61-89	4.6	9.1	26.3	64.6	55.2	87.5	28.0	45.5	0.050	26.5	183.7
drained)	014-080-09	BC	183-254	4.9	4.1	45.5	50.4	36.0	46.7	19.5	24.5	0.000	21.2	167.5
Hagerstown	018-009-01	Ap	0-18	6.2	15.8	62.5	21.7	12.2	33.0	14.5	16.7	0.125	24.7	425.0
(Well	018-009-04	Bt3	38-53	6.0	4.9	19.2	75.9	33.0	46.2	39.7	19.0	0.150	71.7	308.7
drained)	018-009-06	BC	71-81	6.2	9.1	29.3	61.6	32.7	42.5	43.0	20.2	0.100	64.0	438.7
Hagerstown	018-010-01	Ap	0-15	6.0	19.3	64.1	16.6	10.7	33.0	11.5	32.7	0.125	19.5	210.0
(Well	018-010-05	Bt2	53-71	5.3	11.8	56.0	32.2	12.2	34.7	13.2	17.5	0.025	23.5	113.7
drained)	018-010-08	BC2	112-137	5.2	6.6	40.8	52.6	18.2	28.0	20.5	19.5	0.125	27.5	185.0
Hagerstown	022-006-01	Ap	0-23	6.5	1.6	62.2	16.2	19.2	75.0	14.5	52.5	0.300	26.0	643.7
(Well	022-006-05	Bt3	74-89	7.0	9.5	14.3	76.2	38.2	160.0	24.0	66.2	0.100	43.2	352.5
drained)	022-006-08	BC	147-152	6.7	2.8	19.2	78.0	38.5	170.0	34.7	46.7	0.250	43.0	561.2
Hagerstown	022-007-01	Ap	0-18	6.6	15.3	65.3	19.4	13.2	53.7	13.2	26.7	0.175	35.5	490.0
(Well	022-007-05	Bt3	64-71	6.8	26.9	42.3	30.8	23.0	50.7	19.7	31.7	0.100	43.0	290.0
drained)	022-007-09	BC	142-163	6.2	6.9	33.3	59.8	35.5	87.5	39.5	30.5	0.125	32.5	360.0
Hagerstown	036-014-01	Ap	0-20	7.0	14.2	63.2	22.6	15.7	40.7	11.7	20.0	0.100	43.0	665.0
(Well	036-014-04	Bt2	56-84	5.5	6.7	35.3	58.0	16.0	35.2	12.2	19.7	0.025	32.5	333.7
drained)	036-014-08	Bt6	163-190	4.9	8.3	59.4	32.3	10.2	29.0	7.7	19.0	0.000	30.5	262.5
Hagerstown	036-015-01	Ap	0-18	6.0	12.9	68.5	18.6	22.0	37.0	9.7	20.0	0.125	24.2	667.5
(Well	036-015-04	Bt2	58-84	6.8	9.7	31.2	59.1	20.7	50.2	18.5	21.5	0.175	34.5	527.5
drained)	036-015-07	BCt2	157-203	5.1	18.0	32.1	49.9	17.0	39.7	13.5	18.0	0.075	49.7	475.0
Hagerstown	036-019-01	Ap	0-25	6.0	11.2	64.3	24.5	12.5	38.0	12.0	23.7	0.150	33.5	442.5
(Well	036-019-04	Bt3	71-86	5.3	7.6	43.6	48.8	25.5	75.0	26.5	27.3	0.075	27.5	602.5
drained)	036-019-07	C1	142-168	5.1	9.0	47.7	43.3	24.2	95.0	26.0	23.5	0.100	28.2	378.7
Clarksburg	014-081-01	A	0-8	5.0	12.2	69.8	18.0	12.5	82.5	16.7	55.5	0.700	14.5	882.5
(Moderately	014-081-04	Bt	36-69	4.6	9.1	64.6	26.3	27.8	87.5	19.0	15.7	0.225	22.2	347.5
well	014-081-06	Bx2	104-140	5.0	23.5	57.5	19.0	35.7	45.7	19.0	15.2	0.150	27.0	342.5
drained)	014-081-10	2C3	223-259	4.7	20.8	44.0	35.2	18.5	34.5	18.0	17.7	0.225	33.7	330.0

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
					Residual Acid Crystalline Rocks									
Chester	036-049-01	A	0-8	4.1	41.0	41.6	17.4	12.0	26.5	4.2	29.0	0.225	12.7	368.7
(Well	036-049-04	Bw1	36-56	4.5	47.2	33.7	19.1	23.2	25.0	7.5	9.2	0.050	21.0	362.5
drained)	036-049-08	3C2	135-152	5.4	79.2	18.4	2.4	22.2	8.5	3.5	6.5	0.075	17.5	376.2
	036-049-12	3C3	244-386	5.4	75.3	22.3	2.4	16.2	14.2	4.5	10.0	0.050	5.0	360.0
Chester	036-052-01	A	0-8	4.5	26.2	54.5	19.3	10.0	35.5	8.0	31.5	0.275	23.0	296.2
(Well	036-052-04	Bt1	33-48	5.0	27.7	41.4	30.9	17.2	29.5	9.5	14.0	0.150	41.7	241.2
drained)	036-052-07	2Bt4	97-119	5.8	52.6	21.1	26.3	18.8	12.5	5.7	14.7	0.225	37.0	257.5
	036-052-08	2Bt5	119-160	5.8	49.9	23.8	26.3	20.5	19.2	7.0	20.0	0.150	34.2	225.0
Chester	067-008-01	Ap	0-20	5.1	31.6	46.0	22.4	28.7	37.0	11.2	18.5	0.100	32.7	730.0
(Well	067-008-04	Bt2	53-66	6.9	37.6	30.8	31.6	45.7	27.5	10.7	16.5	0.050	38.0	452.5
drained)	067-008-06	C1	71-86	6.1	53.8	16.5	29.7	62.3	23.7	9.2	15.7	0.075	32.2	535.0
Chester	036-050-01	A	0-5	4.8	32.7	50.8	16.5	20.7	32.2	7.5	21.7	0.150	24.5	218.8
(Well	036-050-04	Bt	30-66	5.2	38.1	40.1	21.8	18.5	31.0	9.7	16.2	0.200	38.5	237.5
drained)	036-050-08	3Bt	157-203	5.7	41.4	29.1	29.5	21.2	26.7	8.0	16.2	0.150	38.0	262.5
	036-050-14	9C	328-338	5.6	43.6	22.2	34.2	28.2	41.2	13.0	28.7	0.250	33.0	197.5
Glenelg	006-011-02	A	0-12	4.3	45.3	35.5	19.2	9.5	72.5	7.0	39.5	0.225	10.2	610.0
(Well	006-011-05	Bt2	46-66	4.4	48.4	31.0	20.6	7.7	45.0	7.7	9.0	0.025	14.2	300.0
drained)	006-011-08	C1	124-160	4.6	69.1	19.6	11.3	10.7	36.5	1.8	4.7	0.075	1.0	220.0
	006-011-11	C4	246-322	4.3	60.2	31.8	8.0	9.0	49.2	2.7	4.5	0.050	5.7	285.0
Glenelg	036-027-01	Ap	0-25	7.3	51.6	34.2	14.2	13.0	29.5	8.8	13.5	0.200	14.7	156.3
(Well	036-027-02	Bt1	25-48	7.3	35.1	41.0	23.9	21.2	33.5	11.2	10.2	0.125	26.5	251.3
drained)	036-027-05	C1	84-107	7.1	61.0	35.3	3.7	35.0	33.7	11.7	8.8	0.175	14.7	201.3
Manor	036-028-01	Ap1	0-13	6.9	38.1	45.4	16.5	28.7	91.2	21.7	17.2	0.250	24.0	637.5
(Well	036-028-03	Bw	25-51	6.5	46.5	41.4	12.1	33.2	79.0	20.2	11.0	0.150	19.0	322.5
drained)	036-028-06	C1	84-94	7.2	59.7	36.0	4.3	12.0	68.0	16.7	9.7	0.150	10.7	86.2

Table 2. Cont. Selected soil characterization data and minor elements for the soil samples used in this study. Characterization data from Ciolkosz and Thurman (1992).

Soil and Drainage Class	Soil Number	Horizon	Depth in cm	pH	Percent			Parts Per Million						
					Sand	Silt	Clay	Cu	Zn	Ni	Pb	Cd	Cr	P
						Residual Basic Crystalline Rocks								
Neshaminy	009-051-01	Ap	0-18	6.6	20.2	57.4	22.4	71.5	85.0	45.7	21.5	0.175	141.0	647.5
(Well	009-051-03	Bt2	33-58	6.6	29.0	37.2	33.8	119.7	49.7	76.7	10.7	0.075	172.5	487.5
drained)	009-051-05	C	91-163	6.6	50.6	21.4	28.0	98.7	44.2	64.0	7.2	0.125	139.2	442.5
Neshaminy	046-013-01	Ap	0-15	5.9	25.4	57.2	17.4	68.5	71.2	57.5	15.2	0.200	112.0	558.7
(Well	046-013-05	Bt2	41-51	6.6	38.2	34.0	27.8	75.2	44.5	47.5	5.0	0.175	108.0	100.0
drained)	046-013-08	C1	84-99	7.0	60.4	25.2	14.4	87.0	36.5	43.2	4.2	0.225	62.7	190.0
Mount Lucas	001-016-01	Ap	0-20	6.5	19.7	68.1	12.2	16.5	34.0	19.2	13.0	0.100	134.5	265.0
(Moderately	001-016-04	Bt2	46-61	6.6	43.8	31.5	24.7	50.0	33.2	47.2	8.0	0.050	280.0	85.0
well	001-016-06	C	71-99	6.9	79.7	14.1	6.2	62.7	22.5	35.2	4.7	0.050	129.7	352.5
drained)														
Watchung	009-012-01	Ap	0-20	6.4	9.2	76.6	14.2	12.7	47.0	9.5	18.0	0.175	32.5	227.5
(Poorly	009-012-04	Btg3	53-71	7.0	14.8	55.3	29.9	36.2	38.0	25.7	11.2	0.025	104.2	52.5
drained)	009-012-06	Bx2	99-135	6.9	26.9	64.4	8.7	67.7	39.5	41.2	9.5	0.075	127.5	337.5
Watchung	009-013-01	Ap	0-18	6.3	5.6	70.0	24.4	17.2	70.0	20.7	24.5	0.250	94.2	430.0
(Poorly	009-013-04	Btg2	53-71	6.8	19.7	57.6	22.7	28.7	33.7	40.7	12.7	0.050	170.0	142.5
drained)	009-013-06	Bxg2	104-127	5.5	32.7	43.4	23.9	45.0	39.2	65.5	14.5	0.050	360.0	245.0
						Gray Acid Floodplain								
Pope	014-084-01	A	0-10	4.3	34.7	46.8	18.5	11.7	65.0	15.2	19.5	0.125	16.0	390.0
(Well	014-084-05	Bw3	61-86	4.1	30.2	47.6	22.2	13.2	82.5	17.5	11.0	0.075	18.8	285.0
drained)	014-084-08	2C1	114-142	4.9	51.9	31.3	16.8	19.5	77.5	23.7	18.2	0.250	19.5	455.0

Table 3. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
Fe, %	Glacial Till								
	brown Wisconsinan	4	1.32	0.80	1.82	9	1.80	1.30	2.58
	red Wisconsinan	3	2.20	1.88	3.40	6	2.18	1.77	2.62
	pre-Wisconsinan	2	--	0.78	2.08	4	2.38	1.57	3.27
	Colluvium	3	2.23	1.70	2.45	7	3.60	3.20	3.75
	Loess	3	1.70	1.57	2.60	6	2.78	2.45	3.20
	Residuum								
	sandstone	5	0.67	0.35	4.14	12	2.06	1.05	3.25
	gray acid shale	5	2.10	1.12	2.73	13	3.05	1.98	4.30
	red calcareous shale	2	--	1.25	3.93	4	4.09	1.90	5.55
	gray calcareous shale	3	2.92	2.27	3.02	6	3.30	1.93	4.15
	limestone	23	1.82	1.10	3.83	47	3.40	1.73	5.55
	acid crystalline	7	2.48	2.12	3.60	18	3.98	2.08	6.03
	basic crystalli ne	5	1.44	1.25	6.15	10	4.12	0.97	7.97
	Alluvium, acid floodplain	1	2.33	--	--	2	--	2.90	3.98
Al, %	Glacial Till								
	brown Wisconsinan	4	1.58	1.04	1.82	9	1.40	1.27	2.12
	red Wisconsinan	3	2.52	1.24	3.30	6	1.45	0.90	2.30
	pre-Wisconsinan	2	--	1.16	1.70	4	1.88	0.99	2.58
	Colluvium	3	1.98	1.52	2.08	7	2.08	1.57	2.73
	Loess	3	1.90	1.82	2.35	6	2.15	1.62	3.60
	Residuum								
	sandstone	5	1.29	0.33	1.68	12	1.01	0.51	2.27
	gray acid shale	5	1.95	1.37	2.27	13	2.27	1.43	3.25
	red calcareous shale	2	--	1.37	1.80	4	1.75	1.39	2.33
	gray calcareous shale	3	1.43	1.31	1.57	6	1.62	1.27	2.05
	limestone	23	1.25	0.78	1.91	47	2.59	0.95	4.18
	acid crystalline	7	1.88	1.01	2.52	18	2.92	0.40	4.78
	basic crystalline	5	2.30	1.17	4.80	10	3.64	2.33	6.95
	Alluvium, acid floodplain	1	1.16	--	--	2	--	1.24	1.30

Table 3. Cont. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
Mn, ppm	Glacial Till								
	brown Wisconsinan	4	595	407	1325	9	615	225	893
	red Wisconsinan	3	857	132	2350	6	601	280	930
	pre-Wisconsinan	2	--	227	317	4	186	15	627
	Colluvium	3	3975	1325	4250	7	410	235	1225
	Loess	3	665	428	843	6	295	72	435
	Residuum								
	sandstone	5	79	10	1300	12	232	39	1032
	gray acid shale	5	1750	957	2075	13	325	20	1225
	red calcareous shale	2	--	1450	1775	4	107	35	180
	gray calcareous shale	3	2125	1295	2400	6	762	557	1295
	limestone	23	1800	430	5150	47	385	135	1575
	acid crystalline	7	745	55	1202	18	196	31	1032
	basic crystalline	5	1235	375	1450	10	776	150	1220
	Alluvium, acid floodplain	1	585	--	--	2	--	485	522
Ca, ppm	Glacial Till								
	brown Wisconsinan	4	1185	245	1560	9	462	3	1147
	red Wisconsinan	3	1350	42	2372	6	545	70	1623
	pre-Wisconsinan	2	--	517	720	4	88	32	140
	Colluvium	3	1352	80	1385	7	295	42	1952
	Loess	3	745	542	785	6	381	200	622
	Residuum								
	sandstone	5	240	80	582	12	94	3	497
	gray acid shale	5	755	370	1550	13	115	3	500
	red calcareous shale	2	--	900	927	4	3331	1517	6375
	gray calcareous shale	3	1637	252	1873	6	716	367	2805
	limestone	23	1567	220	7125	47	977	210	132775
	acid crystalline	7	390	38	1255	18	111	5	1265
	basic crystalline	5	1462	1047	1777	10	2088	1192	10782
	Alluvium, acid floodplain	1	557	--	--	2	--	217	547

Table 3. Cont. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
Mg, ppm	Glacial Till								
	brown Wisconsinan	4	2487	1600	2900	9	3550	2825	3950
	red Wisconsinan	3	2950	1295	3025	6	3088	2400	3650
	pre-Wisconsinan	2	--	582	667	4	406	177	760
	Colluvium	3	1475	1325	2100	7	2300	1115	3100
	Loess	3	1950	1875	2000	6	2825	2550	3550
	Residuum								
	sandstone	5	225	63	1825	12	851	55	4350
	gray acid shale	5	1475	852	2725	13	2725	770	3875
	red calcareous shale	2	--	1192	1925	4	2538	1525	3100
	gray calcareous shale	3	1775	1377	2350	6	2500	1925	4425
	limestone	23	1475	441	21700	47	3075	685	78600
	acid crystalline	7	882	542	2625	18	812	25	2375
	basic crystalline	5	2100	1112	2750	10	2713	1725	7325
	Alluvium, acid floo dplain	1	1475	--	--	2	--	1825	1875
Na, ppm	Glacial Till								
	brown Wisconsinan	4	48.8	44.2	89.7	9	62.7	42.0	89.5
	red Wisconsinan	3	76.0	35.2	92.5	6	55.0	38.0	78.0
	pre-Wisconsinan	2	--	51.7	56.5	4	55.2	34.5	85.2
	Colluvium	3	48.2	44.7	62.7	7	60.5	49.5	80.2
	Loess	3	87.2	59.5	110.5	6	101.0	78.0	124.7
	Residuum								
	sandstone	5	45.2	17.2	82.5	12	44.7	31.3	68.5
	gray acid shale	5	58.5	48.0	69.0	13	71.7	46.2	89.2
	red calcareous shale	2	--	67.7	110.0	4	121.4	113.5	147.5
	gray calcareous shale	3	56.3	55.7	64.2	6	70.5	51.5	109.5
	limestone	23	39.7	28.0	97.0	47	52.0	30.2	195.0
	acid crystalline	7	49.7	32.0	68.0	18	43.1	18.2	69.0
	basic crystalline	5	100.5	61.8	110.7	10	155.0	65.0	2050.0
	Alluvium, acid floodplain	1	56.5	--	--	2	--	53.5	57.5

Table 3. Cont. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
K, ppm	Glacial Till								
	brown Wisconsinan	4	908	635	1200	9	1200	725	1700
	red Wisconsinan	3	1675	495	1900	6	1231	520	2000
	pre-Wisconsinan	2	--	860	1025	4	902	335	1375
	Colluvium	3	1175	807	1475	7	2000	1050	3200
	Loess	3	113	101	1162	6	1462	1275	1700
	Residuum								
	sandstone	5	690	450	1525	12	820	537	1675
	gray acid shale	5	1105	835	1825	13	1625	1050	2750
	red calcareous shale	2	--	1475	2700	4	2675	2100	2800
	gray calcareous shale	3	1325	1070	1475	6	1763	1375	2350
	limestone	23	877	655	1475	47	1825	232	8450
	acid crystalline	7	680	375	930	18	652	117	1070
	basic crystalline	5	492	202	557	10	400	322	720
	Alluvium, acid floodplain	1	1325	--	--	2	--	932	1150
P, ppm	Glacial Till								
	brown Wisconsinan	4	572.5	457.5	645.0	9	442.5	237.5	532.5
	red Wisconsinan	3	592.0	138.0	659.0	6	197.5	56.3	375.0
	pre-Wisconsinan	2	--	250.0	412.5	4	160.0	32.5	355.0
	Colluvium	3	327.5	322.5	620.0	7	232.5	87.5	440.0
	Loess	3	377.5	267.5	395.0	6	240.0	83.7	362.5
	Residuum								
	sandstone	5	255.0	67.5	795.0	12	151.3	92.5	382.5
	gray acid shale	5	432.5	320.0	627.5	13	267.5	100.0	540.0
	red calcareous shale	2	--	252.5	322.5	4	144.0	93.8	1697.0
	gray calcareous shale	3	322.5	215.0	512.5	6	185.6	105.0	272.5
	limestone	23	495.0	210.0	882.5	47	255.0	36.2	602.5
	acid crystalline	7	368.7	156.3	730.0	18	260.0	86.2	535.0
	basic crystalline	5	430.0	227.5	647.5	10	217.5	52.5	487.5
	Alluvium, acid floodplain	1	390.0	--	--	2	--	285.0	455.0

Table 3. Cont. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
Cu, ppm	Glacial Till								
	brown Wisconsinan	4	12.0	9.5	12.7	9	22.5	9.5	25.7
	red Wisconsinan	3	11.5	8.5	16.2	6	17.0	8.2	22.2
	pre-Wisconsinan	2	--	12.0	12.2	4	13.5	10.2	31.3
	Colluvium	3	14.7	8.5	15.0	7	27.8	19.5	42.5
	Loess	3	11.7	11.0	12.5	6	19.0	13.8	25.2
	Residuum								
	sandstone	5	9.0	3.8	29.7	12	21.5	6.5	30.5
	gray acid shale	5	16.7	11.5	25.7	13	25.0	16.5	91.0
	red calcareous shale	2	--	16.5	24.0	4	66.6	22.5	68.0
	gray calcareous shale	3	17.7	16.5	19.0	6	27.0	21.5	45.5
	limestone	23	15.7	10.7	23.2	47	23.4	10.2	55.2
	acid crystalline	7	13.0	9.5	28.7	18	20.8	7.7	62.3
	basic crystalline	5	17.2	12.7	71.5	10	65.2	28.7	119.7
	Alluvium, acid floodplain	1	11.7	--	--	2	--	13.2	19.5
Zn, ppm	Glacial Till								
	brown Wisconsinan	4	56.4	50.0	90.0	9	60.0	50.0	90.0
	red Wisconsinan	3	98.2	44.5	162.7	6	55.0	39.5	78.5
	pre-Wisconsinan	2	--	28.0	95.0	4	19.0	17.7	39.2
	Colluvium	3	48.7	48.7	64.5	7	49.5	39.2	140.0
	Loess	3	52.2	47.0	55.5	6	40.4	37.5	60.0
	Residuum								
	sandstone	5	35.0	7.2	87.5	12	39.2	11.5	92.5
	gray acid shale	5	84.7	77.5	112.5	13	82.5	37.2	252.5
	red calcareous shale	2	--	58.0	77.5	4	48.1	35.5	68.2
	gray calcareous shale	3	85.7	65.5	86.5	6	66.6	52.2	90.0
	limestone	23	65.0	33.0	127.5	47	45.6	15.5	170.0
	acid crystalline	7	35.5	26.5	91.2	18	30.2	8.5	79.0
	basic crystalline	5	70.0	34.0	85.0	10	38.6	22.5	49.7
	Alluvium, acid floodplain	1	65.0	--	--	2	--	77.5	82.5

Table 3. Cont. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
Ni, ppm	Glacial Till								
	brown Wisconsinan	4	15.0	13.5	16.0	9	19.7	17.0	26.0
	red Wisconsinan	3	12.5	8.2	15.0	6	14.4	13.0	22.5
	pre-Wisconsinan	2	--	5.7	6.5	4	7.2	4.7	14.0
	Colluvium	3	13.8	9.7	20.0	7	18.8	14.5	27.8
	Loess	3	10.5	10.5	11.2	6	12.8	10.7	15.5
	Residuum								
	sandstone	5	4.2	0.5	12.7	12	7.2	1.3	31.0
	gray acid shale	5	15.0	12.7	21.2	13	24.0	8.8	39.0
	red calcareous shale	2	--	16.0	18.0	4	32.4	17.7	47.7
	gray calcareous shale	3	16.0	15.7	17.0	6	22.4	19.5	34.2
	limestone	23	12.5	9.7	16.7	47	26.2	7.7	44.5
	acid crystalline	7	8.0	4.2	21.7	18	8.6	1.8	20.2
	basic crystall ine	5	20.7	9.5	57.5	10	45.2	25.7	76.7
	Alluvium, acid floodplain	1	15.2	--	--	2	--	17.5	23.7
Pb, ppm	Glacial Till								
	brown Wisconsinan	4	23.5	18.2	44.0	9	16.0	12.0	18.8
	red Wisconsinan	3	15.7	9.5	47.5	6	10.1	2.7	42.2
	pre-Wisconsinan	2	--	11.7	18.5	4	9.6	5.2	15.5
	Colluvium	3	20.0	8.0	20.5	7	12.2	7.0	23.5
	Loess	3	21.2	16.0	23.0	6	11.6	8.5	18.2
	Residuum								
	sandstone	5	8.8	2.2	83.2	12	13.0	9.2	20.5
	gray acid shale	5	19.7	17.0	85.2	13	15.2	10.7	39.5
	red calcareous shale	2	--	33.5	35.0	4	22.4	21.2	38.5
	gray calcareous shale	3	24.5	19.7	28.2	6	15.8	13.0	18.2
	limestone	23	26.7	16.7	77.5	47	18.9	9.7	66.2
	acid crystalline	7	21.7	13.5	39.5	18	10.6	4.5	28.7
	basic crystalline	5	18.0	13.0	24.5	10	8.8	4.2	14.5
	Alluvium, acid floodplain	1	19.5	--	--	2	--	11.0	18.2

Table 3. Cont. Median, minimum, and maximum values for extracted elements of surface (A) and subsurface (B or C) horizons by parent material origin.

		Surface Horizon				Subsurface Horizon			
Element	Parent Material	No.	Median	Minimum	Maximum	No.	Median	Minimum	Maximum
Cd, ppm	Glacial Till								
	brown Wisconsinan	4	0.225	0.100	0.300	9	0.100	0.050	0.175
	red Wisconsinan	3	0.500	0.325	0.700	6	0.188	0.175	0.300
	pre-Wisconsinan	2	--	0.200	0.525	4	0.075	0.025	0.125
	Colluvium	3	0.175	0.150	0.275	7	0.150	0.075	0.200
	Loess	3	0.175	0.175	0.200	6	0.088	0.050	0.125
	Residuum								
	sandstone	5	0.200	0.025	0.400	12	0.025	0.025	0.125
	gray acid shale	5	0.375	0.300	0.525	13	0.100	0.025	0.325
	red calcareous shale	2	--	0.275	0.525	4	0.162	0.075	0.200
	gray calcareous shale	3	0.450	0.400	0.650	6	0.225	0.100	0.350
	limestone	23	0.225	0.050	0.700	47	0.100	0.000	0.850
	acid crystalline	7	0.225	0.100	0.275	18	0.138	0.025	0.250
	basic crystalline	5	0.175	0.100	0.250	10	0.062	0.025	0.225
	Alluvium, acid floodplain	1	0.125	--	--	2	--	0.075	0.250
Cr, ppm	Glacial Till								
	brown Wisconsinan	4	14.4	12.5	18.5	9	16.2	14.5	23.0
	red Wisconsinan	3	22.2	12.5	27.3	6	16.1	10.2	22.5
	pre-Wisconsinan	2	--	15.2	16.0	4	17.8	15.7	25.7
	Colluvium	3	17.5	15.2	19.2	7	28.7	25.7	35.2
	Loess	3	22.0	21.7	34.0	6	36.5	26.5	53.5
	Residuum								
	sandstone	5	7.5	1.3	22.2	12	12.2	2.7	33.2
	gray acid shale	5	21.2	16.7	30.0	13	32.0	21.0	40.0
	red calcareous shale	2	--	23.2	38.2	4	44.8	29.0	51.5
	gray calcareous shale	3	22.0	19.2	22.7	6	22.8	19.2	32.7
	limestone	23	25.0	13.0	43.0	47	36.4	17.7	82.7
	acid crystalline	7	23.0	10.2	32.7	18	23.8	1.0	41.7
	basic crystalline	5	112.0	32.5	141.0	10	134.4	62.7	360.0
	Alluvium, acid floodplain	1	16.0	--	--	2	--	18.8	19.5

Errata

for

Metals Data for Pennsylvania Soils

by

E. J. Ciolkosz, R. C. Stehouwer, and M. K. Amistadi. 1998. Agronomy Series 140

Table 4 in Chapter 5 was omitted in the publication and is given below.

Table 4. State-wide distributions of pH and extracted elements from surface (A) and subsurface (B or C) horizons (66 analyses for each horizon.

Element	Surface Horizon								Subsurface Horizon							
	Mean	Min	Percentile					Max	Mean	Min	Percentile					Max
			10	25	50	75	90				10	25	50	75	90	
pH	5.6	3.4	4.3	5.0	5.6	6.2	6.6	7.3	5.5	4.1	4.6	4.8	5.3	6.0	6.8	7.3
Fe (%)	8.3	0.4	1.5	2.2	4.3	11.6	19.5	42.3	7.3	1.1	2.4	3.0	3.7	5.3	13.3	45.9
Al (%)	1.64	0.30	1.10	1.23	1.51	1.90	2.35	4.80	2.46	0.80	1.36	1.79	2.33	3.11	3.52	6.62
Ca (ppm)	1250	38	243	546	1050	1565	1969	7125	866	3	88	252	520	1274	1706	4875
Cd (ppm)	0.29	0.03	0.11	0.18	0.24	0.40	0.55	0.70	0.11	0.03	0.03	0.05	0.08	0.15	0.20	0.85
Cr (ppm)	27.9	1.3	12.9	16.9	22.1	27.5	36.5	141.0	43.9	8.0	15.4	22.5	31.9	48.2	72.7	280.0
Cu (ppm)	16.9	3.8	9.8	12.0	14.5	18.5	23.6	71.5	27.3	7.5	12.7	18.7	22.9	27.8	42.0	119.7
K (ppm)	934	101	481	668	869	1149	1475	2700	1549	232	581	819	1263	1794	2750	8450
Mg (ppm)	1923	63	674	1123	1475	1994	2738	21700	3049	340	916	1265	2400	3094	5738	28050
Mn (ppm)	1451	10	290	688	1230	1825	2988	5150	401	18	76	202	325	532	815	1575
Na (ppm)	56.7	17.2	35.0	41.2	51.5	66.8	91.3	110.7	69.0	27.0	38.8	44.3	56.0	68.9	110.9	575.0
Ni (ppm)	13.7	0.5	6.8	10.5	12.7	15.5	18.6	57.5	21.3	4.5	9.0	13.4	19.3	25.0	38.5	76.7
P (ppm)	454.4	67.5	238.8	322.5	450.0	599.0	646.3	882.5	233.3	32.5	90.7	125.3	232.5	319.1	377.5	602.5
Pb (ppm)	27.0	2.2	13.3	18.1	21.6	32.5	45.3	85.2	16.3	4.5	8.5	10.8	15.2	18.2	22.8	66.2
Zn (ppm)	64.7	7.2	33.0	40.6	61.3	84.9	99.1	162.7	54.7	17.7	29.3	36.3	44.8	63.5	87.5	252.5

CHAPTER 6

Palmerton Zinc Smelter Study

Introduction

A soil-investigation around the Palmerton zinc smelter was conducted by John Washington as a M.S. degree study (Washington, 1985). Washington's data is given in this chapter because it indicates that a relatively large area can be affected by a pollution source and may affect the perception of background levels of metals if these pollution sources are not taken into consideration.

Material and Methods

Seventy-two composite samples (12 to 20 core subsamples) were collected from the surface soil (A or Ap horizon) by Washington from each of the 72 locations. The samples were air dried and several types of analysis were done on the samples. The data reported here is for Zn, Cd, Pb, Cu, Mg, Ca, and Fe content using the following method as given in Washington (1985). This method was used in the Penn State Environmental Chemistry Laboratory prior to the institution of the EPA's Method 3050, and differs from 3050 mainly in not having a H_2O_2 treatment. In the process of certifying the Penn State Lab to do superfund site analysis, the Penn State method was determined to give similar results as Method 3050.

1. Air dry and sieve sample (< 2 mm).
2. Weigh 5.00 g into a 150 ml beaker ($\pm$ 0.005 g).
3. Add 10 ml concentrated HNO_3.
4. Heat slowly until dry without baking the sample.
5. Remove sample and allow to cool.

6. Add 20 ml 3 M HCl. Cover with watchglass and return to a slightly increased heat.
7. Reflux for 2 hours (volume should decrease approximately 50%).
8. Remove from heat and cool.
9. Filter through 11.0 cm #40 Whatman paper and rinse the residue with 1 molar HNO_3.
10. Dilute sample to 50 ml with 1 M HNO_3.
11. Transfer sample to storage bottle.
12. Dilute samples in 5% HCl-5% HNO_3 if necessary to run by atomic absorption spectrophotometer.

Results and Conclusions

Table 1 gives the data from Washington (1985). In general, the data indicates an impact of 10 to 15 miles down wind (east from the Palmerton site) (see Washington, 1985, for details). The study also indicates that when sampling soils for metal analysis, the location of contamination sources of the area must be noted.

This site was declared a superfund site, and more information on the site is available from the USEPA. An additional, similar study was done in Western Pennsylvania by Bowers (1988).

References

Bowers, M. E. 1988. Soil amendments to reduce cadmium and zinc uptake by plants grown on zinc-smelter contaminated soils. M.S. Thesis. Pennsylvania State Univ., Univ. Park, PA.

Washington, J. W. 1985. Metallic contamination surrounding a zinc smelter. M.S. Thesis. Pennsylvania State Univ., Univ. Park, PA.

Table 1. Metals data for the Palmerton Smelter Site (Washington, 1985).

Sample	Parts Per Million						Percent
Number	Mg	Ca	Cu	Zn	Cd	Pb	Fe
1	2860	1630	93.4	123	0.48	49.3	3.2
2	782	1140	10.0	670	11.28	80.1	0.6
3	3360	2010	16.9	170	1.10	36.5	2.7
4	7270	2810	78.9	170	0.55	68.6	3.5
5	6160	2610	41.8	119	0.42	38.5	3.6
6	4520	1590	91.2	160	0.77	36.4	3.1
7	2730	1780	55.9	98	0.33	32.5	2.9
8	3210	2460	19.1	240	0.52	38.7	2.8
10	3550	2340	32.5	150	0.53	45.4	5.2
11	6860	5800	130.4	170	0.64	39.0	3.7
12	6790	5390	154.6	170	0.67	39.7	3.8
13	1540	4410	24.3	200	1.93	42.5	2.4
14	4030	5970	47.9	230	1.55	54.2	2.7
15	2850	979	37.6	93	0.21	31.8	2.7
16	1580	929	37.3	105	0.63	23.9	2.0
17	7650	3450	33.0	210	1.05	33.8	3.6
18	998	3340	37.7	1300	26.10	354.0	2.0
19	3100	8450	37.6	118	0.42	32.4	2.2
21	2090	1750	9.6	83	0.39	23.3	1.5
22	5940	3200	149.6	180	0.66	49.7	3.6
23	5130	1430	90.6	150	0.87	39.5	3.5
24	1810	1490	22.1	510	9.39	58.1	2.4
25	1440	1390	24.8	760	16.80	114.5	2.0
26	2120	1840	17.1	87	0.36	28.8	2.7
27	6130	3570	46.7	100	0.36	33.2	3.3
28	2450	10900	22.9	130	0.73	37.2	3.7
29	4350	1900	82.8	114	0.33	33.6	3.5
30	6060	8580	115.8	150	0.46	37.7	3.8
31	1690	1800	23.6	330	3.36	51.8	2.3
32	1570	1180	25.7	290	2.08	26.6	2.4
33	5220	2000	73.9	150	0.56	30.7	2.9
34	6050	1560	26.5	130	0.63	29.5	3.4
35	7630	2590	39.9	410	2.73	49.6	4.0
36	4070	4280	50.5	112	0.33	35.6	3.7
37	1900	2860	20.0	220	1.39	43.9	1.8
38	3960	1250	14.8	67	0.20	22.4	2.3
39	4360	1670	57.7	140	0.45	35.5	3.8
40	2330	2100	16.9	115	0.62	37.3	1.9
41	1790	2690	58.7	220	1.42	26.0	2.4

Table 1. Cont. Metals data for the Palmerton Smelter Site (Washington, 1985).

Sample	Parts Per Million						Percent
Number	Mg	Ca	Cu	Zn	Cd	Pb	Fe
42	7320	2940	128.8	180	0.61	38.2	3.8
43	7850	1240	12.4	190	1.76	28.7	1.1
44	4850	1950	53.2	200	1.55	40.1	3.2
45	1750	1860	55.3	99	0.63	26.6	2.1
46	1780	900	29.7	73	0.45	17.1	2.1
47	5550	1460	47.5	180	0.85	45.2	3.5
49	1510	910	27.1	460	6.75	62.4	2.2
50	4510	7760	29.1	130	0.50	42.0	3.5
52	1760	2100	26.3	111	0.65	24.0	2.2
53	7720	9710	48.7	460	4.01	60.8	3.3
55	3380	1420	14.3	119	0.58	31.9	2.5
56	1014	990	13.5	121	1.26	27.5	2.2
57	2100	1110	20.6	210	1.55	35.2	3.0
58	2270	1990	22.8	330	4.39	41.1	2.4
59	1440	920	43.3	150	1.14	41.5	2.2
60	5660	6630	20.3	130	1.17	30.9	2.6
61	1510	8290	20.1	280	3.91	33.5	2.6
63	2230	1450	36.4	1800	34.50	124.3	2.9
64	2660	1450	34.4	87	0.25	34.8	3.7
65	1690	520	19.9	160	1.68	35.9	2.6
66	2870	1380	25.5	1070	13.50	83.9	4.1
67	6610	1900	35.9	113	0.26	31.4	3.4
69	1770	1460	26.8	87	0.47	26.1	2.5
70	5240	5810	134.9	160	0.60	37.7	3.4
71	6850	4090	27.6	130	0.39	35.5	3.6
72	1150	1140	13.7	86	0.58	25.8	2.0

CHAPTER 7

USGS Soils Study

Introduction

Over a period of years, the United States Geological Survey (USGS) collected and analyzed soil samples from across the United States. These data were summarized by Shacklette and Boerngen (1984). In their report, only summary maps were presented. The complete data for the Pennsylvania samples is only available in a difficult to obtain USGS open file report (Boerngen and Shacklette, 1981). Because of this reason, the Pennsylvania data is presented in this chapter in Tables 1 and 2.

Materials and Methods

The soil samples were collected by USGS personnel along roads at about 80 km (about 50 miles) intervals from on undisturbed areas when possible and within 100 meters of the road. The soil sample was taken from a 20 cm depth. The samples were oven dried and passed through a 2 mm sieve. Material > 2 mm in size was pulverized and passed through the 2 mm sieve. The < 2 mm sample was used for the total elemental analyses (see Shacklette and Boerngen, 1981, for details of the method of analysis).

Results

The elemental data in Table 2 is the most extensive known for Pennsylvania soil samples. Although the most extensive, it is uncertain how these data relate to the extraction data presented in the other chapters of this publication. This problem cannot be resolved in this publication.

References

Boerngen, J. G. and H. T. Shacklette. 1981. Chemical analysis of soils and other surficial materials of the conterminous United States. USGS Open-File Report 81-197.

Shacklette, H. T. and J. G. Boerngen. 1984. Element concentration in soils and other surficial materials of the conterminous United States. USGS Prof. Paper 1270.

Table 1. Location and description of Pennsylvania sampling sites (From Boerngen and Shacklette, 1981).

Sample No.	County	Latitude		Longitude		Date Collect		Site and soil Descriptions
1	Bedford	39	57	78	20	10	66	PA Tpk 6 mi W Exit 12; light orange-brown sandy loam
2	Centre	41	2	77	57	9	70	I-80 0.5 mi S Jct Rt 144 on gravel trail
3	Chester	40	7	75	50	10	66	PA Tpk 5 mi E Exit 22; brown clay loam
4	Cumberland	40	10	77	30	10	66	PA Tpk 10 mi E Exit 15; yellowish clay loam
5	Dauphin	40	10	76	37	10	66	PA Tpk 8 mi W Exit 20; red sandy clay loam
6	Erie	41	56	80	29	5	62	I-90 at US 6N Interchange; yellowish-orange sand
7	Erie	42	11	79	50	9	72	Rt 89 3 mi S of North East; heavy clay forest soil
8	Fayette	40	5	79	20	10	66	PA Tpk 2 mi E Exit 9; yellowish brown silty clay loam
9	Jefferson	41	9	78	54	9	70	US 322 2.5 mi E Rt 28 Jct
10	Lehigh	40	44	75	37	11	67	NE Exit Penn. Tpk near Slatington
11	Lycoming	41	12	77	8	9	70	Rt 645 3.9 mi W Jct US 15
12	Mercer	41	12	80	17	9	70	4.5 mi W Jct US 62 and US 19
13	Sullivan	41	23	76	30	10	67	US 220 2 mi S LaPorte; B horizon from sandstone
14	Susquehanna	41	38	75	38	11	67	I-81 5 mi S Lenox
15	Tioga	41	40	77	5	9	70	US 15 2.7 mi S of N turnoff to Arnot
16	Washington	40	10	80	15	10	66	I-70 at Washington; yellowish-orange silty loam

Table 2. Elemental composition of Pennsylvania soil samples (from Boerngen and Shacklette, 1981).

	%*	PPM**					%		PPM			
Sample No.	Al	As	B	Ba	Be	Br	C	Ca	Ce	Co	Cr	Cu
1	7.00	29.0	70	300	2.0	--+	--	0.05	150	30	70.0	50.0
2	5.00	6.1	30	300	N++	--	--	0.06	N	3	30.0	10.0
3	7.00	5.2	20	500	1.5	--	--	0.30	150	20	50.0	70.0
4	####	9.9	50	500	1.5	--	--	0.20	150	15	100.0	50.0
5	7.00	7.0	70	300	3.0	--	--	0.20	150	20	70.0	50.0
6	1.50	6.3	30	300	N	--	--	0.53	N	7	15.0	15.0
7	7.00	15.7	50	500	N	5.3	4.1	0.43	< 150	10	70.0	50.0
8	7.00	10.0	50	500	2.0	--	--	0.45	150	30	70.0	50.0
9	3.00	3.8	30	200	N	--	--	0.03	N	3	15.0	7.0
10	5.00	16.0	70	300	1.5	--	--	0.10	N	15	30.0	50.0
11	####	17.0	50	500	2.0	--	--	0.04	< 150	15	100.0	50.0
12	7.00	14.0	50	500	1.0	--	--	0.15	150	10	50.0	20.0
13	3.00	11.0	30	150	N	--	--	0.05	N	7	15.0	15.0
14	5.00	14.0	70	200	1.5	--	--	0.25	N	10	30.0	15.0
15	7.00	10.0	50	300	1.0	--	--	0.06	< 150	10	30.0	20.0
16	####	31.0	50	500	3.0	--	--	0.25	150	30	100.0	70.0

* % = percent

** = parts per million

+ = no data available (was probably not determined)

++ = not detected in sample

Table 2. Cont. Elemental composition of Pennsylvania soil samples (from Boerngen and Shacklette, 1981).

	PPM**		%*	PPM					%	PPM
Sample No.	Sn	Sr	Ti	Th	U	V	Y	Yb	Zn	Zr
1	--+	150	0.700	--	--	100	50	7.0	60	200
2	--	30	0.300	--	--	20	15	2.0	24	200
3	--	70	0.700	--	--	150	100	10.0	130	150
4	--	150	0.700	--	--	150	30	3.0	60	150
5	--	150	0.700	--	--	150	30	3.0	80	150
6	--	70	0.150	--	--	30	15	3.0	42	200
7	1.79	150	0.300	###	###	100	20	3.0	155	200
8	--	150	0.700	--	--	100	30	5.0	110	200
9	--	10	0.500	--	--	15	20	3.0	31	500
10	--	30	0.300	--	--	70	30	3.0	115	200
11	--	150	0.700	--	--	100	20	3.0	67	150
12	--	70	0.500	--	--	70	30	3.0	113	300
13	--	30	0.200	--	--	30	20	3.0	55	200
14	--	30	0.300	--	--	50	30	3.0	90	300
15	--	50	0.500	--	--	50	30	3.0	80	200
16	--	150	0.500	--	--	100	30	5.0	80	150

* % = percent

** = parts per million

+ = no data available (was probably not determined)

Table 2. Cont. Elemental composition of Pennsylvania soil samples (from Boerngen and Shacklette, 1981).

	%*	PPM**			%	PPM		%	PPM			%
Sample No.	Na	Nb	Bd	Ni	P	Pb	Rb	S	Sb	Sc	Se	Si
1	0.50	15	70	30	0.040	30	--+	--	--	15	0.3	--
2	0.20	10	N++	< 5	--	15	--	--	--	5	0.4	--
3	0.70	10	150	30	0.080	30	--	--	--	15	1.3	--
4	0.70	15	70	30	0.030	20	--	--	--	15	0.4	--
5	1.00	15	70	30	0.030	30	--	--	--	15	0.4	--
6	0.70	10	--	15	0.052	15	--	--	--	7	0.1	--
7	0.70	< 10	< 70	20	--	30	85	< .08	< 1	10	0.2	31
8	0.50	15	70	50	0.040	30	--	--	--	15	0.7	--
9	< .05	10	N	N	--	< 10	--	--	--	5	0.3	--
10	0.15	10	70	30	0.040	30	--	--	--	15	1.1	--
11	0.50	10	70	50	--	10	--	--	--	15	0.4	--
12	0.50	10	100	15	--	20	--	--	--	10	0.4	--
13	0.15	15	70	15	0.024	15	--	--	--	7	0.5	--
14	0.70	15	70	15	0.050	30	--	--	--	7	0.4	--
15	0.30	10	70	10	--	20	--	--	--	7	0.6	--
16	0.50	15	70	30	0.060	30	--	--	--	15	0.3	--

* % = percent

** = parts per million

\+ = no data available (was probably not determined)

++ = not detected in sample

Table 2. Cont. Elemental composition of Pennsylvania soil samples (from Boerngen and Shacklette, 1981).

	%*		PPM**				%	PPM		%	PPM	
Sample No.	F	Fe	Ga	Ge	Hg	I	K	La	Li	Mg	Mn	Mo
1	0.033	3.00	30	--+	0.06	--	2.00	70	37	0.500	500	N++
2	0.009	1.50	5	--	0.13	--	0.78	30	18	0.100	150	N
3	0.026	5.00	30	--	0.07	--	1.90	100	28	0.700	###	3
4	0.080	5.00	30	--	0.12	--	2.00	70	55	1.000	200	N
5	0.053	5.00	30	--	0.07	--	1.30	70	47	1.000	###	N
6	0.009	1.50	15	--	0.04	--	1.08	N	14	0.300	300	N
7	--	3.00	15	2	0.11	2.2	1.51	< 30	39	0.500	700	N
8	0.040	7.00	30	--	0.06	--	1.90	70	64	0.700	700	N
9	0.004	0.70	N	--	0.05	--	0.36	30	12	0.070	300	N
10	0.061	3.00	15	--	0.08	--	2.30	30	27	0.300	300	3
11	0.008	7.00	30	--	0.08	--	3.26	50	78	0.700	700	N
12	0.027	3.00	15	--	0.06	--	1.25	70	35	0.300	700	N
13	0.034	1.50	15	--	0.10	--	0.75	30	41	0.300	200	N
14	0.026	1.50	15	--	0.14	--	1.20	30	40	0.300	700	N
15	0.029	3.00	15	--	0.25	--	1.29	50	39	0.300	###	N
16	0.060	7.00	50	--	0.05	--	2.50	70	80	0.500	300	N

* % = percent

** = parts per million

\+ = no data available (was probably not determined)

++ = not detected in sample