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Distribution of Trace Metals at Hopewell Furnace National Historic Site, Berks and Chester Counties, Pennsylvania

Scientific Investigations Report 2011–5014

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photograph showing the cast house at Hopewell Furnace National Historic site, Pennsylvania. The cast house encloses the furnace. The stone stack of the furnace is visible on the left side of the cast house. In the foreground, part of the furnace slag pile is exposed and makes up the left bank of French Creek.

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in)
millimeter (mm)	0.03937	inch (in)
meter (m)	3.281	foot (ft)
	Volume	
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Distribution of Trace Metals at Hopewell Furnace National Historic Site, Berks and Chester Counties, Pennsylvania

By Ronald A. Sloto and Andrew G. Reif

Abstract

Hopewell Furnace, located approximately 50 miles northwest of Philadelphia, was a cold-blast, charcoal iron furnace that operated for 113 years (1771 to 1883). The purpose of this study by the U.S. Geological Survey, in cooperation with the National Park Service, was to determine the distribution of trace metals released to the environment from an historical iron smelter at Hopewell Furnace National Historic Site (NHS). Hopewell Furnace used iron ore from local mines that contained abundant magnetite and accessory sulfide minerals enriched in arsenic, cobalt, copper, and other metals. Ore, slag, cast iron furnace products, soil, groundwater, stream base flow, streambed sediment, and benthic macroinvertebrates were sampled for this study. Soil samples analyzed in the laboratory had concentrations of trace metals low enough to meet Pennsylvania Department of Environmental Protection standards for non-residential use. Groundwater samples from the supply well met U.S. Environmental Protection Agency drinking-water regulations. Concentrations of metals in surface-water base flow at the five stream sampling sites were below continuous concentration criteria for protection of aquatic organisms. Concentrations of metals in sediment at the five stream sites were below probable effects level guidelines for protection of aquatic organisms except for copper at site HF-3.

Arsenic, copper, lead, zinc, and possibly cobalt were incorporated into the cast iron produced by Hopewell Furnace. Manganese was concentrated in slag along with iron, nickel, and zinc. The soil near the furnace has elevated concentrations of chromium, copper, iron, lead, and zinc compared to background soil concentrations. Concentrations of toxic elements were not present at concentrations of concern in water, soil, or stream sediments, despite being elevated in ore, slag, and cast iron furnace products.

The base-flow surface-water samples indicated good overall quality. The five sampled sites generally had low concentrations of nutrients and major ions but had elevated concentrations of iron, manganese, and strontium when compared to sites sampled in adjacent watersheds. The background site on Baptism Creek generally had the lowest concentrations and yields of constituents. Low concentrations of nutrients and major ions at all five sites indicate that measured concentrations can be attributed to general land use and geology and not to point sources.

Streambed-sediment sampling results indicated higher concentrations of all metals except nickel at sites on French Creek compared to the background site on Baptism Creek. Concentrations of aluminum, cadmium, and nickel were highest in sediment from the sampling site upstream from Hopewell Furnace. The highest concentrations of arsenic, boron, cobalt, copper, iron, lead, manganese, mercury, and zinc were detected at the site just below Hopewell Furnace, which indicates that the source of these metals may be in Hopewell Furnace NHS.

The invertebrate community at the background site on Baptism Creek was dominated by pollution sensitive taxa indicating a healthy, diverse benthic-macroinvertebrate community. Benthic-macroinvertebrate communities at sampling sites on French Creek indicated disturbed communities when compared to the background site on Baptism Creek and that the overall stream quality immediately above and below Hopewell Furnace NHS is degraded. The benthic-macroinvertebrate communities were dominated by pollution-tolerant taxa, and taxa were less diverse than at the background site.

Habitat conditions at the upstream site on French Creek were good but were degraded at downstream sites on French Creek. The major habitat issues at these sites were related to a lack of stable substrate, erosion, and deposition. Water quality and streambed-sediment quality do not indicate that the degraded benthic-macroinvertebrate communities are the result of poor water quality. Habitat conditions (erosion and sedimentation) and physical alterations (water temperature) from the outfall of Hopewell Lake are the most likely causes of the impaired communities.

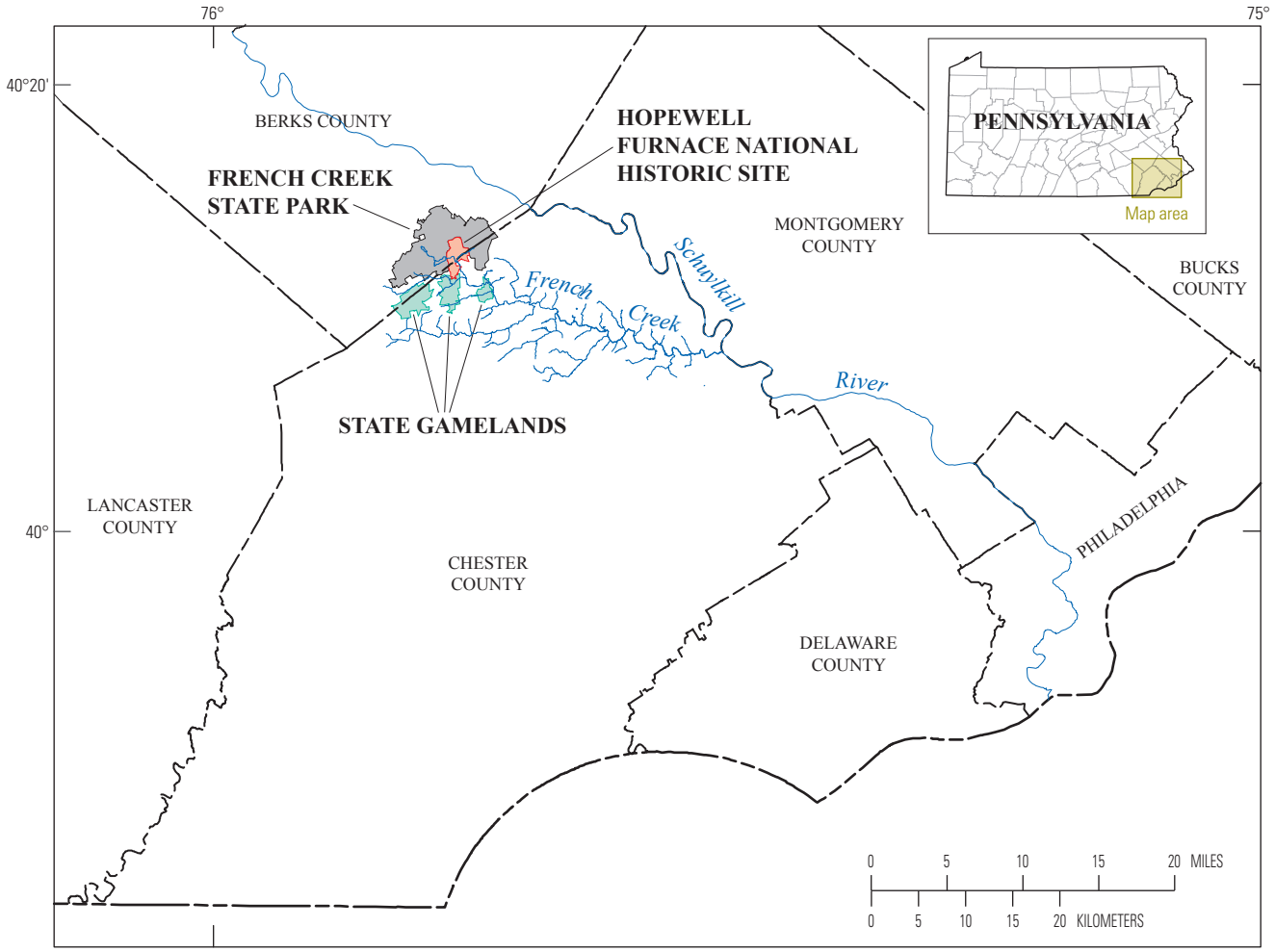
Introduction

Hopewell Furnace National Historic Site (NHS) is one of the finest examples of a rural American 19th-century iron plantation. The buildings include a cold-blast, charcoal-fired

iron furnace, the ironmaster's mansion, and auxiliary structures. Hopewell Furnace began making iron before the Revolutionary War and was in operation for 113 years (1771–1883). The 848-acre site is representative of the hundreds of iron plantations that flourished in the 18th and early 19th centuries.

Hopewell Furnace NHS, located approximately 50 mi northwest of Philadelphia, straddles the Berks-Chester County border in southeastern Pennsylvania (fig. 1). It is adjacent to the 1,800-acre Pennsylvania State Game Lands Number 43 and the popular 7,339-acre French Creek State Park, which offers hunting, fishing, boating, hiking, and camping. Hopewell Furnace NHS and the surrounding French Creek State Park host almost 1 million visitors every year (Hopewell Furnace National Historic Site, 2007).

French Creek flows through the heart of Hopewell Furnace NHS, which is near its headwaters. The Commonwealth of Pennsylvania designated French Creek as a State Wild and Scenic River in 1982 because of its outstanding natural and scenic values. It also bears the Commonwealth's designations of High Quality Waters-Cold Water Fishery and Exceptional Value Stream. French Creek is listed in the National Park Service (NPS) Nationwide Rivers Inventory (NRI), a listing of free-flowing river segments in the United States that possess one or more "outstandingly remarkable" natural or cultural values judged to be of more than local or regional significance (National Park Service, 2009). Under a 1979 Presidential directive, all Federal agencies must seek to avoid or mitigate actions that would adversely affect NRI segments. Outstandingly Remarkable Values listed by the NPS for French Creek include (1) hydrologic (northernmost, least developed, free-flowing river within the Piedmont), (2) historic (river-related National Historic Register sites and an Historic District within the corridor), and (3) geologic (area includes the unique Falls of French Creek). The Hopewell Furnace slag piles are close to and, in some locations, make up the banks of French Creek (fig. 2).



Base from U.S. Geological Survey digital data,1972,
1:2,000,000 Albers Equal-AreaConic Projection
Standard parallels 29°30'N, cental meridian 75°00'W

Figure 1. Location of Hopewell Furnace National Historic Site, Pennsylvania.

Aerial photograph courtesy of the Delaware Valley Regional Planning Commission (DVRPC)

1. Visitor's center
2. Ironmaster's mansion
3. Charcoal house
4. Furnace
5. Cast house
6. Office and store
7. Barn
8. Anthracite furnace
9. Stockyard slag pile 1
10. Slag pile 2 (south and west of cast house)
11. Slag pile 3 (south of anthracite furnace)
12. Location of ore roaster
13. Ore pile
14. Tailrace

Figure 2. Locations of sampled slag piles at Hopewell Furnace National Historic Site, Pennsylvania.

Local mines, mainly the Jones, Warwick, and Hopewell mines, supplied the iron ore used at Hopewell Furnace (fig. 3). The Hopewell mine, 2.8 mi southwest of the furnace, and the Jones mine, 4.5 mi southwest of the furnace, were owned by Hopewell Furnace and supplied most of the ore for the furnace. In later years, some ore came from the Warwick mine in Chester County. Iron ore used at Hopewell Furnace was mined from deposits of magnetite skarn and skarn replacements referred to as Cornwall-type ore bodies (Spencer, 1908) after the large iron ore body mined at Cornwall, Pa. The deposits were formed by replacement of carbonate-bearing rocks during contact metamorphism and metasomatism as a result of diabase intrusions during the early Jurassic. These deposits are mineralogically similar and contain abundant magnetite and accessory sulfide minerals enriched in arsenic, cobalt, copper, and other metals. Arsenic is a carcinogen (Agency for Toxic Substances and Disease Registry, 2007), and cobalt is a possible carcinogen (Agency for Toxic Substances and Disease Registry, 2004). Iron ore containing these trace metals was smelted at Hopewell Furnace during its 113 years of operation. The purpose of this study by the U.S. Geological Survey (USGS), in cooperation with the NPS, was to determine the distribution of trace metals in ore, slag, soil, streambed sediment, and water in Hopewell Furnace NHS related to the iron-smelting process.

Purpose and Scope

This report describes the distribution of trace metals in iron ore, slag, soil, cast iron furnace products, groundwater, stream base flow, and streambed sediment related to iron smelting in and around Hopewell Furnace NHS. In addition, the report presents results of benthic-macroinvertebrate and habitat surveys completed at five sites.

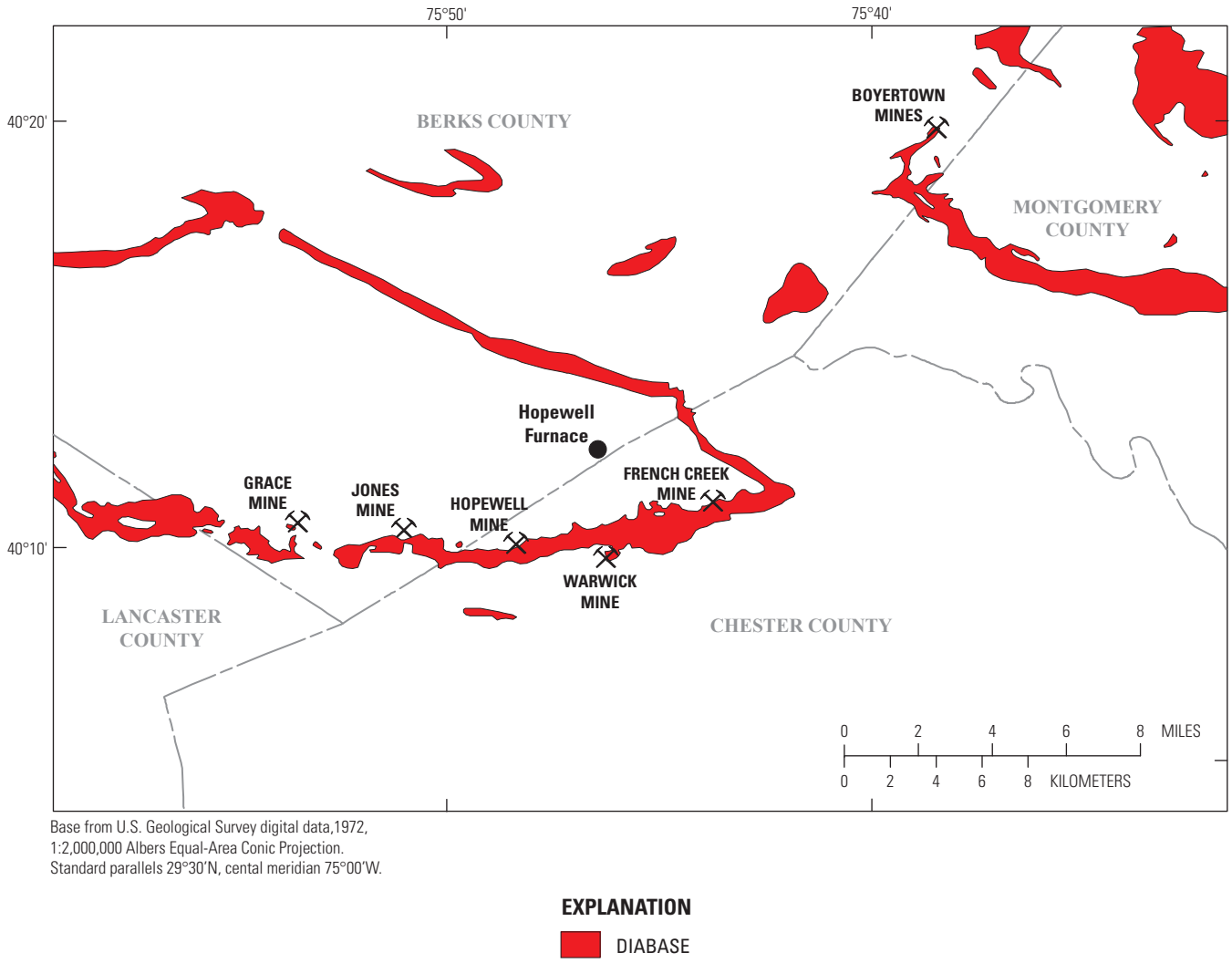


Figure 3. Locations of selected iron mines near Hopewell Furnace National Historic Site, Pennsylvania.

Historical Background

William Bird was born in 1703. Bird initially worked for Thomas Rutter, a pioneer ironmaster, at nearby Pine Forge. When Bird later went into business for himself, he acquired extensive lands near Hay Creek where he built the New Pine Forges in 1744. At that time, he also began construction of Hopewell Forge, believed to have been located at, or near, the present Hopewell Furnace site. By 1756, he had acquired 12 tracts of land totaling about 3,000 acres.

Mark Bird, the son of William Bird, took charge of the family business upon his father's death in 1761 and expanded it. In 1770–71, Bird constructed Hopewell Furnace on French Creek. The location provided ready access to the raw materials necessary for maintaining an iron furnace—iron ore, limestone, and hardwood forests for making charcoal.

The opening of Hopewell Furnace coincided with the beginning of the Revolutionary War. Bird produced cannon shells and other supplies for the war, including the casting of 115 cannons for the Colonial Navy. In 1775, Bird served as lieutenant colonel of the Second Battalion, Berks County Militia. In August 1776, Colonel Bird outfitted 300 men of the battalion with uniforms, tents, and provisions at his own expense. This force marched under his command to Washington's relief after the Battle of Brandywine in late 1777. Bird was a member of the Provincial Conference of 1776 and was elected to the Provincial Assembly. Many of Bird's ironworks, gristmills, and sawmills supplied the Continental Congress with the materials for the Revolutionary War. Bird's patriotic endeavor nearly ruined him when the new government was unable to repay its debts following the Treaty of Paris. Compounding this, a flood on Hay Creek destroyed most of Bird's property there (Kurjack, 1954).

In 1783, Hopewell furnace produced 749.5 tons of pig iron and finished castings. Pig iron was its principal product. Finished castings included pots, kettles, stoves, hammers, anvils, and forge castings. While 1783 was a good year for iron production, the following years were not. In April 1786, Bird unsuccessfully tried to sell Hopewell Furnace along with his Birdsboro and Spring forges. In April 1788, Bird assigned Hopewell Furnace and his 5,000 acres of property to a creditor and moved to North Carolina where he died in poverty (Walker, 1966).

The furnace property changed ownership at least five times before 1800. At that time, Daniel Buckley and his brothers-in-law Thomas and Matthew Brooke purchased the property at auction. It was under the Brooke family that Hopewell reached its greatest prosperity. They updated the furnace technology, improved and extended the boundaries of the property, and rebuilt the waterwheel. A stamping mill was constructed in 1805 to salvage iron from the slag. From 1816 to 1848, Clement Brooke, the son of Thomas Brooke, operated the furnace, first as resident manager and later as ironmaster. Clement Brooke was able to turn Hopewell into a major supplier of iron products. By the 1820s, the furnace was operating at its peak, generally in excess of 300 days per year. Castings were the most profitable product, especially the popular Hopewell Stove. Hopewell produced as many as 23 types and sizes of cooking and heating stoves, which found a ready market in Philadelphia. Over 80,000 stoves were cast at Hopewell. In addition, Hopewell also cast pots, pans, kettles, bake plates, mortars, and waffle irons for the household; moldboards, corn-shelling machines, and windmill irons for the farmer; and machinery castings for industry.

The most productive years for Hopewell Furnace were from 1830 to 1837. During 445 days of continuous production in 1836–37, 1,169 tons of castings were produced. Hopewell's products were so much in demand that the furnace was often forced to turn down orders from new customers. In 1837, an economic panic resulted in a large decline in demand for Hopewell stoves.

The depression of 1837, coupled with the successful introduction of the hot-blast method and the substitution of coke for charcoal in the smelting of iron, signaled the end of the charcoal-burning iron furnace era. Beginning in the 1840s, the iron industry shifted to large-scale, steam-driven coke and anthracite furnaces. By 1845, finished castings on a commercial scale were discontinued at Hopewell because of competition from the newer furnaces. Thereafter, the furnace concentrated on pig iron for which there was still a ready market.

Clement Brooke retired in 1848. His successors found, despite a short reprieve during the Civil War, they could not compete against the new iron and Bessemer steel industries. In 1849, they erected an experimental anthracite furnace, which was to replace the old charcoal furnace. However, a poor design resulted in a catastrophic collapse of the furnace. In addition, the expense of hauling anthracite coal to Hopewell put an end to the experiment. The demand for iron during the Civil War and the simultaneous expansion of the railroad during the 1850s and 1860s temporarily brought the charcoal furnace back to life. When the iron and steel industries consolidated in urban manufacturing centers like Pittsburgh, Bethlehem, and Chicago, small independent rural enterprises like Hopewell could no longer compete, and the furnace ceased operating in 1883 (Kurjack, 1954).

In August 1935, the Federal government purchased over 4,000 acres of property that included the ruins of the iron furnace and community. The property was purchased for the French Creek Recreation Demonstration Area, one of five areas in Pennsylvania in the Recreation Demonstration Area Program, which was one of the many New Deal initiatives to help the nation recover from the Great Depression.

The Civilian Conservation Corps began to convert the land into a public recreation area and engaged the NPS to evaluate the furnace ruins found on the property. NPS historians recognized the value of the buildings in preserving the story of iron making in America and convinced the Department of the Interior that the furnace should be preserved and reconstructed. In 1938, the Acting Secretary of the Interior designated part of the land acquired for the French Creek Recreation Demonstration Area as Hopewell Village National Historic Site under the authority of the Historic Sites Act. The

NPS set the current site boundaries in 1946 and changed the name to Hopewell Furnace National Historic Site in 1985. The land south of the furnace, which included the Hopewell mines, was given to the Commonwealth of Pennsylvania and became State Game Lands Number 43. Other land given to the Commonwealth of Pennsylvania became French Creek State Park (Glaser, 2005).

The Iron-Making Process

Hopewell Furnace, built in 1770–71, was one of the last of the charcoal-burning iron furnaces operated in Pennsylvania. It continued in operation long after most charcoal furnaces were replaced by furnaces that were more modern. It was one of the largest furnaces of its time with an annual capacity of 700 to 1,000 tons. Blast for the furnace was supplied by a bellows powered by a 22-ft diameter water wheel.

The furnace was a truncated pyramid of thick stone 32 ft high and 22 ft square at the base built near the side of a small hill. Iron ore, charcoal, and limestone were carried across a wooden bridge that led from the hill to the opening of the furnace stack, into which they were dumped in alternating layers (fig. 4). Charcoal was the fuel used to smelt the iron ore. The blast was turned in, burning the charcoal at white heat (2,600 to 3,000°F) and melting the iron, which then dropped down to the hearth below. The slag, formed by the chemical fusion of the limestone with the impurities in the ore, floated on top and was drawn off from time to time and dumped outside the furnace. About twice a day, sometimes more often, the molten iron was run into a casting bed of sand. It required about 2 tons of ore, 1 to 2 tons of charcoal, and a few shovelfuls of limestone to make 1 ton of pig iron (Kurjack, 1954).

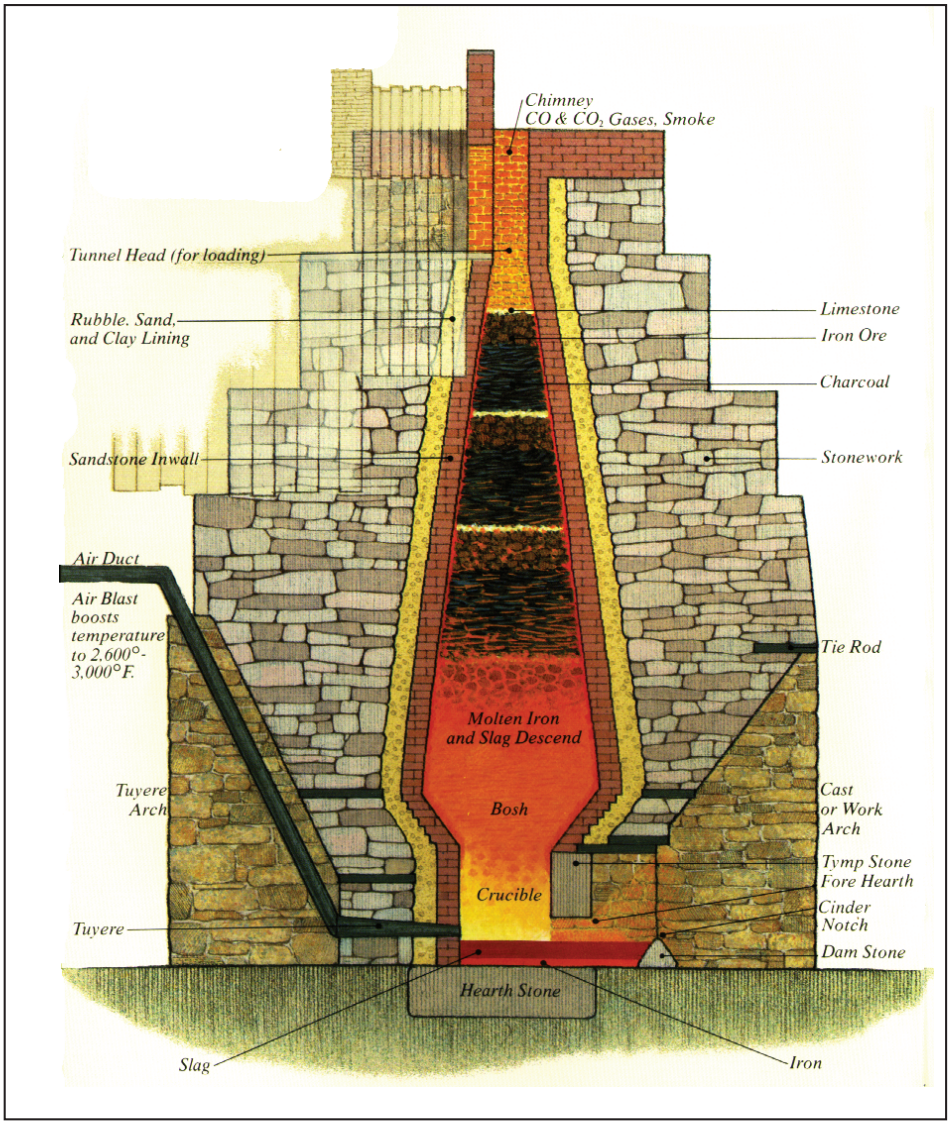


Figure 4. Cross-section diagram of a charcoal iron furnace.

Distribution of Trace Metals

Trace metals from iron ore smelted at Hopewell Furnace could potentially follow several pathways (fig. 5). During the smelting process, trace metals could be (1) volatilized as air emissions by the high temperatures of the furnace, (2) combined with slag, or (3) combined with the iron and incorporated into the cast iron products of the furnace.

Volatilized metals likely were deposited on the land surface downwind from the furnace. Travel distance may have been short because of the low height (32 ft) of the furnace stack. Metals deposited as aerosols may wash off into the surface-water system, be adsorbed onto soil, or be taken up by plants and animals. Erosion could move some of the soil and plant material into the stream system where it would become stream sediment.

Some of the trace metals were incorporated into the slag, which is a glass-like waste material discarded near the furnace. Trace metals present in slag may be immobile or, during physical and chemical weathering, could have leached into the soil or groundwater and surface-water system. Shallow, local groundwater discharges directly to French Creek as base flow (low streamflow). Physical breakdown of the slag may provide metals as solids to the soil or stream sediment.

Ore

Iron ore is the primary source of trace metals present at Hopewell Furnace. Three local mines, the Jones, Hopewell, and Warwick mines (fig. 3), supplied the iron ore used by the furnace. These mines worked iron deposits of a similar origin with a similar mineralogy. The ore bodies contained abundant magnetite and accessory sulfide minerals enriched in arsenic, cobalt, copper, and other trace metals. The major sulfide minerals are chalcopyrite ($CuFeS_2$) and pyrite (FeS_2). Sloto and Dickinson (1994) listed the arsenic-bearing minerals cobaltite [(Ni,Co,Fe)AsS] and erythrite [$Co_3(AsO_4)X8H_2O$] as accessory minerals associated with iron ore from the French Creek mine, which is 2.7 mi southeast of Hopewell Furnace (fig. 3). Smith and others (1988) presented analyses of ore samples from mines in Cornwall-type ore bodies in southeastern Pennsylvania that showed enrichment in arsenic, cobalt, copper, and nickel (table 1).

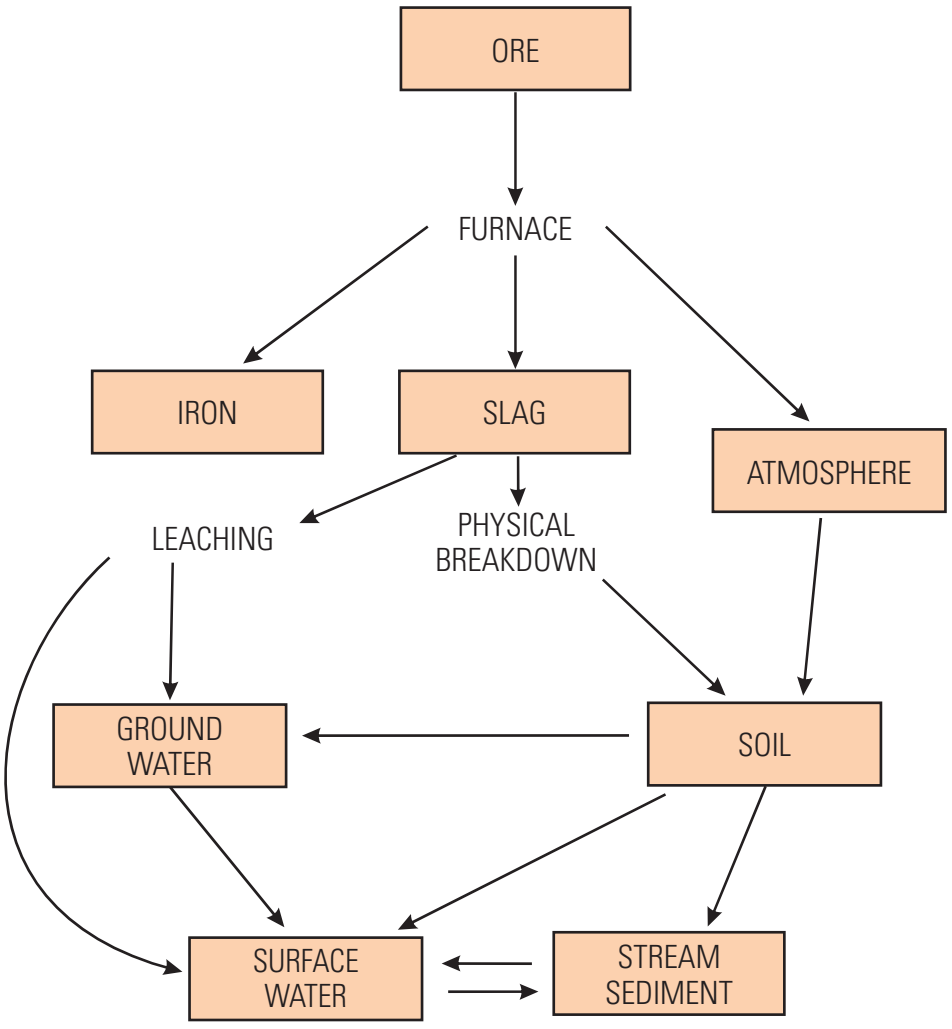


Figure 5. Potential pathways for migration of metals at Hopewell Furnace National Historic Site, Pennsylvania.

Ore samples from the Hopewell and Jones mines were analyzed for this study. Samples from the Hopewell mine were collected from the mine dumps at the eastern, western, and northern open pits (Sloto, 2009, p. 242–249) and composited. The samples were divided into pure or nearly pure magnetite (Ore-1) and magnetite with some sulfide mineralization (Ore-2). Although permission to collect samples from the Jones mine dumps could not be obtained, ore samples from this source were provide by Gregory Kolous of Kutztown University. The samples were obtained from one location in the extensive mine dumps and are not representative of the ore materials. The Warwick mine dumps were not accessible. Complete analyses of ore samples from the Hopewell and Jones mines are given in tables A and B in the appendix. Selected trace metals are summarized in table 2.

The bulk chemical composition of ore samples collected for this study was determined using inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS). The samples were decomposed using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids at low temperature prior to analysis. Major oxide content was measured using wavelength dispersive X-ray fluorescence spectroscopy (WDXRF). The samples were fused with 50/50 lithium metaborate lithium tetraborate flux, and the resultant glass disk was irradiated in a wavelength dispersive X-ray spectrometer using a Rhodium

Table 1. Concentrations of selected trace metals in ore samples from iron mines in southeastern Pennsylvania.

[From Smith and others (1988, p. 330); sample numbers are those of Smith and others (1988, p. 330); ppm, parts per million; <, less than]

Mine	Sample number	Sample composition	Arsenic (ppm)	Cobalt (ppm)	Copper (ppm)	Gold (ppm)	Nickel (ppm)
Jones mine	16	typical ore from dump	5	200	17,900	<0.03	335
French Creek mine	18	typical ore from dump	85	345	10,000	0.25	160
Grace mine	20	chalcopyrite, magnetite, and hematite from dumps	60	520	2,300	0.031	27
Cornwall mine	6	highgraded core	75	790	6,900	0.188	185
Cornwall mine	7	chalcopyrite, pyrite, magnetite from open pit	60	910	50,500	1	430
Cornwall mine	8	chalcopyrite mill concentrates	60	720	225,000	3.25	370
Cornwall mine	9	pyrite mill concentrates	220	11,000	900	<0.03	1,110
Cornwall mine	10	magnetite mill concentrates	5	50	300	<0.03	10
Boyertown mine	25	magnetite, chalcopyrite, and malachite from dumps	80	145	1,600	0.094	155
Crustal abundance (ppm)[1]			**4.8**	**17.3**	**28**	**0.002**	**47**

[1]From Rudnick and Gao (2003, p. 5-6).

Table 2. Concentrations of selected trace metals in ore samples from the Hopewell and Jones mines, southeastern Pennsylvania. Location of mines shown on figure 3.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada; ppm, parts per million; <, less than; >, greater than; --, unable to compute statistic]

Sample identification number	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (percent)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Vanadium (ppm)	Zinc (ppm)
Hopewell mine										
Ore-1	1	7	30.3	3.5	>15	4	1,930	93.6	446	594
Ore-2	107	7	63	349	>15	328	3,160	36.9	37	2,000
Jones mine										
Ore-3	12	1	109	>10,000	>15	423	793	56.3	259	420
Ore-4	11	<1	94.8	>10,000	>15	156	853	73.6	219	558
Ore-5	11	7	76.7	9,080	>15	10.3	992	122	64	59
Mean	**28.4**	**--**	**74.8**	**--**	**>15**	**184**	**1,550**	**76.5**	**205**	**726**
Crustal abundance[1]	**4.8**	**92**	**17.3**	**28**	**3.9**	**17**	**77.5**	**47**	**97**	**67**

[1] From Rudnick and Gao (2003, p. 4–6).

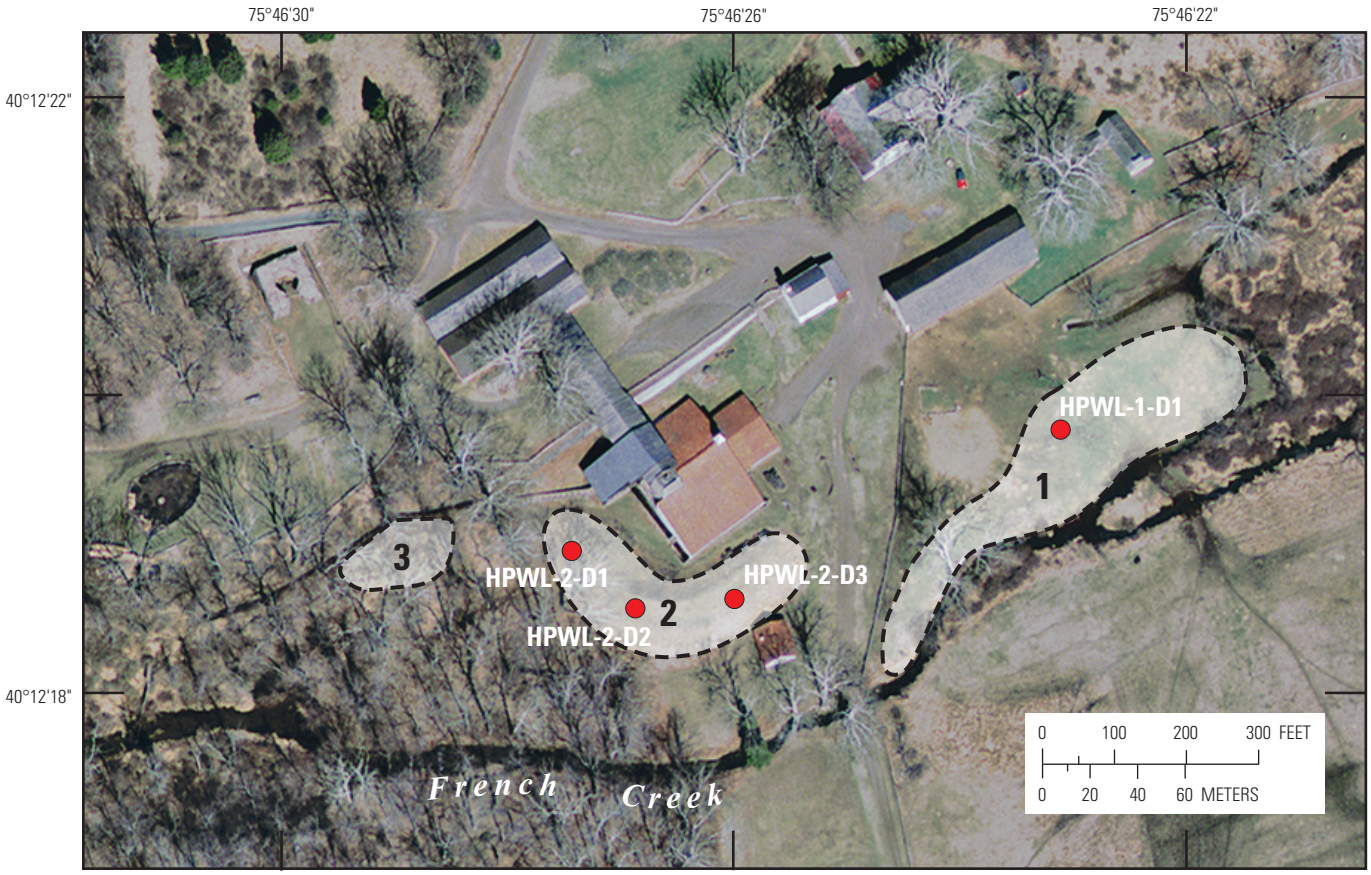
X-ray tube. The mineralogy of the ore samples is described in a separate USGS report (N. M. Piatak and R. R. Seal II, U.S. Geological Survey, written commun., 2011).

Most ore samples contained elevated concentrations of arsenic, cobalt, copper, iron, lead, manganese, nickel, vanadium, and zinc (table 2) when compared to the crustal abundance of these metals reported by Rudnick and Gao (2003, p. 4-6).

Slag

Slag samples for laboratory analysis were collected from three slag piles: in the stockyard south and southeast of the barn (pile 1 on figure 6), south and west of the cast house (pile 2 on figure 6), and south of the anthracite furnace ruins (pile 3 on figure 6). Detailed results of the slag analyses are given in tables C and D in the appendix. Selected trace metals analyzed in the slag samples are summarized in table 3. Concentrations of trace metals in the slag samples were compared to mean concentrations in soil in the eastern United States (east of the 96th meridian) published by Shacklette and Boerngen (1984, p. 6) (table 4). Their sample sites were about 50 mi apart, and samples were collected from 20 cm below land surface.

The bulk chemical composition of slag samples collected for this study was determined using ICP-AES and ICP-MS. The samples were decomposed using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids at low temperature prior to analysis. Major oxide content was measured using WDXRF. The samples were fused with 50/50 lithium metaborate lithium tetraborate flux, and the resultant glass disk was



Aerial photograph courtesy of the Delaware Valley Regional Planning Commission (DVRPC)

EXPLANATION

3 — Approximate location of slag pile and number

HPWL-1-D1 — Location of auger hole and sample number

Figure 6. Locations of slag samples collected at Hopewell Furnace National Historic Site, Pennsylvania.

Table 3. Concentrations of selected trace metals in slag samples, Hopewell Furnace National Historic Site, Pennsylvania.

[Samples were collected on October 28, 2008. Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada; ppm, parts per million; mm, millimeter; <, less than; --, too few data to compute statistic]

Sample identification number	Sample location	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (percent)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Vanadium (ppm)	Zinc (ppm)
					PILE 1–STOCKYARD						
HPWL-1-D1	slag from auger < 2 mm size	6	27	17	56.3	12.50	123	2,390	14.4	72	210
HPWL-1-D2	soil and slag mix from auger < 2 mm size	4	27	10.1	26	5.23	61.9	888	13.2	56	98
HPWL-1-C	surface composite	7	37	21.3	153	10.60	172	2,090	18.1	80	393
HPWL-1-S-a1	slag grab sample	<1	8	1.3	4	3.27	3	7,130	<0.5	134	39
HPWL-1-S-b	slag grab sample	<1	9	1	6.3	1.55	1.5	5,400	<0.5	80	6
HPWL-1-S-d	slag grab sample	12	10	13.3	169	8.72	3.3	3,950	8	60	4
HPWL-1-S-e2	slag grab sample	4	11	4.1	20.6	4.81	1.2	6,840	2.3	78	1
HPWL-1-S-f	slag grab sample	4	5	5.4	102	4.18	3	5,040	3.4	56	5
HPWL-1-S-g2	slag grab sample	<1	12	8.8	79.7	2.54	0.8	4,100	5.3	55	<1
HPWL-1-S-j2	slag grab sample	2	12	3.5	13.4	5.02	3.6	6,260	7.8	110	20
Mean		**[1]4.1**	**15.8**	**8.6**	**63.0**	**5.8**	**37.3**	**4,410**	**[1]7.3**	**78.1**	**[1]77.7**
Median		**4.0**	**11.5**	**7.1**	**41.2**	**4.9**	**3.2**	**4,570**	**6.6**	**75.0**	**13.0**
					PILE 2–SOUTH OF CAST HOUSE						
HPWL-2-D1	auger hole 1, from auger < 2 mm size	6	32	31.8	289	8.84	144	2,440	20.7	89	282
HPWL-2-D2	auger hole 2, from auger < 2 mm size	4	101	25.1	495	6.08	49.9	3,820	23.7	79	79
HPWL-2-D3	auger hole 3, from auger < 2 mm size	5	22	25.9	647	6.82	44.2	2,340	16.5	61	52
HPWL-2-S-A-a2	grab sample	<1	12	2.1	98.2	1.88	0.6	4,510	17.1	117	30
HPWL-2-S-A-c2	grab sample	<1	6	2.3	83.1	0.90	0.8	3,360	12	53	21
HPWL-2-S-A-e3	grab sample	<1	11	5.4	100	1.26	0.8	3,380	8	21	12
HPWL-2-S-A-f3	grab sample	2	39	13.1	85.6	2.46	2.2	3,150	13.2	137	10
HPWL-2-S-A-f3D	grab sample	2	38	11.1	69.7	2.35	3.2	2,770	10.7	127	9
HPWL-2-S-A-g2	grab sample	<1	8	1.9	19.4	0.68	4.5	4,180	1.1	35	3
HPWL-2-S-B-a2	grab sample	<1	4	4.7	282	1.21	3.5	2,540	7.2	28	3
HPWL-2-S-B-b2	grab sample	<1	7	8.9	300	2.04	0.8	3,180	7.1	33	2
HPWL-2-S-B-c2	grab sample	<1	5	2.3	64.2	0.79	0.7	2,800	1.5	34	2
HPWL-2-S-B-e4	grab sample	<1	9	1.3	65.3	1.24	<0.5	3,780	<0.5	102	2
Mean		**[1]1.8**	**22.6**	**10**	**200**	**2.8**	**21.3**	**3,250**	**[1]12**	**70.5**	**39.0**
Median		**<1**	**11**	**5.4**	**98.2**	**1.9**	**2.7**	**3,180**	**11**	**61.0**	**10.0**
					PILE 3–SOUTH OF ANTHRACITE FURNACE						
HPWL-3-S-a1	grab sample	<1	3	1.4	3.9	0.17	0.8	2,020	<0.5	18	3
HPWL-3-S-a3	grab sample	<1	3	1.4	2.7	0.17	0.6	1,450	<0.5	15	1
HPWL-3-S-a4	grab sample	<1	2	1.1	19	0.03	1.5	1,880	<0.5	3	6
HPWL-3-S-b	grab sample	3	6	5.3	90.8	1.58	1.3	2,030	7.4	21	2
Mean		**--**	**3.5**	**2.3**	**29.1**	**0.49**	**1.05**	**1,850**	**--**	**14.3**	**3**
Mean concentration for soil in Eastern U.S.[2]		**4.8**	**33**	**5.9**	**13**	**1.4**	**14**	**260**	**11**	**43**	**40**

[1] Less than values set to one-half the detection limit.

[2] From Shacklette and Boerngen (1984, p. 6).

irradiated in a wavelength dispersive X-ray spectrometer using a Rhodium X-ray tube. The mineralogy and geochemistry of the slag samples are described in a separate USGS report (N.M. Piatak and R.R. Seal, II, U.S. Geological Survey, written commun., 2011).

The large slag pile in the stockyard south of the barn (pile 1 on figure 6) makes up the left bank of French Creek and has little soil cover. The slag is representative of slag produced by Hopewell Furnace; however, the age of the slag is unknown. Slag samples were collected from the surface and from an auger hole (HPWL-1-D1 on figure 6) used to install a well for groundwater sampling.

The mean concentrations of arsenic, chromium, cobalt, and nickel in the slag samples from the stockyard pile (pile 1 on figure 6) were less than or just slightly higher than the mean soil concentrations for the eastern United States (table 3). The arsenic concentrations ranged from less than 1 to 12 ppm, and the mean was 4.1 ppm. The chromium concentrations ranged from 5 to 37 ppm, and the mean was 15.8 ppm. The cobalt concentrations ranged from 1 to 21.3 ppm, and the mean was 8.6 ppm. The nickel concentrations ranged from less than 0.5 to 18.1 ppm, and the mean was 7.3 ppm.

The mean concentrations of copper, lead, vanadium, and zinc in the slag samples from the stockyard pile 1 were higher than the mean soil concentrations for the eastern United States (table 3). The copper concentrations ranged from 4 to 169 ppm, and the mean was 63 ppm. The lead concentrations ranged from 0.8 to 172 ppm, and the mean was 37 ppm. The vanadium concentrations ranged from 55 to 134 ppm, and the mean was 78 ppm. The zinc concentrations ranged from less than 1 to 393 ppm, and the mean was 78 ppm.

The manganese and iron concentrations in the slag samples from the stockyard pile 1 were substantially higher than the mean soil concentration for the eastern United States (table 3). The iron concentrations ranged from 15,500 to 125,000 ppm (1.55 to 12.5 percent), and the mean was 58,000 ppm (5.8 percent). The manganese concentrations ranged from 888 to 7,130 ppm, and the mean was 4,410 ppm.

The slag in the pile south and west of the cast house (pile 2 on figure 6) was not produced at Hopewell Furnace but was brought in from another site for display to park visitors (Rebecca Ross, National Park Service, oral commun., 2008). A path used by park visitors runs along the top of the pile. Samples were collected from three auger holes drilled into the pile (sites HPWL-2-D1, HPWL-2-D2, and HPWL-2-D3 on figure 6) and from the surface of the pile. The mean concentrations of arsenic, chromium, cobalt, iron, lead, nickel, and zinc (table 3) were less than or just slightly higher than the mean soil concentrations for the eastern United States (table 4). Concentrations of vanadium were higher, and concentrations of copper and manganese were substantially higher than the mean soil concentrations for the eastern United States. The cast-house slag pile contained substantially more copper and less arsenic, iron, manganese, and zinc than the stockyard slag pile produced at Hopewell Furnace.

Table 4. Mean concentration and range for selected trace metals in soil in the eastern United States.

[From Shacklette and Boerngen (1984, p. 6); concentrations given in parts per million; <, less than; >, greater than]

Element	Mean concentration	Observed range
Aluminum	33,000	7,000–>100,000
Antimony	0.52	<1–8.8
Arsenic	4.8	<0.1–73
Barium	290	10–1,500
Beryllium	0.55	<1–7
Bromine	0.62	<0.5–53
Cerium	63	<150–300
Chromium	33	1–1,000
Cobalt	5.9	<0.3–70
Copper	13	<1–700
Gallium	9.3	<5–70
Iron	14,000	100–>100,000
Lanthanum	29	<30–200
Lead	14	<10–300
Lithium	17	<5–140
Manganese	260	<2–7,000
Mercury	0.081	0.01–3.4
Molybdenum	0.32	<3–15
Niobium	10	<10–50
Nickel	11	<5–700
Rubidium	43	<20–160
Scandium	6.5	<5–30
Selenium	0.3	<0.1–3.9
Strontium	53	<5–700
Thorium	7.7	2.2–23
Tin	0.86	<0.1–10
Titanium	2,800	70–15,000
Uranium	2.1	0.29–11
Vanadium	43	<7–300
Yttrium	20	<10–200
Zinc	40	<5–2,900
Zirconium	220	<20–2,000

The slag pile south of the anthracite furnace ruins (pile 3 on figure 6) may have been produced by the anthracite furnace experiment in 1849. Mean concentrations of all metals listed in table 3 were less than those of the stockyard slag pile. However, slag pile 3 had the greatest mean concentrations of beryllium, lithium, scandium, strontium, thorium, uranium, and yttrium of the three piles (appendix table C).

Soil

Three sets of soil samples were collected. (1) An initial set of soil samples was collected for laboratory analysis. (2) A second set of samples was collected and analyzed onsite with a portable XRF spectrometer at approximately 3-cm depth intervals. (3) On the basis of the results of the XRF analysis, a set of follow-up samples were collected for laboratory analysis.

Initial soil samples were collected from two sites downwind of the furnace (SOIL-1 and SOIL-2) and from a background site 3,400 ft northeast of the furnace (SOIL-3) (fig. 7). Downwind direction was determined from the wind rose for the Reading Regional Airport (Pennsylvania State University, 2009), which is approximately 16 mi northwest of Hopewell Furnace. The most frequent wind direction (resultant vector) is from 289 degrees resulting in a downwind direction of 109 degrees. One soil core to about 3 ft below land surface was collected at each site using a stainless steel core-sampling tube with a 1-in. diameter plastic sleeve. Bulk chemical composition of soil samples collected for this study analyzed in the laboratory (table 5 at end of report and appendix tables E and F) was determined using ICP-AES and ICP-MS. The samples were decomposed using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids at low temperature prior to analysis. Major oxide content was measured using WDXRF. The samples were fused with 50/50 lithium metaborate lithium tetraborate flux, and the resultant glass disk was irradiated in a wavelength dispersive X-ray spectrometer using a Rhodium X-ray tube. Selected trace metals in soil samples analyzed in the laboratory are summarized in table 5. Complete laboratory analyses are given in tables E and F in the appendix. Concentrations of metals regulated by the Pennsylvania Department of Environmental Protection (PaDEP) (table 6) were below standards for non-residential soil.

Additional soil samples were collected near the ore roaster, the ore pile, and on the south side of French Creek (SOIL-5, SOIL-6, SOIL-7, and SOIL-8 on figure 7). At each sample site, one soil core approximately 1 to 3 ft deep was collected using a stainless steel core-sampling tube with a 1-in. diameter plastic sleeve. Samples were analyzed onsite by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the USGS using a portable XRF spectrometer. The portable XRF spectrometer is accepted by the U.S. Environmental Protection Agency (USEPA) for screening purposes (U.S. Environmental Protection Agency, 2010a); it's use is described under USEPA method 6200 (U.S. Environmental Protection Agency, 2007). Complete analyses for samples analyzed by XRF are given in table G in the appendix, and selected constituents are summarized in table 7 (at end of report); these results should be considered screening-level results.

The field XRF analyses (table 7) indicated that the highest metal concentrations were in about the first foot (35 cm) of soil below the land surface. The concentrations of arsenic, chromium, copper, and lead with depth at soil sampling location SOIL-5 are shown on figure 8.

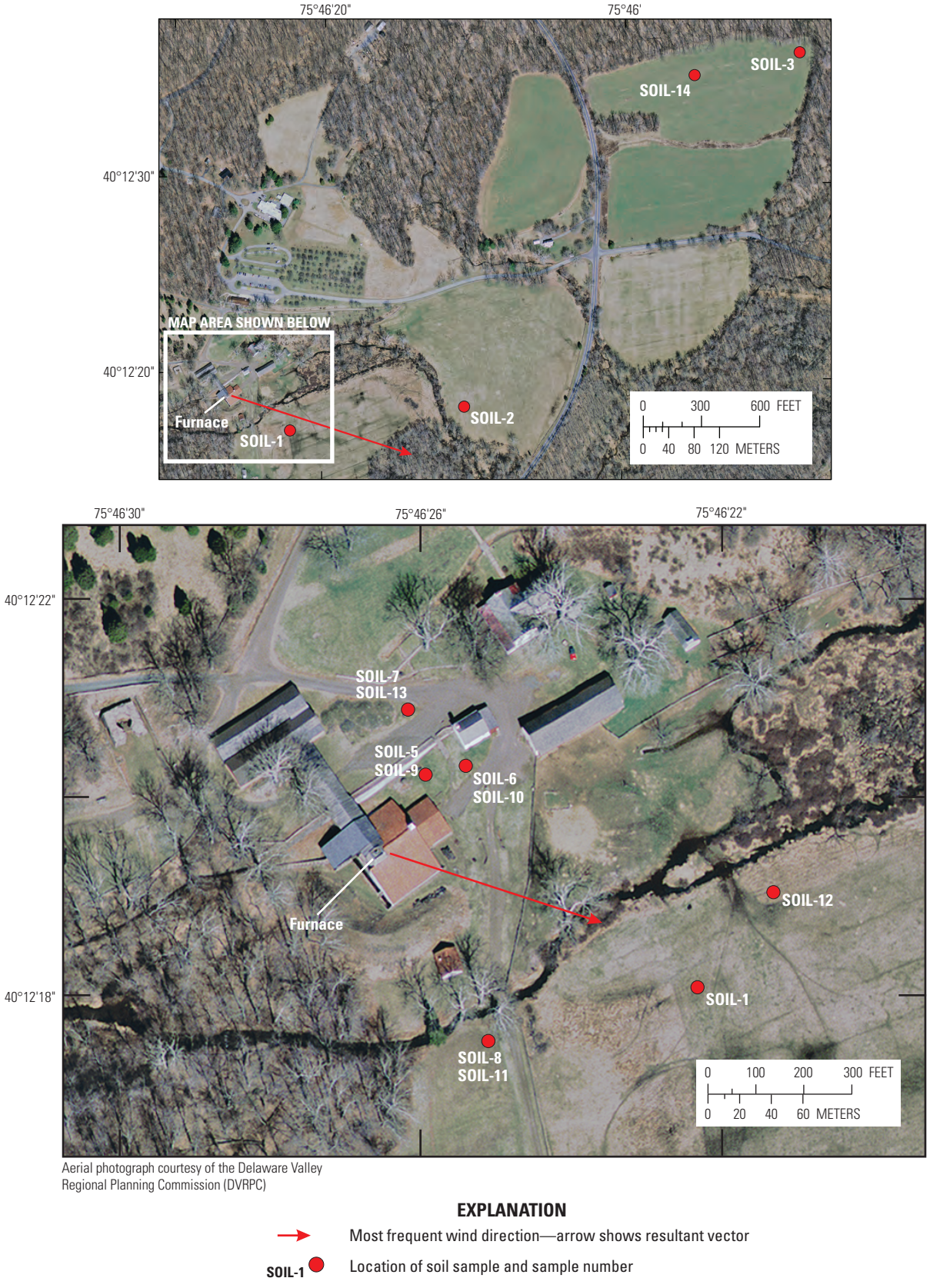
Table 6. Pennsylvania Department of Environmental Protection statewide health standards for soil.

[Standards from Pennsylvania Department of Environmental Protection (2011); concentrations given in parts per million; Concentrations represent direct contact values.]

Regulated constituent	Residential soil (0–15 feet)	Non-residential soil (0–2 feet)
Aluminum	190,000	190,000
Antimony	88	1,100
Arsenic	12	53
Barium and compounds	44,000	190,000
Beryllium	440	5,600
Boron and compounds	44,000	190,000
Cadmium	110	1,400
Chromium III	190,000	190,000
Chromium VI	660	8,400
Cobalt	66	840
Copper	8,100	100,000
Iron	150,000	190,000
Lead	500	1,000
Manganese	10,000	130,000
Mercury	35	450
Nickel	4,400	56,000
Selenium	1,100	14,000
Silver	1,100	14,000
Thallium	15	200
Tin	130,000	190,000
Vanadium	1,500	20,000
Zinc	66,000	190,000

Concentrations of metals regulated by the PaDEP (table 6) were below standards for non-residential soil except for three samples with elevated arsenic and seven samples with elevated iron concentrations from soil sampling location SOIL-5, which was near the ore roaster. Concentrations of arsenic in samples from 22.9 to 33 cm below land surface and concentrations of iron in samples from 15.2 to 35.6 cm below land surface exceeded the PaDEP standard (table 6). Ninety-five percent of arsenic concentrations were below the minimum detection limit. All concentrations of barium, chromium, cobalt, copper, iron, lead, manganese, mercury, and zinc (table G) were below the PaDEP standards for non-residential soil. Antimony, bromine, cadmium, gold, mercury, molybdenum, nickel, rubidium, selenium, silver, strontium, and tin were not detected or, if present, the concentrations were below the minimum reporting level.

Concentrations of cobalt ranged from not detected to 3,710 ppm with a median concentration of 345 ppm. Soil samples with the highest cobalt concentrations also had the highest iron concentrations. These elevated concentrations are likely the result of interference with high concentrations of iron, which were present in the samples. Three soil samples



Aerial photograph courtesy of the Delaware Valley Regional Planning Commission (DVRPC)

EXPLANATION

Most frequent wind direction—arrow shows resultant vector

SOIL-1 Location of soil sample and sample number

Figure 7. Locations of soil samples collected at Hopewell Furnace National Historic Site, Pennsylvania.

were split, with about two-thirds of the sample analyzed in the laboratory and one-third of the sample analyzed with the portable X-ray spectrometer. A comparison of sample results (table 8) shows that reported concentrations for cobalt were substantially higher and titanium concentrations were somewhat higher for the samples analyzed by XRF. Some differences in concentration may result from the different analytical techniques. For the laboratory analysis, the bulk of the sample was dissolved in acid and then analyzed. In contrast, concentrations measured by XRF may be strongly influenced by metals adsorbed onto the surface of soil particles. For the XRF analysis, the depth of penetration of X-rays depends on sample density and the source energy level. For example, the depth of penetration for cobalt is 0.07 mm at an energy level of 10 Kev and 2.9 mm at an energy level of 40 Kev.

On the basis of the results from the portable XRF spectrometer, follow-up soil samples for laboratory analysis for bulk chemical composition were collected from the same areas (SOIL-9, SOIL-10, SOIL-11, and SOIL-13 on figure 7) and two additional areas (SOIL-12 and SOIL-14 on figure 7). At each sample site, three to four cores approximately 1 ft deep were collected from an area about 6 in. in diameter using a stainless steel core-sampling tube with a 1-in. diameter plastic sleeve. The cores for each area were subdivided by depth and then composited for laboratory analysis. Complete analyses are given in tables E and F in the appendix. Selected trace metals in soil samples analyzed in the laboratory are summarized in table 5. Concentrations of all metals in soil samples analyzed in the laboratory were below PaDEP standards for non-residential soils (table 6).

Mean concentrations of arsenic, cobalt, manganese, nickel, and vanadium were similar in soil samples from the furnace area and samples from the background area. Concentrations of arsenic in soil near the furnace ranged from 3 to 9.2 ppm. The mean arsenic concentration was 5.4 ppm, which

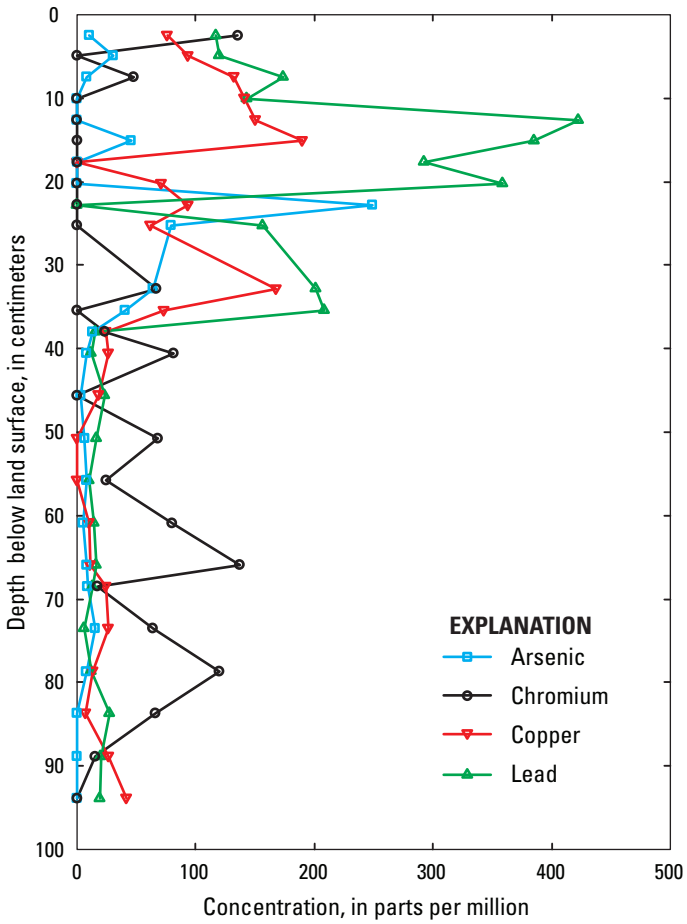


Figure 8. Vertical profile of arsenic, chromium, copper, and lead concentrations in soil at soil sampling site SOIL-5, Hopewell Furnace National Historic Site, Pennsylvania.

Table 8. Comparison of concentrations of selected trace metals in soils analyzed by inductively coupled plasma-atomic emission spectrometry and X-ray fluorescence spectroscopy, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada; XRF analyses by Michael Degnan of the U.S. Geological Survey; XRF, X-ray fluorescence spectrometer; ppm, parts per million; ND, below detection limit of instrument; >, greater than]

Sample-identification number	Number of XRF measurements	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Titanium (ppm)	Zinc (ppm)
SOIL-9_17-22											
XRF median	18	ND	ND	2,990	ND	549,000	430	4,790	ND	6,300	860
Laboratory		10	11	45.6	115	>150,000	558	2,560	53.4	1,800	562
SOIL-9_22-28											
XRF median	22	ND	ND	2,520	127	326,000	231	2,840	ND	7,500	489
Laboratory		10	15	38	139	>150,000	310	1,990	47	1,700	415
SOIL-10_0-7											
XRF median	13	ND	ND	1,020	68	113,000	154	2,420	ND	5,300	338
Laboratory		6	203	17	55	120,000	194	2,270	45	2,200	316

was similar to the mean concentration of soil (5.4 ppm) in the background area and the mean eastern United States soil concentration (4.8 ppm). Concentrations of cobalt in soil near the furnace ranged from 3.7 to 45.6 ppm. The mean cobalt concentration was 16.3 ppm, which was similar to the mean concentration of soil (13.9 ppm) in the background area and slightly higher than the mean eastern United States soil concentration (5.9 ppm). Concentrations of manganese in soil near the furnace ranged from 109 to 2,700 ppm. The mean manganese concentration was 1,170 ppm, which was similar to the mean concentration of soil (1,533 ppm) in the background area and substantially higher than the mean eastern United States soil concentration (260 ppm). Concentrations of nickel in soil near the furnace ranged from 10.5 to 53.8 ppm. The mean concentration was 28 ppm, which was similar to the mean concentration of soil (23 ppm) in the background area and slightly higher than the mean eastern United States soil concentration (11 ppm). Concentrations of vanadium in soil near the furnace ranged from 43 to 182 ppm. The mean concentration was 80.3 ppm, which was similar to the mean concentration of soil (75.4 ppm) in the background area and higher than the mean eastern United States soil concentration (43 ppm).

Mean concentrations of chromium, copper, and iron were higher in soil samples from the furnace area and samples from the background area. Concentrations of chromium in soil near the furnace ranged from 11 to 239 ppm. The mean concentration was 48.8 ppm, which was higher than the mean concentration of soil (13.9 ppm) in the background area and the mean eastern United States soil concentration (5.9 ppm). Concentrations of copper in soil near the furnace ranged from 13.1 to 139 ppm. The mean concentration was 55.1 ppm, which was higher than the mean concentration of soil (23.4 ppm) in the background area and the mean eastern United States soil concentration (13 ppm). Concentrations of iron near the furnace ranged from 1.52 to greater than 15 percent. The mean concentration was 5.8 percent, which was higher than the mean concentration of soil (2.9 percent) in the background area and the mean eastern United States soil concentration (1 percent).

Mean concentrations of lead and zinc were substantially higher in soil samples from the furnace area. Concentrations of lead in soil near the furnace ranged from 8.8 to 646 ppm. The mean concentration was 125 ppm, which was substantially higher than the mean concentration of soil (22 ppm) in the background area and the mean eastern United States soil concentration (14 ppm). Concentrations of zinc in soil near the furnace ranged from 23 to 562 ppm. The mean concentration was 159 ppm, which was substantially higher than the mean concentration of soil (55.8 ppm) in the background area and the mean eastern United States soil concentration (40 ppm).

Cast Iron Furnace Products

The trace-metal concentrations of cast iron furnace products produced at Hopewell Furnace were analyzed by Martin Helmke of West Chester University using a portable XRF spectrometer. The XRF spectrometer was used because it could perform onsite, non-destructive, real-time analysis. The artifacts analyzed, which are on display in the Hopewell NHS museum, included eight cast iron stoves, a footed pot, and a kettle (fig. 9). In addition, a stove cast at the Rock Furnace in Lancaster County was analyzed. Complete analyses are given in table H in the appendix. Concentrations of selected trace metals are summarized in table 9.

Each stove was sampled three times on the ash lip and three times on the top. Mean concentrations are presented in table 9. For the statistics in table 9, zero was used for non-detection. Nickel was not detected in any sample. The mean arsenic concentration for stoves cast at Hopewell Furnace was 499 ppm, the mean cobalt concentration was 11,500 ppm, the mean copper concentration was 2,000 ppm, the mean lead concentration was 588 ppm, and the mean zinc concentration was 1,280 ppm (table 9). Elevated concentrations of cobalt are likely caused by interference from iron. Most concentrations of manganese were non-detect or below the detection limit. All concentrations of antimony, barium, chromium, mercury, silver, tin, and titanium were non-detect or below the detection limit. The stoves contained a mean concentration of 270 ppm gold. Gold was reported in ore samples from Cornwall-type iron deposits by Smith and others (1988, p. 330) (table 1). The stove cast at Rock Furnace had no detectable copper, less cobalt and zinc, about the same arsenic and lead concentration, and substantially more manganese than the stoves cast at Hopewell Furnace.

Groundwater

Hopewell Furnace NHS uses one well as the sole source of water supply for park visitors, employees, and residents. The well is 150 ft deep and cased to 65 ft below land surface. It is approximately 2,500 ft topographically upgradient from the furnace and slag piles. An unfiltered water sample was collected from the well for field (pH, acid neutralizing capacity, specific conductance, dissolved oxygen, and water temperature) and laboratory analysis. Field meters used for water-chemistry measurements were calibrated daily using certified standards and buffers. Field-meter log books were kept with the meters to record calibration and performance information. Thermistors in the field instruments were checked against a National Institute of Standards and Technology certified thermometer (U.S. Geological Survey, 1997 to present). Groundwater samples were analyzed for nutrients, major ions, and metals at the USGS laboratory in Denver, Colo. Complete field and laboratory analyses are given in table I in the appendix, and selected constituents are summarized in table 10. The water from the supply well had a near neutral pH (7.2) and was low in dissolved solids (specific conductance of 209 µS/cm). The well-water sample met all applicable USEPA drinking-water standards (table 11).

A temporary well was installed in slag pile 1 south of the barn at location HPWL-1-D1 on figure 6 using a

Figure 9. Cast iron artifacts in the Hopewell National Historic Site museum sampled for trace-metal concentrations using portable X-ray fluorescence spectroscopy.

Table 9. Mean concentrations of selected trace metals analyzed by X-ray fluorescence spectroscopy in cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University; ppm, parts per million; <, less than; >, greater than; ND, not detected; E, mean uses some estimated data]

Artifact	Arsenic, mean (ppm)	Chromium (ppm)	Cobalt, mean (ppm)	Copper, mean (ppm)	Gold, mean (ppm)	Iron (ppm)	Lead, mean (ppm)	Manganese, mean (ppm)	Nickel (ppm)	Zinc, mean (ppm)
Stove 1	408	[1]58 E	13,000	1,750	261	>900,000	695	ND	ND	1,960
Stove 2	1,030	ND	14,400	2,660	219	>900,000	2,290	[1]658 E	ND	1,550
Stove 3	470	ND	11,000	3,730	341	>900,000	[1]220 E	ND	ND	490
Stove 5	331	[1]183 E	9,650	1,560	267	>900,000	[1]6 E	2,270 E	ND	544
Stove 6	509	<1 E	10,600	[1]114 E	143	>900,000	1,220	[1]1,440 E	ND	1,020
Stove 7	562	ND	9,540	2,300	317	>900,000	252	3,680 E	ND	1,050
Stove 8	327	[1]269 E	11,200	2,610	255	>900,000	[1]525 E	[1]725 E	ND	3,180
Stove 9	353	ND	12,900	1,300	312	>900,000	[1]29 E	[1]448 E	ND	432
Mean for Hopewell stoves	**499**	**[1]64 E**	**11,500**	**[1]2,000 E**	**264**	**>900,000**	**[1]588 E**	**[1]1,320 E**	**ND**	**1,280**
[2]Stove 4	636	[1]116 E	8,000 E	ND	303	>900,000	496	5440 E	ND	859
Footed pot	999	ND	[1]3,180 E	ND	289	>900,000	3,020	[1]1,590 E	ND	1,160
Kettle	ND	ND	ND	ND	282	>900,000	492	5,600	ND	810

[1]Not detected set to zero.

[2]Stove cast at Rock Furnace in Lancaster County.

Table 10. Chemical analysis results for selected constituents in groundwater, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by USGS National Water Quality Laboratory, Denver, Colo.; USGS, U.S. Geological Survey; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated concentration; --, no drinking-water standard]

Well and USGS identifier	Depth of well (feet)	pH (units)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen (mg/L)	Sulfate, dissolved (mg/L)	Aluminum, total (µg/L)	Arsenic, total (µg/L)
Supply well BE-523	150	7.2	209	6.7	8.74	24	3.4
Slag pile well BE-1784	13	7.0	87	9.6	3.19	570	0.8
Drinking-water standard[1]		6.5–8.5	--	--	250	50–200	10

Well and USGS identifier	Chromium, total (µg/L)	Cobalt, total (µg/L)	Copper, total (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Manganese, total (µg/L)	Nickel, total (µg/L)	Zinc, total (µg/L)
Supply well BE-523	0.73	<0.1	<4	32	0.35	0.9	0.3	6.1
Slag pile well BE-1784	1.2	3.9	3.4 E	1,740	13.7	2,430	2.5	11.6
Drinking-water standard[1]	100	--	1,000	300	15	50	--	5,000

[1]From U.S. Environmental Protection Agency (2009).

Table 11. U.S. Environmental Protection Agency maximum contaminant, secondary contaminant, and action levels for constituents in drinking water.

[From U.S. Environmental Protection Agency (2009); --, no standard]

Regulated constituent	Maximum contaminant level (micrograms per liter)	Action level[1] (micrograms per liter)	Secondary maximum contaminant level (milligrams per liter)
Aluminum	--	--	0.050–0.2
Antimony	6	--	--
Arsenic	10	--	--
Barium	2,000	--	--
Beryllium	4	--	--
Cadmium	5	--	--
Chromium, total	100	--	--
Chloride	--	--	250
Copper	--	1,300	1
Iron	--	--	0.3
Lead	--	15	--
Manganese	--	--	0.05
Mercury	2	--	--
Nitrate as N	10,000	--	--
Nitrite	1,000	--	--
Selenium	50	--	--
Silver	--	--	0.1
Sulfate	--	--	250
Thallium	2	--	--
Total dissolved solids	--	--	500
Uranium	30	--	--
Zinc	--	--	5

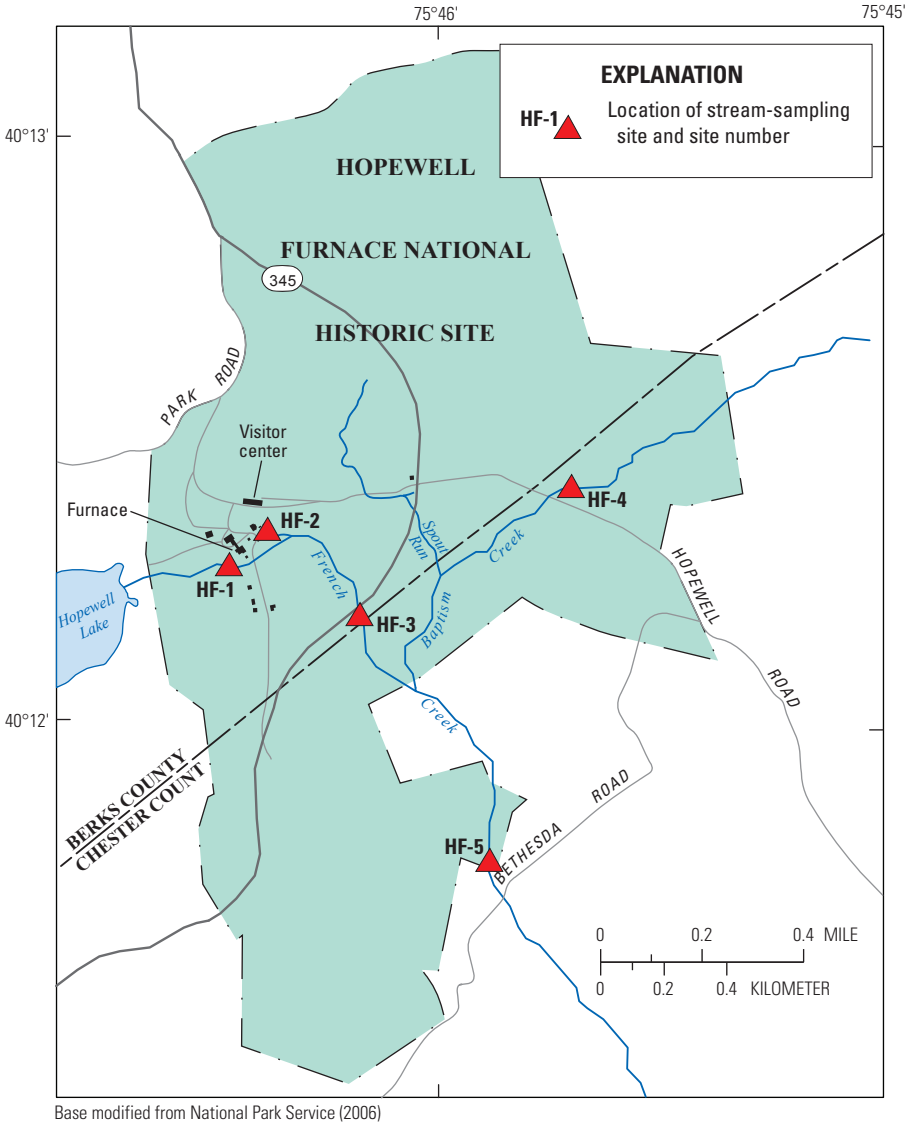
[1] Lead and copper are regulated by a treatment technique that requires water purveyors to control the corrosiveness of their water. If more than 10 percent of tap water samples exceed the action level, the water purveyor must take additional steps.

backhoe-mounted auger. The well was 13 ft deep and extended about 1.5 ft below the bottom of the slag pile. A 2-in. diameter well screen and casing were installed. The well was sampled for field and laboratory chemical analysis. Following sampling, the screen and casing were removed, and the hole was backfilled. Complete field and laboratory analyses are given in table I in the appendix, and selected constituents are summarized in table 10. The water from the slag-pile well had neutral pH (7.0) and was very low in dissolved solids (specific conductance of 87 µS/cm). The water sample contained elevated concentrations of aluminum, iron, and manganese relative to the supply well. Elevated concentrations of these metals may be caused by suspended sediment in the water sample or they may indicate that these metals may be leaching from the slag into the groundwater. The results of leaching experiments on the slag samples are described in a separate USGS report (N.M. Piatak and R.R. Seal, II, U.S. Geological Survey, written commun., 2011).

Stream Sites

Five stream sites (fig. 10) were sampled during base-flow conditions between November 10 and November 14, 2008, to determine if trace-metal or other contamination from the slag piles at Hopewell Furnace was affecting the water quality in French Creek. One site on Baptism Creek (site HF-4) was sampled to indicate background conditions, one site on French Creek (site HF-1) was sampled upstream from Hopewell Furnace, and three sites on French Creek (sites HF-2, HF-3, and HF-5) were sampled downstream from Hopewell Furnace. Samples of water, streambed sediment, and benthic macroinvertebrates were collected and analyzed. An instream habitat assessment was conducted at all sampling locations.

Site HF-1 is on French Creek upstream from the slag piles (fig. 10); much of the flow at this site is from Hopewell Lake, which is upstream from the site (fig. 11). Hopewell Lake is a 62-acre recreational impoundment with a 25-ft high dam



Base modified from National Park Service (2006)

Figure 10. Stream sampling locations at Hopewell Furnace National Historic Site, Pennsylvania.

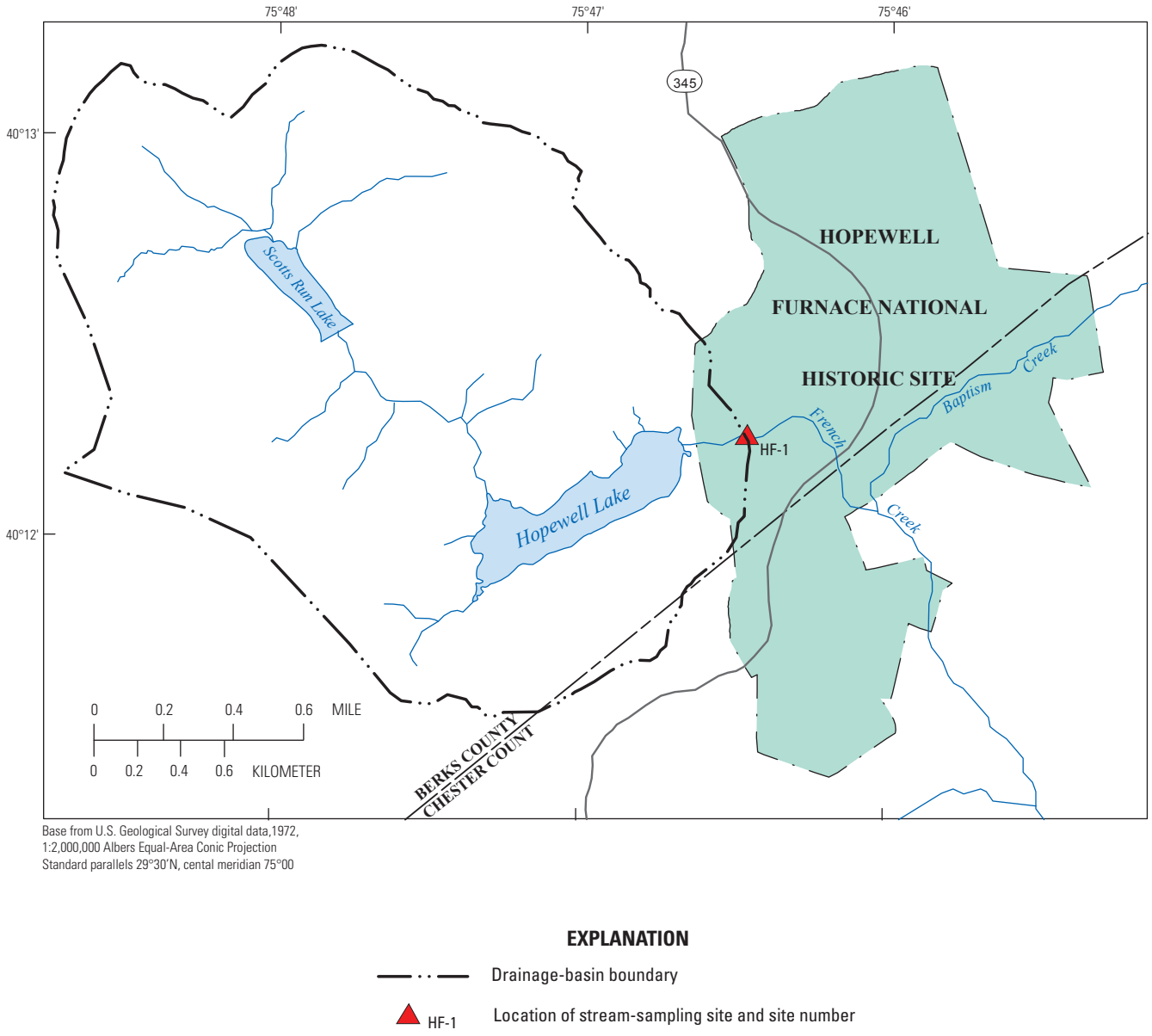


Figure 11. Drainage basin upstream from site HF-1, Hopewell Furnace National Historic Site, Pennsylvania.

in French Creek State Park. The drainage area above Hopewell Lake is 2.5 mi^2. The Commonwealth of Pennsylvania classifies Hopewell Lake as a warm-water fishery. Ninety percent of the Hopewell Lake watershed is forested. Scotts Run Lake is upstream from Hopewell Lake. Scotts Run Lake is a 22-acre recreational impoundment in French Creek State Park with a drainage area of 1 mi^2. The Commonwealth of Pennsylvania classifies Scotts Run Lake as a cold-water fishery.

Site HF-2 is at the downstream end of the tailrace below the furnace water wheel. Water flows underground from the cast house to a point southeast of the barn where it becomes a small tributary to French Creek. The source of water for the millrace is French Creek upstream from the furnace. Streamflow at site HF-2 likely contains some groundwater discharging from the area of slag pile 1. Site HF-3 is on French Creek just upstream from its confluence with Baptism Creek. Site HF-4 is the background site on Baptism Creek. Site HF-5 is on French Creek at the downstream park boundary.

Stream Base Flow

Surface-water samples were collected at the five stream sites (fig. 10) at base flow when the streamflow was composed of groundwater discharge. However, much of the flow at site HF-1 is outflow from Hopewell Lake. Complete chemical analyses are given in table J in the appendix, and selected constituents, loads, and yields are summarized in table 12. Samples were collected using standard USGS field collection procedures (U.S. Geological Survey, 1997 to present). All stream reaches were sampled at three locations in the stream cross section by a narrow-mouthed polyethylene bottle placed in the stream (U.S. Geological Survey, 1997 to present). Stream cross-section subsamples were composited in a churn splitter before being processed into bottles for shipment to the USGS laboratory for analysis. Stream discharge and field water-quality characteristics pH, specific conductance, dissolved oxygen, and water temperature were measured with each sample collected. Methods for field measurements were the same as described for groundwater samples. Samples were analyzed for nutrients, major ions, and metals at the USGS laboratory in Denver, Colo. One equipment blank was collected during the sampling period to evaluate potential bias due to contamination. The field blank was processed at a field site by pouring inorganic blank water into the sampling containers and processing it through normal procedures. The blank sample was analyzed for the same constituents as the streamflow samples. All constituents in the blank sample were below the method detection limits, indicating that no bias due to contamination had occurred.

The analytical results (table 12 and appendix table J) indicate low values of specific conductance along with typical pH values and concentrations of dissolved oxygen near equilibrium with air. Although measured water temperatures were normal for November, the presence of the Hopewell Lake outfall could increase the water temperature downstream from the lake during the summer. Hopewell Lake is a top release lake. During the summer, the temperature of the water at the surface of the lake that is released may be warmer than the background stream water. Low concentrations of dissolved oxygen in the warm water can be stressful to fish and benthic-macroinvertebrate communities. Additional monitoring during the summer months would be needed to evaluate the effects of discharge from the Hopewell Lake outfall on the temperature of French Creek.

The base-flow water samples indicated good overall base-flow surface-water quality. The five sampled sites generally had low concentrations of nutrients and major ions but had elevated concentrations of iron, manganese, and strontium when compared to sites sampled from the adjacent Pickering and Pigeon Creek watersheds (U.S. Geological Survey, 2009). Background site HF-4 generally had the lowest concentrations and yields of constituents. Although the concentrations at the other four sites were higher, all stream-water samples met drinking-water (table 11) and aquatic-life criteria (table 13). Low concentrations of nutrients and major ions at all five sites indicate that measured concentrations can be attributed to general land use and geology and not to point sources. Concentrations of ammonia at sites HF-1 and HF-2 were greater than at background site HF-4, but concentrations decreased to the background concentration at downstream sites HF-3 and HF-5.

Aquatic-life criteria were established to identify concentrations of constituents that may pose a threat to aquatic organisms (U.S. Environmental Protection Agency, 2010b). The criteria categories include criteria maximum concentration (CMC) and criteria continuous concentration (CCC). The CMC is an estimate of the highest concentration of a constituent in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The CCC is an estimate of the highest concentration of a constituent in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. Aquatic-life criteria were created for aluminum, arsenic, cadmium, chromium, iron, lead, nickel, selenium, silver, and zinc. No metal concentrations measured at the five sites exceeded the CMC or CCC (table 13).

The highest concentration of arsenic was measured at site HF-1 (0.39 µg/L). However, arsenic concentrations were similar for all sites with a range of 0.26 to 0.39 µg/L. The highest concentrations of cobalt, iron, lead, manganese, strontium, and zinc were measured immediately downstream from Hopewell Furnace at sites HF-2 and HF-3. Although the highest concentrations of aluminum and nickel were measured at background site HF-4, the highest yields of these metals were measured at site HF-1 (table 12). Beryllium, cobalt, lithium, molybdenum, selenium, and uranium were detected at low concentrations. Antimony, cadmium, chromium, copper, silver, and thallium were not detected in any sample (table 12 and appendix table J).

Although the highest concentrations of metals were at sites close to Hopewell Furnace, the samples collected above Hopewell Furnace at site HF-1 and at the most downstream site HF-5 also had concentrations of metals that were higher

Table 12. Chemical analysis results and estimated loads and yields for selected trace metals in surface-water base-flow samples, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by U.S. Geological Survey National Water Quality Laboratory, Denver, Colo.; mi^2, square miles; --, no data; <, less than; E, estimated concentration]

Site number	Station number	Date sampled	Flow (cubic feet per second)	Drainage area (mi^2)	Aluminum, total			Arsenic, total		
					Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)	Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)
HF-1	014721245	11/14/2008	1.4	2.57	29	99.5	38.7	0.39	1.34	0.52
HF-3	014721253	11/12/2008	1.4	2.83	17	58.3	20.6	0.32	1.10	0.39
HF-5	014721265	11/10/2008	2.7	5.25	23	152	29.0	0.31	2.05	0.39
HF-4	014721259	11/10/2008	0.30	1.67	37	27.2	16.3	0.26	0.19	0.11
HF-2	0147212511	11/12/2008	0.27	--	36	23.8	--	0.36	0.24	--

Site number	Station number	Cobalt, total			Iron, total			Lead, total		
		Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)	Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)	Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)
HF-1	014721245	0.05 E	0.17 E	0.07 E	162	556	216	0.20	0.69	0.27
HF-3	014721253	0.10	0.34	0.12	196	672	238	0.23	0.79	0.28
HF-5	014721265	0.12	0.79	0.15	257	1,700	324	0.15	0.99	0.19
HF-4	014721259	0.05 E	0.04 E	0.02 E	78	57.3	34.3	0.24	0.18	0.11
HF-2	0147212511	0.20	0.13	--	346	229	--	0.61	0.40	--

Site number	Station number	Manganese, total			Nickel, total			Zinc, total		
		Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)	Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)	Concentration (micrograms per liter)	Load (grams per day)	Yield (grams per day per mi^2)
HF-1	014721245	41	141	54.7	0.43	1.5	0.57	1.0 E	3.43 E	1.33 E
HF-3	014721253	47.7	164	58.2	0.35	1.2	0.42	5.5	18.9	6.67
HF-5	014721265	51.4	336	64.3	0.41	2.7	0.52	1.4 E	9.26 E	1.76 E
HF-4	014721259	8.4	6.17	3.7	0.60	0.4	0.26	1.6 E	1.18 E	0.70 E
HF-2	0147212511	50.8	34	--	0.39	0.3	--	1.2 E	0.79 E	--

Site number	Station number	Chromium, total concentration (micrograms per liter)	Copper, total concentration (micrograms per liter)
HF-1	014721245	<0.4	<4
HF-3	014721253	<0.4	<4
HF-5	014721265	<0.4	<4
HF-4	014721259	<0.4	<4
HF-2	0147212511	<0.4	<4

Table 13. Comparison of published criteria maximum and continuous concentrations to measured maximum concentrations of selected trace metals in stream sediment at Hopewell Furnace National Historic Site, Pennsylvania.

[From U.S. Environmental Protection Agency (2010b); concentrations given in micrograms per gram; --, no data; <, less than]

Element	Criteria maximum concentration	Criterion continuous concentration	Maximum concentration at sampled sites	Maximum concentration site location
Aluminum	750	87	37	HF-4
Arsenic	340	150	0.39	HF-1
Cadmium	2	0.25	<0.06	All sites
Chromium (VI)	16	11	<0.04	All sites
Iron	--	1,000	346	HF-2
Lead	65	2.5	0.61	HF-2
Nickel	470	52	0.6	HF-4
Selenium	--	5	0.14	HF-2
Silver	3.2	--	<0.06	All sites
Zinc	120	120	5.5	HF-3

than background site HF-4. This indicates that the source of the metals is not limited to the area immediately around the Hopewell Furnace slag piles.

USGS has two historical sampling sites near Hopewell Furnace NHS, site 01472126 (French Creek near Trythall, Pa.) and site 01472124 (Hopewell Lake at Hopewell, Pa.). Neither site is currently active. Site 01472124 was sampled twice in 2005 for field determinations, selected nutrients, and selected inorganic constituents. Site 01472126, which is downstream from the park boundary, was sampled annually from 1971 to 1982 and in 2000 for field determinations, nutrients, inorganic constituents, and selected trace constituents. Constituents analyzed and detection limits varied from year to year. Results from these historic samples indicate that concentrations of nutrients, ions, and metals measured prior to 1982 were higher than concentrations measured after 1982 (Moore, 1989; Reif, 1999).

Streambed Sediment

Streambed-sediment samples were collected at the five stream sites (fig. 10) concurrent with the water samples. At each site, samples were collected from depositional areas within the 100-m stream reach selected for macroinvertebrate sampling. An effort was made to collect the most fine-grained streambed sediments available at each site. Samples were collected manually from the top 6 in. of sediment using a polyethylene scoop and were sieved through a 2-mm polyethylene sieve with native water to remove gravel. Sand, silt, and clay-sized particles that passed through the sieve were collected in a polyethylene basin, homogenized, transferred into glass jars, and kept on ice for shipment to the laboratory. All equipment was washed between each sample with soap, 5 percent hydrochloric acid, and a deionized water rinse. All equipment was then rinsed in native water prior to sampling. Samples were analyzed for metals at the USGS laboratory in Denver, Colo. Samples were analyzed by collision/reaction cell inductively coupled plasma-mass spectrometry (cICP/MS) following digestion in acid. Complete analyses are given in table 14.

Sediment-quality guidelines have been established to identify environmental conditions that may pose a threat to aquatic resources (MacDonald and others, 2000). Concentrations below the probable effects concentration (PEC) are unlikely to cause adverse effects in aquatic communities. Harmful effects in aquatic communities are likely to be observed when concentrations above the PEC are measured. Sediment guidelines have been created for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. The concentration of copper at site HF-3 was the only metal concentration measured above the PEC (table 15).

PECs have not been established in the United States for aluminum, iron, and manganese. Concentrations of aluminum in streambed-sediment samples from Hopewell Furnace NHS sites are higher and concentrations of iron and manganese are about the same as concentrations in samples from streams in Berks and Chester Counties. The concentrations of aluminum in streambed-sediment samples from Hopewell Furnace NHS sites ranged from 5,700 to 33,500 µg/g, and the mean was 14,600 µg/g. The range of aluminum concentrations for six samples collected in Berks and Chester Counties during 1972–2000 was 6,800 to 8,700 µg/g, and the mean was 7,900 µg/g (USGS National Water Information System data retrieval made on July 26, 2010). The concentrations of iron in streambed-sediment samples from Hopewell Furnace NHS sites ranged from 7,140 to 44,900 µg/g, and the mean was

Table 14. Chemical analysis results for trace metals in streambed sediment samples, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by U.S. Geological Survey National Water Quality Laboratory, Denver, Colo.; concentrations given in micrograms per gram; <, less than; --, no standard]

Site number	Station number	Date sampled	Aluminum	Arsenic	Boron	Cadmium	Chromium	Cobalt
HF-1	014721245	11/14/2008	34,000	7.5	<5.4	0.54	34	13.6
HF-2	0147212511	11/12/2008	12,000	3.3	8.8	0.22	60	6
HF-3	014721253	11/12/2008	16,000	8	41	0.38	19	19.8
HF-4	014721259	11/10/2008	5,700	1.5	3.8	0.14	6.3	3.3
HF-5	014721265	11/10/2008	6,200	1.9	<5.4	0.14	6.5	4.2
Probable effects concentration[1]			--	33	--	4.98	111	--

Site number	Station number	Copper	Iron	Lead	Manganese	Mercury	Nickel	Zinc
HF-1	014721245	31	34,000	56	890	0.071	28.5	150
HF-2	0147212511	37	31,000	57	730	0.032	9.9	120
HF-3	014721253	190	45,000	86	2,300	0.126	22.4	160
HF-4	014721259	7	7,100	9	210	0.017	6.1	32
HF-5	014721265	19	11,000	20	330	0.031	5.9	46
Probable effects concentration[1]		149	--	128	--	1.06	48.6	459

[1] MacDonald and others (2000).

Table 15. Comparison of published probable effects concentrations and measured maximum concentrations of selected trace metals in streambed sediment at Hopewell Furnace National Historic Site, Pennsylvania.

[Guidelines from MacDonald and others (2000); concentrations given in micrograms per gram]

Element	Probable effects concentration	Maximum measured concentration	Maximum concentration site location
Arsenic	33	7.5	HF-1
Cadmium	4.98	0.54	HF-1
Chromium	111	59.7	HF-2
Copper	149	190	HF-3
Lead	128	86.1	HF-3
Mercury	1.06	0.13	HF-3
Nickel	48.6	28.5	HF-1
Zinc	459	155	HF-3

14,200 µg/g. The range of iron concentrations for 61 samples collected in Berks and Chester Counties during 1972–2000 was 30 to 40,000 µg/g, and the mean was 13,300 µg/g (USGS National Water Information System data retrieval made on July 26, 2010). The concentrations of manganese in streambed-sediment samples from Hopewell Furnace NHS sites ranged from 206 to 2,270 µg/g, and the mean was 883 µg/g. The range of manganese concentrations for 60 samples collected in Berks and Chester Counties during 1972–2000 was 53 to 1,900 µg/g; the mean was 539 µg/g (USGS National Water Information System data retrieval made on July 26, 2010).

Although concentrations of metals in streambed sediment detected at the five sampling sites were below the PEC except for copper at site HF-3 (table 15), background site HF-4 on Baptism Creek had lower concentrations of metals than the other four sites, except for nickel, which was lower at site HF-5. Concentrations of aluminum, cadmium, and nickel were highest at site HF-1 and generally decreased in concentration downstream. This indicates the source of these metals is upstream from site HF-1 and may be related to discharge from Hopewell Lake. Oxidizing conditions or elevated pH could promote the formation of iron oxide and aluminum oxide coatings and adsorption of metals, effectively concentrating these constituents locally. The concentration of chromium was highest in sediment from site HF-2. The highest concentrations of arsenic, boron, cobalt, copper, iron, lead, manganese, mercury, and zinc were detected at site HF-3 below Hopewell Furnace. This indicates that the source of these metals may be in Hopewell Furnace NHS between sites HF-1 and HF-3.

Benthic Macroinvertebrates

Benthic-macroinvertebrate samples were collected at the five stream sites (fig. 10) concurrent with the water and sediment samples. Benthic-macroinvertebrate samples were collected following the USEPA Rapid Bioassessment Protocols (RBP) (Barbour and others, 1999). The samples were collected using a 500-micron D-frame net. Three 1-m^2 kick samples were collected at each site within a 100-m reach and composited. The samples were sieved and rinsed using a Standard No. 30 sieve to remove fine sediments. The samples were preserved with 95-percent ethanol in the field and returned to the laboratory for sorting and identification.

In the laboratory, composited samples were subsampled (300 organisms) using methods described in the USEPA RBP methodology (Barbour and others, 1999). All sorted organisms were identified to the lowest practical taxonomic level (genus) except for midge larve (chironomidae) and worms (oligocheatae), which were identified to the family level. Complete counts are given in table K in the appendix and summarized in table 16. In addition to benthic-macroinvertebrate identifications, biometric indices ("metrics") were calculated for each 300-organism sample. Many of the metrics rely on pollution tolerance values (PTV) that are assigned to each organism on the basis of its ability to survive in degraded environments. PTVs range from 0 (pollution sensitive) to 10 (pollution tolerant).

Calculated metrics include:

1. Total Taxa Richness, which is a measurement of the total number of taxa (taxonomic distinct organism) present. Higher taxa richness generally reflects a healthier macroinvertebrate community.

2. Ephemeroptera, Plecoptera, Trichoptera (EPT) Taxa Richness, which is a count of the number of taxa belonging to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Only EPT taxa with PTVs between 0 and 4 are counted. EPT taxa richness generally decreases with increasing ecosystem stress because of the loss of these pollution-sensitive taxa.

3. Hilsenhoff Biotic Index (HBI), which summarizes the overall pollution tolerance of the benthic-macroinverte-

Table 16. Biometrics for benthic macroinvertebrates sampled at Hopewell Furnace National Historic Site, Pennsylvania.

[300 organism subsamples; HBI, Hilsenhoff's biotic index; EPT, Ephemeroptera, Plecoptera, and Trichoptera; PTV, pollution tolerant value]

Station number	014721245	0147212511	0147212511	014721253	014721259	014721265
Site number	HF-1	HF-2	HF-2 replicate	HF-3	HF-4	HF-5
Date sampled	11/14/08	11/12/08	11/12/08	11/12/08	11/10/08	11/10/08
Grids	8	9	10	10	12	28
Total count	317	336	303	302	330	93
Total Taxa Richness	21	26	30	25	33	19
EPT Taxa Richness (0–4 PTV)	3	3	4	8	17	5
HBI	5.27	5.85	5.97	5.46	4.05	5.26
Beck's Index	1	0	6	5	19	6
Shannon Diversity	1.6	1.9	1.8	2.0	2.3	2.3
Percent Sensitive Individuals (0–3 PTV)	21.77	8.93	4.95	14.9	46.67	24.73

brate community. The range of values is from 0 to 10; values generally increase with increasing ecosystem stress, reflecting increased dominance of pollution-tolerant organisms.

4. Beck's Index (version 3), which is a weighted count of taxa with PTVs of 0, 1, or 2. Values will generally decrease with increasing ecosystem stress because of the loss of pollution-sensitive taxa.

5. Percent Sensitive Individuals (PTV = 0 to 3), which is a community composition and tolerance metric that is based on the percentage of individuals with PTVs between 0 and 3. This metric will generally decrease with increasing ecosystem stress because of the loss of pollution-sensitive taxa.

6. Shannon Diversity, which is a community-composition metric that measures taxonomic richness and evenness of individuals across taxa. This metric will generally decrease with increasing ecosystem stress because of the loss of pollution-sensitive taxa and increasing dominance of a few pollution-tolerant taxa.

Quality control for the benthic-macroinvertebrate samples involved the processing of a replicate subsample from the sample collected at site HF-2. The replicate invertebrate sample indicated that most of the biological metrics for the sample were within 15 percent of the original sample with the exception of percent sensitive individuals and Beck's index. This was due to the presence in the replicate sample of a few individuals with low pollution tolerance values. The difference between the replicate and original sample does not alter the overall assessment of the site and is consistent with the natural variability of biological samples and sample processing.

The benthic-macroinvertebrate communities at the French Creek sites (HF-1, HF-2, HF-3, and HF-5) were similar to each other but differed greatly from the benthic-macroinvertebrate community at the Baptism Creek background site HF-4. Pollution-sensitive organisms dominated the benthic-macroinvertebrate community at site HF-4. When compared to the other four sites, site HF-4 had the lowest HBI score (4.05) and highest values for total taxa richness (33), EPT taxa richness (17), Beck's Index (19), Shannon Diversity (2.3), and percent sensitive individuals (46.67) (table 16). All the metric values indicated a diverse community low in pollution-tolerant taxa and high in pollution-sensitive taxa. The benthic-macroinvertebrate communities at the French Creek sites contained fewer taxa and were dominated by pollution-tolerant taxa. This is an indication that chemical and (or) physical conditions in French Creek near Hopewell Furnace are degraded compared to the background site on Baptism Creek.

Site HF-1 was immediately downstream from the Hopewell Lake outfall and upstream from Hopewell Furnace and the slag piles. Site HF-1 was dominated by Hydropsychid caddisflies (PTV = 5–6), contained numerous non-insect taxa, and had a Beck's Index value of 1. The metrics indicated a disturbed macroinvertebrate community. Sites HF-2 and HF-3 had increased numbers of EPT taxa but also had increased HBI values when compared to site HF-1. This was due to a decrease in dominance in Hydropsychid caddisflies and an increase in midges (PTV = 6). Sites HF-2 and HF-3 also had relatively few pollution-sensitive taxa and had metric values that indicated a disturbed community. Site HF-5 is at the park boundary and is the most-downstream site sampled. Decreased HBI and increased values for percent sensitive individuals and Shannon Diversity indicate a slight improvement over the upstream sites, but site HF-5 is still degraded when compared to background site HF-4.

The benthic-macroinvertebrate sampling indicated that all four sites sampled on French Creek had disturbed communities when compared to background site HF-4 on Baptism Creek. The French Creek sites were dominated by pollution-tolerant taxa and had relatively few pollution-sensitive taxa. There were small differences in community structure and metric values, but the overall evaluation indicated degraded conditions in French Creek near Hopewell Furnace.

Habitat Evaluations

Habitat evaluations (table 17) were performed to assess the structure of the surrounding physical habitat that influences the quality of the water resources and the condition of the benthic-macroinvertebrate community. Habitat parameters pertinent to the assessment of habitat quality include the variety and quality of the substrate, channel morphology, bank structure, and riparian areas. Barbour and others (1999) described habitat-assessment criteria in detail. Ten parameters were evaluated and rated on a numerical scale of 0 to 20 for each sampling reach with higher scores indicating improved habitat quality. Each category is divided into four groups: optimal, suboptimal, marginal, and poor.

Habitat scores at the five sites sampled ranged from 113 to 160 (table 17). Background site HF-4 on Baptism Creek had a score of 151 with 7 of the 10 categories ranked in the optimal range. The stream in this reach is 2.4 m wide and had bottom substrate composed of a mix of cobbles, gravel, and sand. The reach was a mixture of riffles, runs, and pools. The riparian area was a mix of woods and pasture. The three parameters that scored in the suboptimal range were depth regime, sediment deposition, and bank stability. Baptism Creek is a small stream and had no deep sections in the sampling reach, which caused the lower depth-regime score. The scores for sediment deposition and bank stability were related to minor erosion and deposition in the sampling reach.

Site HF-1 is on French Creek downstream from Hopewell Lake and upstream from Hopewell Furnace. The stream in this reach is 2.5 m wide and had bottom substrate composed of a mix of boulders, cobbles, and gravel. The reach was a mixture of riffles, runs, and pools. The riparian area was heavily wooded and undisturbed. This site had a habitat score of 160, the highest score of the five sites. Eight of the 10 categories

Table 17. Results of habitat survey conducted at Hopewell Furnace National Historic Site, Pennsylvania.

[LB, left bank; RB, right bank]

Station number	014721245	0147212511	014721253	014721259	014721265
Site number	HF-1	HF-2	HF-3	HF-4	HF-5
Date	11/14/08	11/12/08	11/12/08	11/10/08	11/10/08
			Habitat parameters		
1. Epifaunal substrate/available cover	17	7	9	16	7
2. Embeddedness	14	12	13	15	9
3. Velocity/depth regime	15	9	11	10	11
4. Sediment deposition	13	10	7	13	8
5. Channel flow status	17	16	16	16	18
6. Channel alteration	15	15	16	18	18
7. Frequency of riffles (or bends)	16	7	10	16	6
8. Bank stability					
LB	9	8	6	7	6
RB	8	8	6	7	6
9. Vegetative protection					
LB	9	5	7	8	7
RB	9	5	7	8	7
10. Riparian vegetative zone width					
LB	9	6	8	9	10
RB	9	5	8	8	10
TOTAL	**160**	**113**	**124**	**151**	**123**

were ranked in the optimal range. This site had excellent habitat quality with complete canopy cover, stable varied substrate, and stable banks. The site had some minor sedimentation that caused the embeddedness and sediment deposition scores to be ranked suboptimal.

The stream at site HF-2 was 1.8 m wide and had bottom substrate composed of a mix of sand and gravel with a few cobbles. The reach was mostly run areas with a few sand-bottom riffles. The riparian area was pasture with few trees. The banks were grass covered, and the stream was open to the sunlight. This site had a habitat score of 113, the lowest of the five sites. Eight of the 10 categories were ranked below optimal. The major habitat problems at site HF-2 include unstable substrate, pasture riparian area, and heavy sedimentation.

Site HF-3 is on French Creek below Hopewell Furnace. The stream in this reach is 3.9 m wide and had bottom substrate composed of a mix of cobbles, gravel, and sand. The reach was mostly pool with a few small cobble-bottomed riffles. The riparian area was heavily wooded and undisturbed below the bridge at State Route 345. This site had a habitat score of 124 with 8 of the 10 categories ranked below optimal. The major habitat problems at site HF-3 include unstable substrate and heavy sedimentation.

Site HF-5 is on French Creek at the downstream park boundary below the confluence with Baptism Creek. The stream in this reach is 3.5 m wide and had bottom substrate composed of sand and gravel. The reach was mostly pool and run areas with a few small riffles. There were few cobbles exposed on the stream bottom. The riparian area was heavily wooded and undisturbed. This site had a habitat score of 123 with 8 of the 10 categories ranked below optimal. The major habitat problems at site HF-5 include unstable substrate and heavy sedimentation.

The overall habitat quality at the five sites sampled varied from good to marginal. The habitat at sites HF-1 and HF-4 was sufficient to support a diverse benthic-macroinvertebrate community. These sites featured wooded riparian areas, stable bank and stream-bottom substrate, and minor erosion and sedimentation issues. The overall habitat quality at sites HF-2, HF-3, and HF-5 was marginal. The lack of stable bottom substrate and heavy sand and gravel deposition may limit the diversity of the benthic-macroinvertebrate community at these sites.

Statistical Summary of Selected Metals

Minimum, maximum, mean, and median concentrations of selected metals for all media sampled are summarized in table 18. Arsenic was present in ore samples at a mean concentration of 28.4 ppm (table 18). Arsenic appears to be concentrated in cast iron furnace products (mean concentration of 499 ppm). The mean arsenic concentrations in soil near the furnace (5.5 ppm), in samples from slag pile 1 (4.1 ppm), and in streambed sediment (4.4 ppm) were about the same as the mean concentration of background soil samples (5 ppm) and the mean concentration (4.8 ppm) for soil in the eastern United States. Concentrations of arsenic in groundwater and stream base flow were less than 0.004 ppm.

The mean concentration of chromium was 4.5 ppm for ore samples, 15.8 ppm for samples from slag pile 1, and 25 ppm for streambed sediments (table 18). The mean chromium concentration in soil near the furnace (51.3 ppm) was slightly higher than the mean concentration of background soil samples (28 ppm) and the mean concentration (33 ppm) for soil in the eastern United States. Chromium concentrations were less than the detection limit for cast iron furnace products and stream base flow. Concentrations of chromium in groundwater were less than 0.002 ppm.

Cobalt was present in ore samples at a mean concentration of 74.8 ppm (table 18). The mean cobalt concentration in soil near the furnace (16.1 ppm) was about the same as the mean concentration of background soil samples (15.3 ppm), both of which were slightly higher than the mean concentration (5.9 ppm) for soil in the eastern United States (table 4). The elevated concentrations of cobalt in cast iron analyzed by X-ray fluorescence spectroscopy was likely caused by interference from high concentrations of iron. Cobalt was detectable in the stoves but was not quantifiable. The mean cobalt concentration was 8.6 ppm in samples from slag pile 1 and 9.4 ppm in streambed sediments. Concentrations of cobalt in groundwater and stream base flow were less than 0.004 ppm.

Copper was present in ore samples at a median concentration of 9,080 ppm (table 18). Copper appears to be concentrated in cast iron furnace products (mean of 1,860 ppm and median of 2,000 ppm). The mean copper concentrations of samples from slag pile 1 (41.2 ppm), from soil near the furnace (53.9 ppm), and from streambed sediment (56.6 ppm) were similar and were slightly higher than the mean concentration of background soil samples (20.7 ppm) and the mean concentration (13 ppm) for soil in the eastern United States. Copper was not detected in stream base flow and was less than 0.004 ppm in groundwater.

Iron was the major constituent of ore (concentrations greater than 150,000 ppm) (table 18). The median iron concentrations in soil near the furnace (39,300 ppm) and in samples from slag pile 1 (49,200 ppm) were greater than the median concentration of background soil samples (29,000 ppm) and the mean concentration (14,000 ppm) for soil in the eastern United States. The median iron concentration was 31,100 ppm for streambed sediment. The concentration of iron in the water sample from the well drilled into the slag pile (1.74 ppm) was substantially higher than the concentration in the water sample from the supply well (0.032 ppm). The iron concentration was less than 0.4 ppm in stream base flow.

Lead was present in ore samples at a mean concentration of 184 ppm (table 18). Lead appears to be concentrated in cast iron furnace products (mean of 588 ppm). The mean lead concentrations in soil near the furnace (137 ppm), in samples from slag pile 1 (37.3 ppm), and in streambed sediment (45.6 ppm) were greater than the mean concentration of background soil samples (18.1 ppm) and the mean concentration (14 ppm) for soil in the eastern United States. Concentrations of lead in groundwater and stream base flow were less than 0.02 ppm.

Manganese was present in ore samples at a mean concentration of 1,550 ppm (table 18). Manganese was detected in only three of the eight cast iron stoves sampled. Manganese appears to be concentrated in slag (mean of 4,410 ppm). The mean manganese concentration in soil near the furnace (1,190 ppm) was about the same as the mean concentration of background soil samples (1,340 ppm); mean soil concentrations were substantially higher than the mean concentration (260 ppm) for soil in the eastern United States. The concentration of manganese in the water sample from the well drilled into the slag pile (2.43 ppm) was substantially higher than the concentration in the supply well (0.0023 ppm). The mean manganese concentration was 883 ppm in streambed sediment and 0.04 ppm in stream base flow.

Nickel was present in ore samples at a mean concentration of 76.5 ppm (table 18). Nickel was not detected in cast iron furnace products. The mean nickel concentrations in soil near the furnace (29.1 ppm), in samples from slag pile 1 (7.3 ppm), and in streambed sediment (14.6 ppm) were about the same as the mean concentration of background soil samples (21.2 ppm) and the mean concentration (11 ppm) for soil in the eastern United States. Concentrations of nickel in groundwater and stream base flow were less than 0.003 ppm.

Zinc was present in ore samples at a mean concentration of 726 ppm (table 18). Zinc appears to be concentrated in cast iron furnace products (mean of 1,280 ppm). The mean zinc concentrations in soil near the furnace (173 ppm), in samples from slag pile 1 (77.7 ppm), and in streambed sediment (101 ppm) were greater than the mean concentration of background soil samples (46.6 ppm) and the mean concentration (40 ppm) for soil in the eastern United States. Concentrations of zinc in groundwater and stream base flow were less than 0.02 ppm.

Table 18. Summary statistics for concentrations of selected trace metals in ore, slag, cast iron artifacts, soil, groundwater, stream baseflow, and streambed sediment, Hopewell Furnace National Historic Site, Pennsylvania.

[n, number of samples; concentration in parts per million; <, less than; >, greater than; ND, not detected; E estimated value; --, unable to compute statistic]

	n	Arsenic				Chromium				Cobalt			
		Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
Ore	5	1	107	28.4	11	<1	7	[1]4.5	7	30.3	109	74.8	76.7
Slag pile 1	10	<1	12	[1]4.1	4	5	37	15.8	11.5	1	21.3	8.6	7.1
Cast iron stoves	48	ND	1,330	499	438	ND	941 E	[2]64 E	ND	5,600 E	17,700	11,500	11,300
Soil, laboratory analysis	28	3.3	9.2	5.5	5.3	11	239	51.3	34.5	3.7	45.6	16.1	13
Soil, background samples	8	3	6	5.0	5.1	20	32	28.0	28.5	13.5	20.9	15.3	14.2
Groundwater, supply well	1	0.0034	--	--	--	0.0007	--	--	--	<0.0001	--	--	--
Groundwater, slag pile well	1	0.0008	--	--	--	0.0012	--	--	--	0.0039	--	--	--
Stream baseflow	5	0.0003	0.0004	0.0003	0.0003	<0.0004	<0.0004	--	--	0.00005E	0.0002	[1]0.0001	0.0001
Streambed sediment	5	1.5	7.5	4.4	3.3	6.3	59.7	25.1	18.7	3.28	19.8	9.38	6.03

	n	Copper				Iron				Lead			
		Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
Ore	5	3.5	>10,000	--	9,080	>150,000	>150,000	--	--	4	423	184	156
Slag pile 1	10	4.0	169	63.0	41.2	15,500	125,000	58,400	49,200	0.8	172	37.3	3.2
Cast iron stoves	48	ND	4,790	[2]2000 E	1,860	>900,000	>900,000	--	--	ND	3,150	[2]588 E	319
Soil, laboratory analysis	28	13.1	139	59.3	43.2	15,200	>150,000	--	39,300	14.7	646	137	79.1
Soil, backfground samples	8	13.1	25.5	20.7	22.3	25,200	33,400	28,900	29,200	8.8	25.1	18.1	17.4
Groundwater, supply well	1	<0.004	--	--	--	0.032	--	--	--	0.000	--	--	--
Groundwater, slag pile well	1	0.0034 E	--	--	--	1.74	--	--	--	0.014	--	--	--
Stream baseflow	5	<0.004	<0.004	--	--	0.078	0.35	0.21	0.20	0.0002	0.0006	0.0003	0.0002
Streambed sediment	5	7.1	190	56.6	30.7	7,140	44,900	25,800	31,100	9	86.1	45.6	55.9

	n	Manganese				Nickel				Zinc			
		Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
Ore	5	793	3,160	1,550	992	36.9	122	76.5	73.6	59	2,000	726	558
Slag pile 1	10	888	7,130	4,410	4,570	<0.5	18.1	[1]7.3	6.6	<1	393	77.7	13.0
Cast iron stoves	48	ND	7,000	[2]1,320 E	240 E	ND	ND	--	--	120 E	8,220	1,280	834
Soil, laboratory analysis	28	109	2,700	1,190	1,090	10.5	53.8	29.1	26.0	35	562	173	155
Soil, background samples	8	785	1,880	1,340	1,290	16.2	24	21.2	22.1	23	64	46.6	45.0
Groundwater, supply well	1	0.001	--	--	--	0.000	--	--	--	0.006	--	--	--
Groundwater, slag pile well	1	2.43	--	--	--	0.003	--	--	--	0.012	--	--	--
Stream base flow	5	0.0084	0.051	0.040	0.048	0.0004	0.0006	0.0004	0.0004	<0.002	0.0055	[1]0.0021	0.0014
Streambed sediment	5	206	2,270	883	726	5.87	28.5	14.6	9.93	31.7	155	101	120

[1] Less than value set to one-half of detection limit.

[2] Not detected (ND) set equal to zero.

Summary and Conclusions

The 848-acre Hopewell Furnace National Historic Site (NHS) is one of the finest examples of a rural American 19th-century iron plantation. Hopewell Furnace was in operation for 113 years (1771–1883). Hopewell Furnace NHS, located approximately 50 mi northwest of Philadelphia, straddles the Berks-Chester County border in southeastern Pennsylvania. The purpose of this study by the U.S. Geological Survey, in cooperation with the National Park Service, was to determine the distribution of trace metals in Hopewell Furnace NHS related to iron smelting. Local mines supplied the iron ore used at Hopewell Furnace. These ore deposits contained abundant magnetite and accessory sulfide minerals enriched in arsenic, cobalt, copper, and other metals.

Trace metals from ore smelted at Hopewell Furnace followed several pathways. During the smelting process, trace metals were (1) volatilized as air emissions from the furnace, (2) combined with slag, or (3) incorporated into the cast iron products of the furnace. Volatilized metals likely were deposited on the land and other surfaces downwind from the furnace. Travel distance may have been short because of the low height (32 ft) of the furnace stack. Metals deposited on the land may have been washed into the surface-water system, adsorbed onto soil, or taken up by plants and animals. Erosion would move some of the soil and plant matter into the stream system where it would become stream sediment. Trace metals present in slag, which is a glass-like waste material deposited near the furnace, could be immobile or, during physical and chemical weathering, could have leached into the soil or groundwater and surface-water system. Shallow, local groundwater discharges directly to French Creek.

Ore, slag, cast iron furnace products, soil, groundwater, stream base flow, and streambed sediment were sampled and analyzed for trace-element concentrations. In addition, benthic macroinvertebrates were analyzed from the five stream sites where surface-water base flow and streambed-sediment samples were collected.

Arsenic, copper, lead, zinc, and possibly cobalt were incorporated into the cast iron produced by Hopewell Furnace. Manganese was concentrated in slag along with iron, nickel, and zinc. The soil near the furnace had elevated concentrations of chromium, copper, iron, lead, and zinc compared to background soil concentrations.

The base-flow surface-water samples indicated good overall quality. The five sampled sites generally had low concentrations of nutrients and major ions but had elevated concentrations of iron, manganese, and strontium when compared to sites sampled in adjacent watersheds. Background site HF-4 generally had the lowest concentrations and yields of constituents. Low concentrations of nutrients and major ions at all five sites indicate that measured concentrations can be attributed to general land use and geology and not to point sources.

The highest concentration and yield of arsenic was measured at site HF-1; however, arsenic concentrations were similar for all sites with a range of 0.26 to 0.39 µg/L. The highest concentrations of cobalt, iron, lead, manganese, strontium, and zinc were measured immediately downstream from Hopewell Furnace at sites HF-2 and HF-3. Although the highest concentrations of aluminum and nickel were measured at background site HF-4, the highest yields of these metals were measured at site HF-1.

Streambed-sediment sampling results indicated higher concentrations of all metals except nickel at sites on French Creek compared to the background site on Baptism Creek. Although metal concentrations in streambed sediments were higher than the background site, all concentrations measured were below the probable effects limits except for copper at site HF-3. Concentrations of aluminum, cadmium, and nickel were highest in sediment at site HF-1 and generally decreased in concentration downstream, which indicates the source of these metals is upstream from site HF-1 and may be related to discharge from Hopewell Lake. The highest concentrations of arsenic, boron, cobalt, copper, iron, lead, manganese, mercury, and zinc were detected at site HF-3 below Hopewell Furnace, which indicates that the source of these metals may be in Hopewell Furnace NHS between sites HF-1 and HF-3.

The invertebrate community at the background site on Baptism Creek was dominated by pollution-sensitive taxa indicating a healthy, diverse benthic-macroinvertebrate community. Benthic-macroinvertebrate communities at sampling sites on French Creek indicated that the overall stream quality immediately above and below Hopewell Furnace NHS was degraded. The benthic-macroinvertebrate community sampled at the sites on French Creek indicated disturbed communities when compared to the background site on Baptism Creek. The benthic-macroinvertebrate communities were dominated by pollution-tolerant taxa, and taxa were less diverse than the background site.

Habitat conditions at upstream site HF-1 were good but were degraded at downstream sites HF-2, HF-3, and HF-5. The major habitat issues at these sites were related to a lack of stable substrate, erosion, and deposition. Water quality and streambed-sediment quality do not indicate that the degraded benthic-macroinvertebrate communities are the result of poor water quality. Habitat conditions (erosion and sedimentation) and physical alterations (water temperature) from the outfall of Hopewell Lake are the most likely cause of the impaired communities.

In conclusion, soil samples collected from the Hopewell Furnace NHS and analyzed in the laboratory met Pennsylvania Department of Environmental Protection standards for non-residential use. Groundwater samples from the park supply well met U.S. Environmental Protection Agency drinking-water standards. Concentrations of metals in surface-water base flow at the five stream sampling sites were below criteria continuous concentrations for protection of aquatic organisms. Concentrations of metals in sediment at the five stream sampling sites were below probable effects level guidelines for protection of aquatic organisms except for copper at site HF-3.

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Tables 5 and 7

Table 5. Concentrations of selected trace metals in soil samples analyzed by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by SGS Laboratories, Toronto, Ontario, Canada; cm, centimeters; ppm, parts per million; >, greater than; --, unable to compute statistic]

Sample identification number	Sample location	Depth (cm)	Date sampled	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Vanadium (ppm)	Zinc (ppm)
SOIL-1_6-12	377 feet southeast of furnace	15–30	12/4/2008	4	29	11.9	105	34,800	68.2	851	11.7	43	145
SOIL-2_6-14	1,350 feet southeast of furnace	15–36	12/4/2008	8	37	11.6	16.7	32,200	22	509	18.1	82	55
SOIL-2_4-22	1,350 feet southeast of furnace	36–56	12/4/2008	7	32	13.4	17.2	31,600	15.8	449	19.6	77	42
SOIL-2_22-32	1,350 feet southeast of furnace	56–81	12/4/2008	6	28	15.3	15.1	29,700	14.8	619	16.4	65	35
SOIL-9_0-7	13.5 feet east of ore roaster	0–7	11/30/2009	5.4	37	23.7	109	124,000	221	1,480	30.1	84	279
SOIL-9_7-12	13.5 feet east of ore roaster	7–12	11/30/2009	5.1	31	25	123	119,000	191	1,420	53.8	85	257
SOIL-9_12-17	13.5 feet east of ore roaster	12–17	11/30/2009	5	41	24.1	128	115,000	240	1,570	33.6	99	257
SOIL-9_17-22	13.5 feet east of ore roaster	17–22	11/30/2009	8.6	11	45.6	115	>150,000	558	2,560	53.4	117	562
SOIL-9_22-28	13.5 feet east of ore roaster	22–30	11/30/2009	9.2	15	38	139	>150,000	310	1,990	47	116	415
SOIL-10_0-7	43 feet east of ore roaster	0–7	11/30/2009	5.6	203	16.8	55.1	122,000	194	2,270	45.4	84	316
SOIL-10_0-7-D	43 feet east of ore roaster	0–7 duplicate	11/30/2009	5.7	198	16.4	54	116,000	219	2,480	70.3	84	267
SOIL-10_7-12	43 feet east of ore roaster	7–12	11/30/2009	5.3	46	16.2	46.4	133,000	158	1,250	30.2	66	218
SOIL-10_12-17	43 feet east of ore roaster	12–17	11/30/2009	5.3	30	16.3	37.2	143,000	160	1,290	41.5	69	201
SOIL-10_17-22	43 feet east of ore roaster	17–22	11/30/2009	3.5	34	15	32	112,000	194	1,170	23.1	67	282
SOIL-10_22-30	43 feet east of ore roaster	22–30	11/30/2009	5.3	38	12	34.5	86,100	95.6	1,740	28.2	83	159
SOIL-11_0-7	230 feet southeast of furnace	0–7	11/30/2009	4.6	39	11.4	40	40,600	60.5	1,080	22.7	81	120
SOIL-11_7-12	230 feet southeast of furnace	7–12	11/30/2009	3.5	37	11.7	36.2	37,900	45.8	880	28.4	85	98
SOIL-11_12-17	230 feet southeast of furnace	12–17	11/30/2009	3.8	33	12	29.6	34,400	84.4	732	25.7	79	76
SOIL-11_17-22	230 feet southeast of furnace	17–22	11/30/2009	4	30	12	22.8	30,900	41.5	856	24.4	75	61
SOIL-11_22-28	230 feet southeast of furnace	22–28	11/30/2009	3.7	35	11.6	36.9	33,600	646	1,130	53.8	81	71
SOIL-12_0-7	415 feet southeast of furnace	0–7	11/30/2009	3.5	27	7.2	67.6	22,400	76.3	433	14.6	46	161
SOIL-12_7-12	415 feet southeast of furnace	7–12	11/30/2009	4	27	8.6	69.9	28,100	76	602	19.9	46	167
SOIL-12_12-18	415 feet southeast of furnace	12–18	11/30/2009	3.8	28	9.5	72.3	25,300	64.4	530	13.9	50	151
SOIL-12_18-24	415 feet southeast of furnace	18–24	11/30/2009	3.3	22	3.7	13.1	15,200	14.7	109	10.5	43	38
SOIL-13_0-7	15 feet east of ore pile	0–7	11/30/2009	7.1	239	22.9	112	77,500	87.6	2,700	41.1	182	221
SOIL-13_7-12	15 feet east of ore pile	7–12	11/30/2009	7.4	156	16.2	70.1	54,500	81.9	2,020	32.7	111	169
SOIL-13_7-12-D	15 feet east of ore pile	7–12 duplicate	11/30/2009	8	186	15.5	179	56,600	77.8	2,160	32.1	114	220
SOIL-13_12-17	15 feet east of ore pile	12–17	11/30/2009	7.1	56	12.6	33.2	37,100	32.9	1,100	26.3	93	87
SOIL-13_17-22	15 feet east of ore pile	17–22	11/30/2009	7.2	47	11.7	31.2	34,800	33.9	851	23.1	91	83
SOIL-13_22-30	15 feet east of ore pile	22–30	11/30/2009	6.6	48	15.5	51.2	48,200	45.7	1,010	25.2	95	115
Mean				**5.5**	**51.3**	**16.1**	**59.3**	**--**	**137**	**1,190**	**29.1**	**82.0**	**173**

Table 5. Concentrations of selected trace metals in soil samples analyzed by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry, Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories, Toronto, Ontario, Canada; cm, centimeters; ppm, parts per million; >, greater than; --, unable to compute statistic]

Sample identification number	Sample location	Depth (cm)	Date sampled	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Vanadium (ppm)	Zinc (ppm)
SOIL-3_6-14	3,400 feet northeast of furnace	15–36	12/4/2008	6	28	20.9	17.5	30,100	14.5	1,120	16.2	68	38
SOIL-3_14-22	3,400 feet northeast of furnace	36–56	12/4/2008	5	28	16.2	18.3	29,700	11.6	1,010	21	69	33
SOIL-3_22-32	3,400 feet northeast of furnace	56–81	12/4/2008	3	20	16	13.1	25,200	8.8	924	17	56	23
SOIL-3_22-32D	3,400 feet northeast of furnace	59–81 duplicate	12/4/2008	3	21	16.8	14.2	24,900	8.9	951	18	56	25
SOIL-14_0-7	2,820 feet northeast of furnace	0–7	11/30/2009	5.1	32	14.3	23	27,600	25	1,880	23.1	68	63
SOIL-14_7-12	2,820 feet northeast of furnace	7–12	11/30/2009	5.4	29	13.5	23.9	28,700	25.1	1,860	24	75	64
SOIL-14_12-17	2,820 feet northeast of furnace	12–17	11/30/2009	5.6	28	13.8	21.8	26,200	24.9	1,690	23.7	77	62
SOIL-14_17-22	2,820 feet northeast of furnace	17–22	11/30/2009	4.6	30	14.1	22.7	30,500	20	1,450	23.2	77	51
SOIL-14_22-30	2,820 feet northeast of furnace	22–30	11/30/2009	5	29	13.8	25.5	33,400	14.8	785	21.1	80	39
Mean				**5.0**	**28.0**	**15.3**	**20.7**	**28,900**	**18.1**	**1,340**	**21.2**	**71.3**	**46.6**
Mean concentration for soil in Eastern U.S.[1]				**4.8**	**33**	**5.9**	**13**	**14,000**	**14**	**260**	**11**	**43**	**40**
Pennsylvania statewide health standard[2]				**53**	**190,000**	**840**	**100,000**	**190,000**	**1,000**	**130,000**	**56,000**	**20,000**	**190,000**

[1] From Shacklette and Boerngen (1984, p. 6).

[2] From Pennsylvania Department of Environmental Protection (2011).

Table 7. Concentration of selected trace metals in soil samples analyzed by X-ray fluorescence spectroscopy, Hopewell Furnace National Historic Site, Pennsylvania.

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey; cm, centimeters; ppm, parts per million; ND, not detected; E, estimated value below the level of detection; >, greater than; --, no standard]

Sample-identification number	Depth below land surface (cm)	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Titanium (ppm)	Zinc (ppm)
Sample location: 14 feet east of ore roaster											
SOIL-5-1-2	2.5	10 E	135 E	1,010	76	127,000	117	1,370	ND	4,640	270
SOIL-5-1-5	5.1	30 E	ND	1,350	93	112,000	120	2,150	ND	4,420	271
SOIL-5-1-7	7.6	8 E	48 E	773	132	118,000	174	1,710	ND	4,340	311
SOIL-5-1-10	10.2	ND	ND	625	141	72,100	143	1,430	ND	2,080 E	198
SOIL-5-1-12	12.7	ND	ND	1,110 E	150	113,000	423	1,770	ND	4,330 E	242
SOIL-5-1-15	15.2	46 E	ND	3,710	190	450,000	385	2,120	ND	11,800	351
SOIL-5-1-17	17.8	ND	ND	3,320 E	ND	868,000	293	2,560 E	ND	2,550 E	842
SOIL-5-1-20	20.3	ND	ND	1,450 E	71 E	871,000	359	3,610	ND	11,800 E	451
SOIL-5-1-22	22.9	249	ND	2,480 E	93 E	>900,000	ND	4,680	ND	ND	676
SOIL-5-1-25	25.4	79	ND	79 E	62 E	387,000	157	1,300	ND	1,650 E	392
SOIL-5-2-33	33.0	64	67 E	1,400 E	168	530,000	201	2,800	ND	6,620	532
SOIL-5-2-35	35.6	41 E	ND	2,480	73 E	521,000	208	3,960	ND	7,050	601
SOIL-5-2-38	38.1	13 E	23 E	174 E	24 E	40,500	15 E	3,180	42 E	5,300	77
SOIL-5-2-40	40.6	8 E	81 E	217 E	26 E	23,000	12 E	2,330	34 E	5,190	47 E
SOIL-5-2-45	45.7	3 E	ND	380	18 E	38,100	23 E	2,600	ND	5,840	105
SOIL-5-2-50	50.8	6 E	68 E	450	ND	22,400	16 E	2,100	38 E	4,510	66
SOIL-5-2-55	55.9	8 E	24 E	138 E	ND	23,900	10 E	2,110	73 E	5,760	56 E
SOIL-5-2-61	61.0	5 E	80 E	307	10 E	24,200	14 E	1,220	23 E	5,110	62
SOIL-5-2-66	66.0	8 E	137	215 E	11 E	31,200	16 E	922	40 E	5,510	51 E
SOIL-5-3-68	68.6	9 E	17 E	350	24 E	24,400	13 E	843	34 E	5,350	46 E
SOIL-5-3-73	73.7	15 E	64 E	242 E	26 E	25,200	6 E	1,240	69	6,000	55 E
SOIL-5-3-78	78.7	8 E	120 E	345	13 E	27,500	12 E	487	27 E	6,190	53 E
SOIL-5-3-84	83.8	ND	66 E	341	7 E	29,500	27 E	444	64 E	6,730	40 E
SOIL-5-3-88	88.9	ND	15 E	199 E	26 E	25,100	20 E	304	41 E	6,020	46 E
SOIL-5-3-94	94.0	ND	ND	221 E	42 E	25,200	19 E	654	19 E	4,840	31 E

Table 7. Concentration of selected trace metals in soil samples analyzed by X-ray fluorescence spectroscopy, Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey; cm, centimeters; ppm, parts per million; ND, not detected; E, estimated value below the level of detection; >, greater than; --, no standard]

Sample-identification number	Depth below land surface (cm)	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Titanium (ppm)	Zinc (ppm)
Sample location: 43 feet east of ore roaster											
SOIL-6-1-3	3.0	6 E	163 E	928	47 E	68,900	153	1,260	7 E	1,970	366
SOIL-6-1-6	6.1	ND	83 E	773	93	84,300	207	2,000	2 E	5,320	357
SOIL-6-1-9	9.1	14 E	344	1,060	99	97,900	166	2,150	34 E	7,070	378
SOIL-6-1-12	12.2	15 E	106 E	745	104	105,000	198	2,060	ND	7,520	342
SOIL-6-1-15	15.2	32 E	106 E	754	189	97,200	89	1,900	55 E	6,010	245
SOIL-6-1-18	18.3	9 E	22 E	296 E	53 E	55,900	30 E	1,130	18 E	2,710	92
SOIL-6-1-21	21.3	13 E	8 E	626	107	99,100	48 E	2,180	ND	6,680	214
SOIL-6-1-24	24.4	6 E	109 E	673	162	105,000	90	2,090	15 E	7,470	267
SOIL-6-1-27	27.4	24 E	176 E	330 E	107	135,000	35 E	2,300	ND	6,490	198
SOIL-6-1-30	30.5	8 E	ND	830 E	106	189,000	78	2,170	ND	6,520	288
Sample location: 5 feet east of ore pile											
SOIL-7-1-3	3.0	24 E	112 E	866	150	127,000	84	2,920	ND	11,300	257
SOIL-7-1-6	6.1	7 E	391	393 E	148	156,000	133	4,220	ND	8,600	372
SOIL-7-1-9	9.1	7 E	639	ND	131	170,000	175	3,920	34 E	3,530	396
SOIL-7-1-12	12.2	23 E	417	194 E	139	101,000	110	4,400	5 E	4,830	342
SOIL-7-1-15	15.2	12 E	379	253 E	84	81,800	147	3,740	ND	5,180	282
SOIL-7-1-18	18.3	ND	73 E	25 E	16 E	14,700	26 E	1,500	21 E	3,470	62
SOIL-7-1-21	21.3	ND	72 E	287	22 E	15,200	29 E	232	6 E	3,990	34 E
SOIL-7-1-24	24.4	11 E	23 E	272 E	67	47,500	43 E	686	28 E	5,400	83
SOIL-7-1-27	27.4	ND	12 E	273 E	ND	31,100	31 E	1,470	12 E	6,270	54 E
SOIL-7-1-30	30.5	6 E	63 E	168 E	34 E	28,500	34 E	575	21 E	5,480	62

Table 7. Concentration of selected trace metals in soil samples analyzed by X-ray fluorescence spectroscopy, Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey; cm, centimeters; ppm, parts per million; ND, not detected; E, estimated value below the level of detection; >, greater than; --, no standard]

Sample-identification number	Depth below land surface (cm)	Arsenic (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Iron (ppm)	Lead (ppm)	Manganese (ppm)	Nickel (ppm)	Titanium (ppm)	Zinc (ppm)
Sample location: 190 feet southeast of furnace											
SOIL-8-1-3	3.0	ND	57 E	238	28 E	22,200	45 E	720	6 E	3,020	72
SOIL-8-1-6	6.1	ND	26 E	253	34 E	27,100	45 E	850	13 E	3,850	69
SOIL-8-1-9	9.1	ND	ND	141 E	22 E	29,900	46 E	828	25 E	4,270	78
SOIL-8-1-12	12.2	8 E	88 E	544	48 E	42,100	26 E	1,750	23 E	6,130	94
SOIL-8-1-15	15.2	3 E	112 E	560	16 E	51,400	27 E	615	16 E	6,040	100
SOIL-8-1-18	18.3	ND	51 E	537	38 E	37,400	34 E	1,260	17 E	5,660	56 E
SOIL-8-1-21	21.3	18 E	91 E	260 E	8 E	31,500	13 E	887	34 E	7,170	64
SOIL-8-1-24	24.4	10 E	21 E	222 E	25 E	40,200	18 E	1,510	45 E	6,330	69
SOIL-8-1-27	27.4	ND	70 E	258 E	14 E	46,500	25 E	1,600	54 E	6,040	64
SOIL-8-1-30	30.5	ND	ND	362 E	43 E	43,600	27 E	1,350	ND	5,050	73
SOIL-8-1-33	33.5	14 E	99 E	328	31 E	32,300	14 E	627	25 E	4,380	75
SOIL-8-1-36	36.6	12 E	100 E	339	24 E	30,500	23 E	1,560	36 E	6,890	74
SOIL-8-1-39	39.6	5 E	24 E	318	18 E	27,800	22 E	722	35 E	5,700	56 E
SOIL-8-1-42	42.7	7 E	51 E	390	18 E	30,200	16 E	687	15 E	5,820	69
Mean concentration for soil in Eastern U.S.[1]		**4.8**	**33**	**5.9**	**13**	**14,000**	**14**	**260**	**11**	**2,800**	**40**
Pennsylvania statewide health staNDard[2]		**53**	**190,000**	**840**	**100,000**	**190,000**	**1,000**	**130,000**	**56,000**	**--**	**190,000**

[1]From Shacklette and Boerngen (1984, p. 6).

[2]From Pennsylvania Department of Environmental Protection (2009).

Appendix 1. Tables A–K

Table A. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of ore samples from the Hopewell and Jones mines, southeastern Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; --, no data]

Sample identification number	Sample location	Antimony (ppm)	Arsenic (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)	Cadmium (ppm)	Cerium (ppm)
Ore-1	Hopewell mine	0.13	1	59	1	<0.04	1.7	1.99
Ore-2	Hopewell mine	0.18	107	76	0.6	0.28	4.2	62
Ore-3	Jones mine	0.41	12	10	0.1	0.17	0.5	0.44
Ore-4	Jones mine	0.48	11	5	<0.1	0.12	0.8	0.31
Ore-5	Jones mine	0.29	11	37	<0.1	0.16	<0.1	5.94
Crustal abundance (ppm)[1]		0.4	4.8	624	2.1	0.16	0.09	63

Sample identification number	Cesium (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Gallium (ppm)	Indium (ppm)	Lanthanum (ppm)	Lead (ppm)	Lithium (ppm)
Ore-1	<5	7	30.3	3.5	28.8	0.06	1.2	4	10
Ore-2	<5	7	63	349	9.76	1.89	29.8	328	6
Ore-3	<5	1	109	>10,000	17.8	0.99	<0.5	423	13
Ore-4	<5	<1	94.8	>10,000	17.3	0.77	<0.5	156	14
Ore-5	<5	7	76.7	9,080	13.9	0.38	3.4	10.3	12
Crustal abundance (ppm)[1]	4.9	92	17.3	28	17.5	0.056	31	17	21

Sample identification number	Manganese (ppm)	Molybdenum (ppm)	Niobium (ppm)	Nickel (ppm)	Phosphorus (ppm)	Rubidium (ppm)	Scandium (ppm)	Silver (ppm)	Strontium (ppm)
Ore-1	1,930	0.1	0.3	93.6	<50	6	0.5	<1	12.7
Ore-2	3,160	2.04	2.2	36.9	130	6.3	1.7	<1	8.3
Ore-3	793	0.33	0.8	56.3	<50	0.9	0.8	1	3.8
Ore-4	853	0.24	0.6	73.6	<50	0.6	0.7	<1	2.2
Ore-5	992	3.49	1.4	122	1,180	22.3	2.3	<1	17.4
Crustal abundance (ppm)[1]	77.5	1.1	12	47	65.5	84	14	0.053	320

Table A. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of ore samples from the Hopewell and Jones mines, southeastern Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; --, no data]

Sample identification number	Tellurium (ppm)	Thallium (ppm)	Thorium (ppm)	Tin (ppm)	Tungsten (ppm)	Uranium (ppm)	Vanadium (ppm)	Yttrium (ppm)	Zinc (ppm)
Ore-1	<0.1	<0.1	0.6	0.5	<0.1	0.3	446	1.2	594
Ore-2	<0.1	<0.1	2	8.4	73.3	14.3	37	26.3	2,000
Ore-3	0.3	<0.1	0.2	1.5	0.7	0.9	259	0.8	420
Ore-4	0.2	<0.1	<0.2	1.2	0.6	0.6	219	0.7	558
Ore-5	0.2	<0.1	1.2	1	0.3	0.4	64	2.1	59
Crustal abundance (ppm)[1]	--	0.9	10.5	2.1	1.9	2.7	97	21	67

Sample identification number	Aluminum (percent)	Calcium (percent)	Iron (percent)	Magnesium (percent)	Potassium (percent)	Sodium (percent)	Sulfur (percent)	Titanium (percent)
Ore-1	0.50	0.98	>15	0.50	0.13	0.08	0.02	0.05
Ore-2	0.77	11.7	>15	0.29	0.23	0.11	1.16	0.04
Ore-3	0.27	0.08	>15	5.21	0.02	0.01	1.48	0.03
Ore-4	0.26	0.05	>15	5.4	<0.01	<0.01	1.43	0.03
Ore-5	1.15	3.9	>15	6.25	0.31	0.02	1.4	0.09
Crustal abundance (percent)[1]	8.2	2.6	3.9	1.5	2.3	2.4	0.062	0.38

[1] From Rudnick and Gao (2003, p. 4–6).

Table B. Results of laboratory analysis by wavelength dispersive X-ray fluorescence of ore samples from the Hopewell and Jones mines, southeastern Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. <, less than; --, no data]

Sample identification number	Sample location	Aluminum oxide Al_2O_3 (percent)	Calcium oxide CaO (percent)	Chromium(III) oxide Cr_2O_3 (percent)	Iron(III) oxide Fe_2O_3 (percent)	Potassium oxide K_2O (percent)	Magnesium oxide MgO (percent)
Ore-1	Hopewell mine	0.88	1.59	<0.01	92.2	0.22	0.87
Ore-2	Hopewell mine	1.57	18.2	<0.01	49.4	0.32	0.53
Ore-3	Jones mine	0.58	0.1	<0.01	77.4	0.01	9.1
Ore-4	Jones mine	0.71	0.09	<0.01	75.9	0.01	9.0
Ore-5	Jones mine	2.32	5.43	<0.01	59.9	0.31	10.5
Crustal abundance (percent)[1]		15.4	3.59	--	--	2.8	2.48

Sample identification number	Manganese oxide MnO (percent)	Sodium oxide Na_2O (percent)	Phosphorous pentoxide P_2O_5 (percent)	Silicon dioxide(silica) SiO_2 (percent)	Titanium dioxide TiO_2 (percent)	Loss on ignition (percent)
Ore-1	0.31	0.16	0.02	5.73	0.1	<0.01
Ore-2	0.45	0.24	0.03	27.2	0.08	1.53
Ore-3	0.11	<0.01	0.01	8.71	0.04	1.8
Ore-4	0.1	0.06	0.02	8.64	0.04	2.23
Ore-5	0.13	0.03	0.28	9.83	0.16	5.8
Crustal abundance (percent)[1]	0.1	3.27	0.15	66.6	0.64	--

[1] From Rudnick and Gao (2003, p. 4).

Table C. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; mm, millimeters; --, no data]

Sample identification number	Sample description	Antimony (ppm)	Arsenic (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)
HPWL-1-D1	pile 1 stockyard slag from auger < 2 mm size	0.53	6	598	2	0.13
HPWL-1-D2	pile 1 stockyard soil and slag mix from auger < 2 mm size	0.42	4	381	1.4	0.25
HPWL-1-C	pile 1 stockyard surface composite	0.74	7	507	1.8	0.38
HPWL-1-S-a1	pile 1 stockyard slag grab sample	0.14	<1	1,630	5.4	<0.04
HPWL-1-S-b	pile 1 stockyard slag grab sample	<0.05	<1	1,240	4.3	<0.04
HPWL-1-S-d	pile 1 stockyard slag grab sample	0.39	12	1,660	5.4	<0.04
HPWL-1-S-e2	pile 1 stockyard slag grab sample	0.12	4	2,030	6.4	<0.04
HPWL-1-S-f	pile 1 stockyard slag grab sample	0.25	4	1,830	4.6	<0.04
HPWL-1-S-g2	pile 1 stockyard slag grab sample	<0.05	<1	743	6.2	<0.04
HPWL-1-S-j2	pile 1 stockyard slag grab sample	0.11	2	1,740	6	<0.04
HPWL-2-D1	pile 2 south of cast house auger hole 1, from auger < 2 mm size	0.63	6	557	2.4	0.23
HPWL-2-D2	pile 2 south of cast house auger hole 2, from auger < 2 mm size	0.56	4	573	2.8	0.09
HPWL-2-D3	pile 2 south of cast house auger hole 3, from auger < 2 mm size	0.44	5	477	2.4	0.06
HPWL-2-S-A-a2	pile 2 south of cast house grab sample	<0.05	<1	802	3.6	<0.04
HPWL-2-S-A-c2	pile 2 south of cast house grab sample	<0.05	<1	1,040	3	<0.04
HPWL-2-S-A-e3	pile 2 south of cast house grab sample	<0.05	<1	956	6.7	<0.04
HPWL-2-S-A-f3	pile 2 south of cast house grab sample	0.18	2	705	3.6	<0.04
HPWL-2-S-A-f3 D	pile 2 south of cast house grab sample	0.2	2	664	3.4	<0.04
HPWL-2-S-A-g2	pile 2 south of cast house grab sample	<0.05	<1	1,190	8.2	<0.04
HPWL-2-S-B-a2	pile 2 west of cast house grab sample	0.06	<1	762	2.9	<0.04
HPWL-2-S-B-b2	pile 2 west of cast house grab sample	0.07	<1	1,120	2.7	<0.04
HPWL-2-S-B-c2	pile 2 west of cast house grab sample	<0.05	<1	713	3	<0.04
HPWL-2-S-B-e4	pile 2 west of cast house grab sample	<0.05	<1	703	4	<0.04
HPWL-3-S-a1	pile 3 south of anthracite furnace grab sample	<0.05	<1	926	6.8	<0.04
HPWL-3-S-a3	pile 3 south of anthracite furnace grab sample	<0.05	<1	920	8	<0.04
HPWL-3-S-a4	pile 3 south of anthracite furnace grab sample	<0.05	<1	783	9.5	<0.04
HPWL-3-S-b	pile 3 south of anthracite furnace grab sample	0.06	3	904	9.2	<0.04
Mean concentration for soil in eastern United States[1]		0.52	4.8	290	0.55	--

Table C. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; mm, millimeters; --, no data]

Sample-identification number	Cadmium (ppm)	Cerium (ppm)	Cesium (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Gallium (ppm)	Indium (ppm)	Lanthanum (ppm)	Lead (ppm)
HPWL-1-D1	0.2	78.8	<5	27	17	56.3	9.18	0.06	60.2	123
HPWL-1-D2	<0.1	60.6	<5	27	10.1	26	9.88	0.05	38.4	61.9
HPWL-1-C	0.4	70.4	<5	37	21.3	153	8.97	0.1	47.7	172
HPWL-1-S-a1	0.3	230	<5	8	1.3	4	2.74	<0.02	197	3
HPWL-1-S-b	<0.1	122	<5	9	1	6.3	1.33	<0.02	73.6	1.5
HPWL-1-S-d	<0.1	165	<5	10	13.3	169	4.73	<0.02	160	3.3
HPWL-1-S-e2	<0.1	195	<5	11	4.1	20.6	3.49	<0.02	175	1.2
HPWL-1-S-f	<0.1	156	<5	5	5.4	102	2.74	<0.02	131	3
HPWL-1-S-g2	<0.1	135	<5	12	8.8	79.7	1.84	<0.02	96.8	0.8
HPWL-1-S-j2	<0.1	255	<5	12	3.5	13.4	4.43	<0.02	211	3.6
HPWL-2-D1	0.3	79.5	<5	32	31.8	289	9.07	0.12	54.4	144
HPWL-2-D2	0.1	64	<5	101	25.1	495	6.7	0.03	43	49.9
HPWL-2-D3	<0.1	55.1	<5	22	25.9	647	7.78	0.03	36.6	44.2
HPWL-2-S-A-a2	<0.1	79.5	<5	12	2.1	98.2	1.35	<0.02	68.7	0.6
HPWL-2-S-A-c2	<0.1	56.6	<5	6	2.3	83.1	0.9	<0.02	50.5	0.8
HPWL-2-S-A-e3	<0.1	112	<5	11	5.4	100	1.96	<0.02	92.3	0.8
HPWL-2-S-A-f3	<0.1	108	<5	39	13.1	85.6	5.62	<0.02	62.7	2.2
HPWL-2-S-A-f3 D	<0.1	105	<5	38	11.1	69.7	5.76	<0.02	59.5	3.2
HPWL-2-S-A-g2	<0.1	153	<5	8	1.9	19.4	1.47	<0.02	145	4.5
HPWL-2-S-B-a2	<0.1	62.9	<5	4	4.7	282	1.26	<0.02	42.8	3.5
HPWL-2-S-B-b2	<0.1	58	<5	7	8.9	300	1.6	<0.02	44.8	0.8
HPWL-2-S-B-c2	<0.1	52.8	<5	5	2.3	64.2	0.79	<0.02	36.1	0.7
HPWL-2-S-B-e4	<0.1	98.4	<5	9	1.3	65.3	1.26	<0.02	77.2	<0.5
HPWL-3-S-a1	<0.1	109	<5	3	1.4	3.9	1.1	<0.02	71.4	0.8
HPWL-3-S-a3	<0.1	114	<5	3	1.4	2.7	1.15	<0.02	74	0.6
HPWL-3-S-a4	<0.1	96.8	<5	2	1.1	19	0.89	<0.02	63.4	1.5
HPWL-3-S-b	<0.1	100	<5	6	5.3	90.8	1.74	<0.02	65.5	1.3
Mean concentration for soil in eastern United States[1]	--	63	--	33	5.9	13	9.3	--	29	14

Table C. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; mm, millimeters; --, no data]

Sample identification number	Lithium (ppm)	Manganese (ppm)	Molybdenum (ppm)	Niobium (ppm)	Nickel (ppm)	Phosphorus (ppm)	Rubidium (ppm)	Scandium (ppm)	Silver (ppm)	Strontium (ppm)
HPWL-1-D1	18	2,390	0.75	6.3	14.4	560	63.9	7.2	<1	117
HPWL-1-D2	17	888	0.83	6.3	13.2	310	66.3	6.9	<1	58.4
HPWL-1-C	19	2,090	0.89	6.1	18.1	1,010	56	7.3	<1	88.6
HPWL-1-S-a1	30	7,130	0.32	12.8	<0.5	50	82.2	18.2	<1	311
HPWL-1-S-b	36	5,400	0.17	4.3	<0.5	<50	54.8	16.9	<1	205
HPWL-1-S-d	29	3,950	0.74	5.2	8	200	80.1	18.5	<1	299
HPWL-1-S-e2	37	6,840	0.39	8.6	2.3	130	80.5	18.8	<1	289
HPWL-1-S-f	31	5,040	0.33	6	3.4	100	43.6	17	<1	387
HPWL-1-S-g2	58	4,100	0.54	4.4	5.3	<50	50.9	18.6	<1	218
HPWL-1-S-j2	27	6,260	0.37	14.9	7.8	150	79.6	22.5	<1	330
HPWL-2-D1	25	2,440	0.86	6.8	20.7	410	58.2	9.5	<1	92.9
HPWL-2-D2	31	3,820	2.85	5.7	23.7	430	49.2	7.8	<1	116
HPWL-2-D3	26	2,340	0.56	5.5	16.5	370	58.7	7.1	<1	94.8
HPWL-2-S-A-a2	59	4,510	0.4	5.2	17.1	<50	56.5	16.6	<1	255
HPWL-2-S-A-c2	42	3,360	0.22	2.6	12	<50	13.4	11.4	<1	235
HPWL-2-S-A-e3	68	3,380	0.38	1.9	8	<50	29.5	16.9	<1	310
HPWL-2-S-A-f3	51	3,150	0.65	12.9	13.2	140	55.3	13.1	<1	180
HPWL-2-S-A-f3 D	47	2,770	0.67	13.3	10.7	150	57.1	12.5	<1	159
HPWL-2-S-A-g2	71	4,180	0.65	3.3	1.1	<50	36.8	20.5	<1	324
HPWL-2-S-B-a2	48	2,540	0.24	1.1	7.2	<50	18.9	11.7	<1	203
HPWL-2-S-B-b2	40	3,180	0.36	2.2	7.1	90	17.1	11.2	<1	241
HPWL-2-S-B-c2	42	2,800	0.32	1.2	1.5	<50	25.1	12.5	<1	184
HPWL-2-S-B-e4	59	3,780	0.23	4	<0.5	<50	53.5	17.2	<1	179
HPWL-3-S-a1	60	2,020	0.2	0.9	<0.5	<50	15.8	21.9	<1	268
HPWL-3-S-a3	57	1,450	0.15	0.8	<0.5	<50	9.8	23.5	<1	300
HPWL-3-S-a4	61	1,880	0.1	0.2	<0.5	<50	4.6	21.5	<1	270
HPWL-3-S-b	64	2,030	0.28	1.6	7.4	100	12.3	22.1	<1	336
Mean concentration for soil in eastern United States[1]	17	260	0.32	10	11	--	43	6.5	--	53

Table C. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; mm, millimeters; --, no data]

Sample identification number	Tellurium (ppm)	Thallium (ppm)	Thorium (ppm)	Tin (ppm)	Tungsten (ppm)	Uranium (ppm)	Vanadium (ppm)	Yttrium (ppm)	Zinc (ppm)
HPWL-1-D1	<0.1	0.2	7.6	1.9	1.2	2.8	72	37.8	210
HPWL-1-D2	<0.1	0.3	8.1	1.7	1	2	56	17.2	98
HPWL-1-C	<0.1	0.2	7.4	5.3	1.3	2.5	80	30.7	393
HPWL-1-S-a1	<0.1	<0.1	21.8	<0.1	0.2	10.4	134	109	39
HPWL-1-S-b	<0.1	<0.1	13.8	<0.1	0.1	8.3	80	58.1	6
HPWL-1-S-d	<0.1	<0.1	17.6	0.4	0.6	8	60	103	4
HPWL-1-S-e2	<0.1	<0.1	21.3	0.2	0.4	8.9	78	132	1
HPWL-1-S-f	<0.1	<0.1	17.1	0.3	0.4	9.6	56	75.6	5
HPWL-1-S-g2	<0.1	<0.1	13	<0.1	0.1	4.4	55	58.3	<1
HPWL-1-S-j2	<0.1	<0.1	23.5	0.2	0.5	11.3	110	141	20
HPWL-2-D1	<0.1	0.3	7.7	3.5	1	2.7	89	35.5	282
HPWL-2-D2	0.1	0.1	5.8	1.8	1.8	2.2	79	24.5	79
HPWL-2-D3	0.2	0.1	5.7	1.3	0.5	2.1	61	20.2	52
HPWL-2-S-A-a2	<0.1	<0.1	10.5	0.1	<0.1	3.1	117	44	30
HPWL-2-S-A-c2	<0.1	<0.1	7.6	<0.1	<0.1	3.3	53	35.6	21
HPWL-2-S-A-e3	<0.1	<0.1	12.6	<0.1	0.1	4.8	21	60.2	12
HPWL-2-S-A-f3	<0.1	0.2	11.2	0.6	1	4	137	44.7	10
HPWL-2-S-A-f3 D	<0.1	0.2	11.2	0.6	1.1	3.9	127	42.8	9
HPWL-2-S-A-g2	<0.1	<0.1	14.8	<0.1	0.1	5.3	35	85.1	3
HPWL-2-S-B-a2	<0.1	<0.1	7.6	0.1	0.1	3.7	28	33.1	3
HPWL-2-S-B-b2	<0.1	<0.1	7.6	0.1	0.2	3.3	33	33.6	2
HPWL-2-S-B-c2	<0.1	<0.1	7.7	<0.1	<0.1	3.1	34	29.4	2
HPWL-2-S-B-e4	<0.1	<0.1	12	<0.1	<0.1	3.6	102	48.9	2
HPWL-3-S-a1	<0.1	<0.1	17	<0.1	0.2	7.7	18	169	3
HPWL-3-S-a3	<0.1	<0.1	18.2	<0.1	0.2	8.6	15	171	1
HPWL-3-S-a4	<0.1	<0.1	14.8	<0.1	0.1	10.9	3	140	6
HPWL-3-S-b	<0.1	<0.1	15.3	<0.1	0.2	12.3	21	137	2
Mean concentration for soil in eastern United States[1]	--	--	7.7	0.86	--	2.1	43	20	40

Table C. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. ppm, parts per million; <, less than; >, greater than; mm, millimeters; --, no data]

Sample identification number	Aluminum (percent)	Calcium (percent)	Iron (percent)	Magnesium (percent)	Potassium (percent)	Sodium (percent)	Sulfur (percent)	Titanium (percent)
HPWL-1-D1	3.06	2.66	12.5	0.82	1.40	0.30	0.03	0.23
HPWL-1-D2	3.54	0.89	5.23	0.39	1.20	0.32	0.01	0.20
HPWL-1-C	2.99	2.25	10.6	1.11	1.17	0.22	0.05	0.21
HPWL-1-S-a1	7.22	9.98	3.27	2.88	2.92	0.56	0.07	0.62
HPWL-1-S-b	5.75	11.2	1.55	6.07	1.98	0.37	0.05	0.45
HPWL-1-S-d	5.75	7.28	8.72	3.53	2.45	0.36	0.08	0.34
HPWL-1-S-e2	6.88	7.95	4.81	2.40	2.92	0.28	0.05	0.50
HPWL-1-S-f	5.77	9.12	4.18	4.33	3.00	0.39	0.07	0.39
HPWL-1-S-g2	6.61	7.92	2.54	7.28	1.43	0.16	0.03	0.51
HPWL-1-S-j2	5.91	8.54	5.02	2.18	2.65	0.31	0.06	0.57
HPWL-2-D1	3.38	3.21	8.84	2.56	1.22	0.20	0.03	0.26
HPWL-2-D2	3.26	3.52	6.08	3.66	1.05	0.14	0.03	0.26
HPWL-2-D3	2.80	2.49	6.82	3.11	0.96	0.10	0.02	0.22
HPWL-2-S-A-a2	6.98	5.50	1.88	10.4	1.45	0.17	0.02	0.51
HPWL-2-S-A-c2	4.44	10.9	0.90	12.1	0.61	0.12	0.05	0.36
HPWL-2-S-A-e3	6.85	9.92	1.26	9.70	1.09	0.16	0.04	0.44
HPWL-2-S-A-f3	5.64	6.46	2.46	6.50	1.33	0.31	0.04	0.51
HPWL-2-S-A-f3 D	5.40	5.69	2.35	5.55	1.30	0.32	0.03	0.50
HPWL-2-S-A-g2	7.75	10.1	0.68	6.82	1.34	0.16	0.03	0.56
HPWL-2-S-B-a2	4.97	8.34	1.21	14.2	0.96	0.15	0.07	0.31
HPWL-2-S-B-b2	4.46	9.76	2.04	12.5	0.72	0.12	0.06	0.34
HPWL-2-S-B-c2	4.67	9.29	0.79	12.4	0.99	0.11	0.04	0.37
HPWL-2-S-B-e4	7.22	5.41	1.24	11.3	1.42	0.17	0.03	0.51
HPWL-3-S-a1	8.07	>15	0.17	9.34	0.60	0.13	0.73	0.56
HPWL-3-S-a3	8.74	>15	0.17	10.3	0.34	0.08	0.74	0.49
HPWL-3-S-a4	6.05	13.9	0.03	10.9	0.22	0.10	0.66	0.40
HPWL-3-S-b	7.36	14.3	1.58	10.3	0.49	0.12	0.96	0.47
Mean concentration for soil in eastern United States[1]	--	--	1.4	--	--	--	--	0.28

[1] From Shacklette and Boerngen (1984, p. 6).

Table D. Results of laboratory analysis by wavelength dispersive X-ray fluorescence of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. <, less than; mm, millimeters]

Sample identification number	Sample description	Aluminum oxide Al_2O_3 (percent)	Calcium oxide CaO (percent)	Chromium(III) oxide Cr_2O_3 (percent)	Iron(III) oxide Fe_2O_3 (percent)	Potassium oxide K_2O (percent)
HPWL-1-D1	pile 1 stockyard slag from auger < 2 mm size	6.42	4.21	<0.01	19.9	1.92
HPWL-1-D2	pile 1 stockyard soil and slag mix from auger < 2 mm size	7.17	1.30	0.02	8.71	1.62
HPWL-1-C	pile 1 stockyard surface composite	6.17	3.51	<0.01	15.1	1.42
HPWL-1-S-a1	pile 1 stockyard slag grab sample	13.4	14.7	<0.01	4.88	3.47
HPWL-1-S-b	pile 1 stockyard slag grab sample	10.7	16.6	<0.01	2.33	2.33
HPWL-1-S-d	pile 1 stockyard slag grab sample	11.8	12.2	<0.01	13.8	3.29
HPWL-1-S-e2	pile 1 stockyard slag grab sample	13.2	12.1	<0.01	7.60	3.67
HPWL-1-S-f	pile 1 stockyard slag grab sample	10.9	15.0	<0.01	6.55	3.51
HPWL-1-S-g2	pile 1 stockyard slag grab sample	13.9	11.7	<0.01	3.56	1.91
HPWL-1-S-j2	pile 1 stockyard slag grab sample	12.3	14.2	<0.01	7.65	3.59
HPWL-2-D1	pile 2 south of cast house drill hole 1, from auger < 2 mm size	7.65	4.78	<0.01	13.5	1.53
HPWL-2-D2	pile 2 south of cast house drill hole 2, from auger < 2 mm size	6.32	5.22	0.02	9.52	1.28
HPWL-2-D3	pile 2 south of cast house drill hole 3, from auger < 2 mm size	5.90	4.02	<0.01	9.84	1.31
HPWL-2-S-A-a2	pile 2 south of cast house grab sample	13.4	8.32	<0.01	2.80	1.74
HPWL-2-S-A-c2	pile 2 south of cast house grab sample	8.71	17.8	<0.01	1.51	0.74
HPWL-2-S-A-e3	pile 2 south of cast house grab sample	13.0	15.2	<0.01	1.98	1.30
HPWL-2-S-A-f3	pile 2 south of cast house grab sample	10.6	9.87	<0.01	3.87	1.64
HPWL-2-S-A-f3 D	pile 2 south of cast house grab sample	10.7	8.90	<0.01	3.81	1.68
HPWL-2-S-A-g2	pile 2 south of cast house grab sample	15.0	16.0	<0.01	0.99	1.63
HPWL-2-S-B-a2	pile 2 west of cast house grab sample	9.12	12.5	<0.01	1.80	1.12
HPWL-2-S-B-b2	pile 2 west of cast house grab sample	8.46	15.1	<0.01	3.15	0.84
HPWL-2-S-B-c2	pile 2 west of cast house grab sample	8.64	14.0	<0.01	1.18	1.15
HPWL-2-S-B-e4	pile 2 west of cast house grab sample	13.8	8.21	<0.01	1.92	1.72
HPWL-3-S-a1	pile 3 south of anthracite furnace grab sample	15.0	26.0	<0.01	0.28	0.69
HPWL-3-S-a3	pile 3 south of anthracite furnace grab sample	16.2	26.2	<0.01	0.26	0.43
HPWL-3-S-a4	pile 3 south of anthracite furnace grab sample	13.7	23.4	<0.01	0.09	0.25
HPWL-3-S-b	pile 3 south of anthracite furnace grab sample	14.7	23.2	<0.01	2.64	0.58

Table D. Results of laboratory analysis by wavelength dispersive X-ray fluorescence of slag samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. <, less than; mm, millimeters]

Sample identification number	Magnesium oxide MgO (percent)	Manganese oxide MnO (percent)	Sodium oxide Na_2O (percent)	Phosphorous pentoxide P_2O_5 (percent)	Silicon dioxide (silica) SiO_2 (percent)	Titanium dioxide TiO_2 (percent)	Loss on ignition (percent)
HPWL-1-D1	1.59	0.31	0.44	0.13	59.7	0.57	4.89
HPWL-1-D2	0.70	0.09	0.46	0.07	75.9	0.57	3.51
HPWL-1-C	2.08	0.27	0.34	0.24	61.7	0.57	8.70
HPWL-1-S-a1	5.21	0.89	0.76	0.01	56.2	1.05	<0.01
HPWL-1-S-b	10.7	0.68	0.49	<0.01	55.7	0.76	<0.01
HPWL-1-S-d	6.91	0.54	0.54	0.05	49.9	0.66	<0.01
HPWL-1-S-e2	4.32	0.89	0.40	0.03	54.0	0.88	2.26
HPWL-1-S-f	7.82	0.62	0.53	0.03	53.9	0.68	0.15
HPWL-1-S-g2	14.2	0.58	0.26	<0.01	53.3	0.98	<0.01
HPWL-1-S-j2	4.23	0.89	0.46	0.03	55.8	1.10	<0.01
HPWL-2-D1	4.52	0.35	0.32	0.09	60.3	0.66	5.99
HPWL-2-D2	6.40	0.46	0.19	0.10	65.1	0.53	5.36
HPWL-2-D3	5.90	0.31	0.15	0.09	67.6	0.50	4.47
HPWL-2-S-A-a2	18.6	0.58	0.24	<0.01	54.3	0.90	<0.01
HPWL-2-S-A-c2	22.6	0.46	0.21	<0.01	47.5	0.66	<0.01
HPWL-2-S-A-e3	17.0	0.44	0.24	<0.01	49.9	0.78	0.36
HPWL-2-S-A-f3	11.4	0.41	0.43	0.03	59.8	0.90	0.99
HPWL-2-S-A-f3 D	10.2	0.37	0.45	0.04	61.0	0.91	1.34
HPWL-2-S-A-g2	12.4	0.56	0.24	<0.01	51.8	1.00	0.03
HPWL-2-S-B-a2	24.7	0.32	0.23	<0.01	49.0	0.52	0.17
HPWL-2-S-B-b2	22.1	0.42	0.17	0.02	49.3	0.61	<0.01
HPWL-2-S-B-c2	21.4	0.35	0.17	<0.01	52.5	0.64	0.03
HPWL-2-S-B-e4	19.9	0.49	0.26	<0.01	52.2	0.90	0.06
HPWL-3-S-a1	18.3	0.28	0.22	<0.01	37.0	1.07	<0.01
HPWL-3-S-a3	18.1	0.21	0.14	<0.01	36.4	0.99	<0.01
HPWL-3-S-a4	21.3	0.26	0.16	<0.01	37.3	0.73	1.81
HPWL-3-S-b	19.1	0.28	0.17	0.02	38.2	0.86	<0.01

Table E. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. cm, centimeters; ppm, parts per million; --, no data; <, less than; >, greater than]

Sample number	Sample location	Depth (cm)	Date sampled	Antimony (ppm)	Arsenic (ppm)	Arsenic[1] (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)
SOIL-1_6-12	377 feet southeast of furnace	15–30	12/4/2008	0.52	4	--	302	0.9	0.17
SOIL-2_6-14	1,350 feet southeast of furnace	15–36	12/4/2008	0.52	8	--	361	1.7	0.21
SOIL-2_4-22		36–56	12/4/2008	0.5	7	--	328	1.5	0.22
SOIL-2_22-32		56–81	12/4/2008	0.52	6	--	273	1.5	0.22
SOIL-3_6-14	3,400 feet northeast of furnace	15–36	12/4/2008	0.5	6	--	375	1.7	0.21
SOIL-3_14-22		36–56	12/4/2008	0.4	5	--	322	1.8	0.17
SOIL-3_22-32		56–81	12/4/2008	0.27	3	--	354	1.8	0.08
SOIL-3_22-32D		59–81 duplicate	12/4/2008	0.26	3	--	371	1.8	0.08
SOIL-9_0-7	13.5 feet east of ore roaster	0–7	11/30/2009	0.54	5.4	6	306	1.4	0.23
SOIL-9_7-12		7–12	11/30/2009	0.48	5.1	6	335	1.3	0.17
SOIL-9_12-17		12–17	11/30/2009	0.49	5	5	366	1.3	0.15
SOIL-9_17-22		17–22	11/30/2009	0.56	8.6	10	291	1.8	0.21
SOIL-9_22-28		22–30	11/30/2009	0.69	9.2	10	299	1.6	0.21
SOIL-10_0-7	43 feet east of ore roaster	0–7	11/30/2009	0.76	5.6	6	279	1.4	0.32
SOIL-10_0-7-D		0–7 duplicate	11/30/2009	0.65	5.7	6	269	1.2	0.28
SOIL-10_7-12		7–12	11/30/2009	0.23	5.3	5	254	1.1	0.18
SOIL-10_12-17		12–17	11/30/2009	0.26	5.3	5	340	1.1	0.18
SOIL-10_17-22		17–22	11/30/2009	0.26	3.5	4	310	1.2	0.17
SOIL-10_22-30		22–30	11/30/2009	0.39	5.3	5	446	1.9	0.14
SOIL-11_0-7	230 feet southeast of furnace	0–7	11/30/2009	0.73	4.6	4	387	1.9	0.21
SOIL-11_7-12		7–12	11/30/2009	0.58	3.5	4	439	2.4	0.21
SOIL-11_12-17		12–17	11/30/2009	0.48	3.8	4	440	2.7	0.22
SOIL-11_17-22		17–22	11/30/2009	0.36	4	5	475	2.8	0.21
SOIL-11_22-28		22–28	11/30/2009	0.46	3.7	4	1,050	2.9	0.2
SOIL-12_0-7	415 feet southeast of furnace	0–7	11/30/2009	0.72	3.5	4	271	1	0.2
SOIL-12_7-12		7–12	11/30/2009	0.69	4	5	272	1	0.18
SOIL-12_12-18		12–18	11/30/2009	0.59	3.8	4	296	1	0.16
SOIL-12_18-24		18–24	11/30/2009	0.14	3.3	3	266	1	0.12
SOIL-13_0-7	15 feet east of ore pile	0–7	11/30/2009	1.39	7.1	7	354	1.5	0.32
SOIL-13_7-12		7–12	11/30/2009	1.17	7.4	8	402	1.7	0.39
SOIL-13_7-12-D		7–12 duplicate	11/30/2009	1.24	8	8	404	2	0.34
SOIL-13_12-17		12–17	11/30/2009	0.9	7.1	8	407	1.9	0.24
SOIL-13_17-22		17–22	11/30/2009	0.73	7.2	8	395	1.8	0.23
SOIL-13_22-30		22–30	11/30/2009	0.68	6.6	7	405	1.9	0.24
SOIL-14_0-7	2,820 feet northeast of furnace	0–7	11/30/2009	0.76	5.1	6	450	2.5	0.21
SOIL-14_7-12		7–12	11/30/2009	0.79	5.4	6	466	2.3	0.22
SOIL-14_12-17		12–17	11/30/2009	0.73	5.6	6	456	2.7	0.22
SOIL-14_17-22		17–22	11/30/2009	0.64	4.6	5	444	2.3	0.2
SOIL-14_22-30		22–30	11/30/2009	0.54	5	7	387	2.2	0.22

Table E. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. cm, centimeters; ppm, parts per million; --, no data; <, less than; >, greater than]

Sample number	Cadmium (ppm)	Cerium (ppm)	Cesium (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Gallium (ppm)	Indium (ppm)	Lanthanum (ppm)	Lead (ppm)
SOIL-1_6-12	0.2	49.4	<5	29	11.9	105	7.75	0.07	29.2	68.2
SOIL-2_6-14	<0.1	83.7	<5	37	11.6	16.7	15	0.05	40.6	22
SOIL-2_4-22	<0.1	69.9	<5	32	13.4	17.2	14.5	0.05	33	15.8
SOIL-2_22-32	<0.1	64.8	<5	28	15.3	15.1	12.1	0.04	32.5	14.8
SOIL-3_6-14	<0.1	79.1	<5	28	20.9	17.5	15	0.05	41.9	14.5
SOIL-3_14-22	<0.1	84.4	<5	28	16.2	18.3	16.3	0.06	41.2	11.6
SOIL-3_22-32	<0.1	84.3	<5	20	16	13.1	15.7	0.06	39.7	8.8
SOIL-3_22-32D	<0.1	77.8	<5	21	16.8	14.2	16	0.06	36.8	8.9
SOIL-9_0-7	0.3	54.7	<5	37	23.7	109	10.5	0.1	38.2	221
SOIL-9_7-12	0.3	54.8	<5	31	25	123	10.5	0.1	36.2	191
SOIL-9_12-17	0.2	52.5	<5	41	24.1	128	10.8	0.09	34.8	240
SOIL-9_17-22	0.5	53.1	<5	11	45.6	115	15.9	0.26	59.5	558
SOIL-9_22-28	0.4	45.1	<5	15	38	139	14.7	0.2	43.9	310
SOIL-10_0-7	0.4	69.2	<5	203	16.8	55.1	9.09	0.1	42.2	194
SOIL-10_0-7-D	0.3	71.9	<5	198	16.4	54	8.74	0.09	42.9	219
SOIL-10_7-12	0.2	48.5	<5	46	16.2	46.4	9.32	0.09	30.7	158
SOIL-10_12-17	0.1	52.4	<5	30	16.3	37.2	10.2	0.08	33.6	160
SOIL-10_17-22	0.2	51.9	<5	34	15	32	10.7	0.08	29.7	194
SOIL-10_22-30	0.1	61.2	<5	38	12	34.5	9.91	0.06	42.5	95.6
SOIL-11_0-7	0.3	74.5	<5	39	11.4	40	11.9	0.05	40.7	60.5
SOIL-11_7-12	0.2	69.4	<5	37	11.7	36.2	13.5	0.05	38.3	45.8
SOIL-11_12-17	0.2	67.7	5	33	12	29.6	14.8	0.05	35.9	84.4
SOIL-11_17-22	0.1	74.9	<5	30	12	22.8	15.3	0.05	38.4	41.5
SOIL-11_22-28	0.1	72.1	<5	35	11.6	36.9	14.1	0.05	40.6	646
SOIL-12_0-7	0.3	54.2	<5	27	7.2	67.6	7.84	0.07	30	76.3
SOIL-12_7-12	0.3	52.9	<5	27	8.6	69.9	7.55	0.06	29.1	76
SOIL-12_12-18	0.2	58	<5	28	9.5	72.3	8.43	0.07	32.6	64.4
SOIL-12_18-24	<0.1	63.3	<5	22	3.7	13.1	9.21	0.03	33.4	14.7
SOIL-13_0-7	0.4	101	<5	239	22.9	112	12.5	0.1	57.2	87.6
SOIL-13_7-12	0.3	96.6	<5	156	16.2	70.1	12.8	0.08	53.2	81.9
SOIL-13_7-12-D	0.3	101	<5	186	15.5	179	13.1	0.08	55.5	77.8
SOIL-13_12-17	0.2	75.7	<5	56	12.6	33.2	13.8	0.05	39.1	32.9
SOIL-13_17-22	0.1	72	<5	47	11.7	31.2	13.9	0.05	38.2	33.9
SOIL-13_22-30	0.2	69.5	<5	48	15.5	51.2	14.2	0.06	38.2	45.7
SOIL-14_0-7	0.2	97.8	<5	32	14.3	23	13.2	0.04	62.2	25
SOIL-14_7-12	0.2	110	<5	29	13.5	23.9	13.6	0.05	70	25.1
SOIL-14_12-17	0.2	111	<5	28	13.8	21.8	14.3	0.05	70.1	24.9
SOIL-14_17-22	0.1	96	<5	30	14.1	22.7	14.6	0.05	56.5	20
SOIL-14_22-30	<0.1	75	<5	29	13.8	25.5	15.8	0.05	37.5	14.8

Table E. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. cm, centimeters; ppm, parts per million; --, no data; <, less than; >, greater than]

Sample number	Lithium (ppm)	Manganese (ppm)	Molybdenum (ppm)	Niobium (ppm)	Nickel (ppm)	Phosphorus (ppm)	Rubidium (ppm)	Scandium (ppm)	Silver (ppm)	Strontium (ppm)
SOIL-1_6-12	16	851	0.59	7.4	11.7	440	44.2	5.4	<1	54.6
SOIL-2_6-14	29	509	1.01	13.4	18.1	340	81.4	11.6	<1	55.2
SOIL-2_4-22	28	449	0.9	11.4	19.6	240	86.5	11.7	<1	50
SOIL-2_22-32	23	619	0.82	8.3	16.4	230	79.9	9.7	<1	33.6
SOIL-3_6-14	17	1,120	0.75	9.5	16.2	320	90.1	10	<1	32.2
SOIL-3_14-22	15	1,010	0.65	9.8	21	290	89.2	11	<1	33.1
SOIL-3_22-32	10	924	0.37	9.2	17	240	83	10	<1	34.6
SOIL-3_22-32D	11	951	0.39	9.2	18	240	84.2	10.5	<1	35.7
SOIL-9_0-7	15	1,480	1.76	6.8	30.1	690	44.8	7	<1	39.6
SOIL-9_7-12	16	1,420	1.44	6.9	53.8	590	44.9	6.5	<1	55.9
SOIL-9_12-17	18	1,570	1.66	7	33.6	650	45.7	7.5	<1	48.7
SOIL-9_17-22	12	2,560	1.57	7.1	53.4	710	32.4	6.8	<1	23.8
SOIL-9_22-28	13	1,990	1.56	6	47	830	34.2	5.9	<1	27
SOIL-10_0-7	17	2,270	5.4	6.4	45.4	530	43.8	6.1	<1	44.8
SOIL-10_0-7-D	17	2,480	4.99	5.9	70.3	510	40.8	5.2	<1	50.1
SOIL-10_7-12	13	1,250	1.64	5.5	30.2	280	47.1	5.1	<1	31.4
SOIL-10_12-17	13	1,290	0.91	5.9	41.5	280	51.1	5.3	<1	43
SOIL-10_17-22	14	1,170	0.89	6.5	23.1	270	68	5.7	<1	36.1
SOIL-10_22-30	19	1,740	0.9	7.8	28.2	380	72.7	7.5	<1	73.2
SOIL-11_0-7	25	1,080	0.99	10.4	22.7	460	83.5	8.1	<1	56.7
SOIL-11_7-12	22	880	1.17	9.5	28.4	340	97.5	8.8	<1	50.6
SOIL-11_12-17	20	732	0.57	8.6	25.7	270	116	9.6	<1	49.2
SOIL-11_17-22	21	856	0.52	6.8	24.4	240	119	9.7	<1	47
SOIL-11_22-28	20	1,130	0.56	10.1	53.8	230	111	9.4	<1	56.7
SOIL-12_0-7	17	433	0.53	9.5	14.6	450	43.2	4.8	<1	40
SOIL-12_7-12	16	602	0.49	8.8	19.9	350	41.1	4.5	<1	39.6
SOIL-12_12-18	17	530	0.43	10.1	13.9	300	47.4	5	<1	41.7
SOIL-12_18-24	23	109	0.19	2.1	10.5	150	61	5.8	<1	47.2
SOIL-13_0-7	28	2,700	7.4	9	41.1	850	46.2	14.4	<1	122
SOIL-13_7-12	32	2,020	4.35	11.3	32.7	600	79.7	10.1	<1	76.5
SOIL-13_7-12-D	32	2,160	4.62	11.6	32.1	620	81.2	10.3	<1	75.2
SOIL-13_12-17	31	1,100	1.92	12.2	26.3	410	94.5	9.7	<1	50.9
SOIL-13_17-22	28	851	1.46	12.1	23.1	350	96	9.1	<1	46
SOIL-13_22-30	30	1,010	1.03	10.6	25.2	300	101	9.8	<1	50.8
SOIL-14_0-7	17	1,880	0.87	11.4	23.1	740	97.9	7.7	<1	35.5
SOIL-14_7-12	18	1,860	0.85	11.7	24	540	100	7.9	<1	32.1
SOIL-14_12-17	17	1,690	0.82	12.1	23.7	500	103	8.5	<1	29
SOIL-14_17-22	18	1,450	0.69	10.8	23.2	370	106	8.9	<1	30.4
SOIL-14_22-30	18	785	0.61	9.7	21.1	270	115	10	<1	28.3

Table E. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. cm, centimeters; ppm, parts per million; --, no data; <, less than; >, greater than]

Sample number	Tellurium (ppm)	Thorium (ppm)	Tin (ppm)	Titanium (ppm)	Tungsten (ppm)	Uranium (ppm)	Vanadium (ppm)	Yttrium (ppm)	Zinc (ppm)
SOIL-1_6-12	<0.1	6.2	1.4	0.3	0.7	1.7	43	12.1	145
SOIL-2_6-14	<0.1	12.5	2.1	0.5	1.1	3.1	82	14.5	55
SOIL-2_4-22	<0.1	10.9	1.9	0.5	0.9	2.6	77	11.1	42
SOIL-2_22-32	<0.1	10	1.6	0.5	0.8	2.2	65	11.1	35
SOIL-3_6-14	<0.1	13.4	2	0.5	0.9	2.8	68	15.7	38
SOIL-3_14-22	<0.1	14.5	2.2	0.5	0.9	3.2	69	11	33
SOIL-3_22-32	<0.1	12.1	2.1	0.4	0.8	2.8	56	9	23
SOIL-3_22-32D	<0.1	10.1	2.1	0.4	0.8	2.7	56	8.8	25
SOIL-9_0-7	0.1	6.1	3.1	0.3	6.7	2	84	24.4	279
SOIL-9_7-12	0.1	7.4	2.4	0.3	1.9	2	85	23	257
SOIL-9_12-17	<0.1	6.5	3.1	0.4	1.7	2.2	99	25.5	257
SOIL-9_17-22	0.1	5.2	2.4	0.6	3.4	2.6	117	58.4	562
SOIL-9_22-28	0.1	5.8	2.1	0.5	2.6	2.2	116	42.2	415
SOIL-10_0-7	<0.1	8.2	5.3	0.3	4.5	2.1	84	25	316
SOIL-10_0-7-D	<0.1	7.2	3.7	0.3	3.9	2.1	84	24.4	267
SOIL-10_7-12	<0.1	6.8	1.7	0.3	1.6	1.9	66	16.5	218
SOIL-10_12-17	<0.1	7.5	1.6	0.3	1.2	2.1	69	16.8	201
SOIL-10_17-22	<0.1	7.5	1.8	0.4	1.3	2	67	14.7	282
SOIL-10_22-30	<0.1	8.4	2.3	0.3	1.8	2.7	83	31.7	159
SOIL-11_0-7	<0.1	10	3.3	0.4	1.6	2.3	81	21.9	120
SOIL-11_7-12	<0.1	9.2	2.8	0.5	1.5	2.3	85	21.9	98
SOIL-11_12-17	<0.1	9.7	2.8	0.6	1	2.2	79	17.9	76
SOIL-11_17-22	<0.1	11.4	2.6	0.6	0.6	2.6	75	16.9	61
SOIL-11_22-28	<0.1	10.5	2.4	0.5	1.1	2.5	81	23.2	71
SOIL-12_0-7	<0.1	7.5	2.7	0.3	1.3	2	46	11.5	161
SOIL-12_7-12	<0.1	7.3	2	0.3	1	1.8	46	11.2	167
SOIL-12_12-18	<0.1	8.6	1.8	0.3	1	2.1	50	12.4	151
SOIL-12_18-24	<0.1	9.4	1.4	0.3	0.1	2.4	43	10.5	38
SOIL-13_0-7	<0.1	9.4	5	0.3	4.7	2.7	182	49.7	221
SOIL-13_7-12	<0.1	11.5	4.4	0.4	3.6	3	111	38.2	169
SOIL-13_7-12-D	<0.1	11.6	4.8	0.5	3.8	3.2	114	36.7	220
SOIL-13_12-17	<0.1	10.4	3.2	0.5	1.8	3	93	22.3	87
SOIL-13_17-22	<0.1	10.7	3.2	0.5	1.6	3.1	91	21.1	83
SOIL-13_22-30	<0.1	10.8	3.3	0.5	1.3	2.7	95	21.5	115
SOIL-14_0-7	<0.1	11.2	3.5	0.5	2.2	3.1	68	48.7	63
SOIL-14_7-12	<0.1	13.1	3.3	0.5	2.2	3.2	75	52.7	64
SOIL-14_12-17	<0.1	13	3	0.5	1.3	3.1	77	52.9	62
SOIL-14_17-22	<0.1	13.1	2.8	0.5	1.3	3	77	33.4	51
SOIL-14_22-30	<0.1	13.1	2.6	0.6	1	3.1	80	15	39

Table E. Results of laboratory analysis by inductively coupled plasma-atomic emission spectrometry and inductively coupled plasma-mass spectrometry of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. cm, centimeters; ppm, parts per million; --, no data; <, less than; >, greater than]

Sample number	Aluminum (percent)	Calcium (percent)	Iron (percent)	Magnesium (percent)	Potassium (percent)	Sodium (percent)	Sulfur (percent)	Titanium (percent)
SOIL-1_6-12	2.88	0.71	3.48	0.32	0.71	0.23	0.03	0.23
SOIL-2_6-14	5.62	0.19	3.22	0.40	1.42	0.41	0.01	0.38
SOIL-2_4-22	5.53	0.13	3.16	0.40	1.51	0.35	<0.01	0.33
SOIL-2_22-32	4.59	0.07	2.97	0.33	1.35	0.18	<0.01	0.24
SOIL-3_6-14	5.60	0.11	3.01	0.26	1.49	0.29	<0.01	0.27
SOIL-3_14-22	6.35	0.10	2.97	0.24	1.61	0.45	<0.01	0.27
SOIL-3_22-32	6.36	0.06	2.52	0.16	1.70	0.69	<0.01	0.25
SOIL-3_22-32D	6.58	0.06	2.49	0.16	1.72	0.71	<0.01	0.25
SOIL-9_0-7	3.26	0.69	12.4	0.42	0.85	0.25	0.03	0.23
SOIL-9_7-12	3.33	0.69	11.9	0.43	0.9	0.25	0.02	0.23
SOIL-9_12-17	3.76	0.84	11.5	0.63	0.98	0.3	0.01	0.25
SOIL-9_17-22	2.59	0.56	>15	0.2	0.66	0.17	<0.01	0.18
SOIL-9_22-28	2.78	0.51	>15	0.29	0.73	0.15	<0.01	0.17
SOIL-10_0-7	3.07	1.34	12.2	0.6	0.89	0.22	0.04	0.22
SOIL-10_0-7-D	2.94	1.53	11.6	0.67	0.87	0.21	0.04	0.21
SOIL-10_7-12	2.99	0.54	13.3	0.27	0.99	0.23	<0.01	0.19
SOIL-10_12-17	3.19	0.75	14.3	0.27	1.09	0.28	<0.01	0.2
SOIL-10_17-22	3.73	0.42	11.2	0.26	1.33	0.33	<0.01	0.23
SOIL-10_22-30	4.35	1.59	8.61	0.55	1.48	0.32	<0.01	0.28
SOIL-11_0-7	6.05	0.68	4.06	0.68	1.57	0.64	0.04	0.39
SOIL-11_7-12	5.82	0.55	3.79	0.74	1.68	0.7	0.02	0.34
SOIL-11_12-17	6.23	0.32	3.44	0.63	1.97	0.72	0.01	0.34
SOIL-11_17-22	6.58	0.18	3.09	0.55	2.05	0.73	<0.01	0.36
SOIL-11_22-28	6.13	0.6	3.36	0.83	1.94	0.77	0.02	0.34
SOIL-12_0-7	3.04	0.36	2.24	0.24	0.79	0.27	0.04	0.32
SOIL-12_7-12	2.97	0.33	2.81	0.22	0.8	0.27	0.02	0.31
SOIL-12_12-18	3.16	0.29	2.53	0.23	0.85	0.29	0.01	0.34
SOIL-12_18-24	3.8	0.12	1.52	0.23	1.05	0.34	<0.01	0.37
SOIL-13_0-7	5.53	4.77	7.75	1.84	0.95	0.76	0.1	0.47
SOIL-13_7-12	5.51	2.17	5.45	0.96	1.35	0.33	0.06	0.4
SOIL-13_7-12-D	5.56	2.26	5.66	0.98	1.38	0.33	0.07	0.4
SOIL-13_12-17	5.67	0.53	3.71	0.52	1.51	0.28	0.02	0.42
SOIL-13_17-22	5.41	0.39	3.48	0.49	1.47	0.26	0.01	0.39
SOIL-13_22-30	5.72	0.66	4.82	0.74	1.69	0.27	0.01	0.39
SOIL-14_0-7	5.21	0.28	2.76	0.32	1.44	0.17	0.03	0.37
SOIL-14_7-12	5.57	0.2	2.87	0.31	1.52	0.18	0.02	0.38
SOIL-14_12-17	5.12	0.16	2.62	0.3	1.41	0.17	0.02	0.37
SOIL-14_17-22	5.73	0.14	3.05	0.31	1.61	0.18	0.01	0.38
SOIL-14_22-30	6.13	0.11	3.34	0.33	1.84	0.16	<0.01	0.35

[1] Analysis by hydride generation atomic absorption spectrometry.

Table F. Results of laboratory analysis by wavelength dispersive X-ray fluorescence of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by SGS Laboratories,Toronto, Ontario, Canada. cm, centimeters; <, less than]

Sample number	Sample location	Depth (cm)	Aluminum oxide Al_2O_3 (percent)	Calcium oxide CaO (percent)	Chromium(III) oxide Cr_2O_3 (percent)	Iron(III) oxide Fe_2O_3 (percent)	Potassium oxide K_2O (percent)
SOIL-1_6-12	377 feet southeast of furnace	15–30	6.01	1.03	<0.01	5.57	1.01
SOIL-2_6-14	1,350 feet southeast of furnace	15–36	11.2	0.28	<0.01	4.90	1.87
SOIL-2_4-22	1,350 feet southeast of furnace	36–56	11.1	0.19	<0.01	4.94	2.01
SOIL-2_22-32	1,350 feet southeast of furnace	56–81	9.22	0.10	<0.01	4.71	1.81
SOIL-3_6-14	3,400 feet northeast of furnace	15–36	11.4	0.16	<0.01	4.62	2.01
SOIL-3_14-22	3,400 feet northeast of furnace	36–56	12.4	0.14	<0.01	4.64	2.08
SOIL-3_22-32	3,400 feet northeast of furnace	56–81	12.7	0.09	<0.01	3.87	2.25
SOIL-3_22-32D	3,400 feet northeast of furnace	59–81 duplicate	12.8	0.09	<0.01	3.89	2.26

Sample number	Magnesium oxide MgO (percent)	Manganese oxide MnO (percent)	Sodium oxide Na_2O (percent)	Phosphorous pentoxide P_2O_5 (percent)	Silicon dioxide (silica) SiO_2 (percent)	Titanium dioxide TiO_2 (percent)	Loss on ignition (percent)
SOIL-1_6-12	0.58	0.11	0.36	0.11	62.3	0.68	22.30
SOIL-2_6-14	0.72	0.04	0.58	0.08	73	0.94	6.36
SOIL-2_4-22	0.73	0.05	0.5	0.05	74.7	0.87	4.58
SOIL-2_22-32	0.60	0.08	0.27	0.05	79	0.66	3.63
SOIL-3_6-14	0.48	0.13	0.44	0.07	75.7	0.83	5.20
SOIL-3_14-22	0.44	0.12	0.62	0.07	72.8	0.83	5.37
SOIL-3_22-32	0.32	0.11	0.95	0.05	74.4	0.77	4.52
SOIL-3_22-32D	0.31	0.1	1	0.05	74.2	0.77	4.60

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Sample location	Depth below land surface (cm)	Antimony (ppm)			Arsenic (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	14 feet east of ore roaster	2.5	58 E	41	123	10 E	11	33
SOIL-5-1-5		5.1	7 E	66	198	30 E	18	54
SOIL-5-1-7		7.6	ND	46	138	8 E	13	39
SOIL-5-1-10		10.2	ND	47	141	ND	13	39
SOIL-5-1-12		12.7	91 E	85	255	ND	35	105
SOIL-5-1-15		15.2	199 E	96	288	46 E	44	132
SOIL-5-1-17		17.8	195 E	169	507	ND	61	183
SOIL-5-1-20		20.3	74 E	141	423	ND	57	171
SOIL-5-1-22		22.9	8 E	88	264	249	39	117
SOIL-5-1-25		25.4	135 E	60	180	79	20	60
SOIL-5-2-33		33.0	ND	57	171	64	21	63
SOIL-5-2-35		35.6	ND	57	171	41 E	20	60
SOIL-5-2-38		38.1	5 E	33	99	13 E	5	15
SOIL-5-2-40		40.6	7 E	32	96	8 E	4	12
SOIL-5-2-45		45.7	47 E	33	99	3 E	5	15
SOIL-5-2-50		50.8	ND	32	96	6 E	4	12
SOIL-5-2-55		55.9	26 E	43	129	8 E	6	18
SOIL-5-2-61		61.0	ND	33	99	5 E	4	12
SOIL-5-2-66		66.0	ND	34	102	8 E	5	15
SOIL-5-3-68		68.6	ND	33	99	9 E	4	12
SOIL-5-3-73		73.7	45 E	35	105	15 E	4	12
SOIL-5-3-78		78.7	ND	33	99	8 E	4	12
SOIL-5-3-84		83.8	ND	34	102	ND	5	15
SOIL-5-3-88		88.9	21 E	33	99	ND	4	12
SOIL-5-3-94		94.0	ND	33	99	ND	4	12
SOIL-6-1-3	43 feet east of ore roaster	3.0	ND	33	99	6 E	9	27
SOIL-6-1-6		6.1	ND	37	111	ND	11	33
SOIL-6-1-9		9.1	ND	38	114	14 E	10	30
SOIL-6-1-12		12.2	24 E	40	120	15 E	12	36
SOIL-6-1-15		15.2	26 E	39	117	32 E	9	27
SOIL-6-1-18		18.3	52 E	37	111	9 E	6	18
SOIL-6-1-21		21.3	52 E	40	120	13 E	8	24
SOIL-6-1-24		24.4	12 E	42	126	6 E	9	27
SOIL-6-1-27		27.4	ND	43	129	24 E	8	24
SOIL-6-1-30		30.5	ND	44	132	8 E	10	30
SOIL-7-1-3	5 feet east of ore pile	3.0	ND	42	126	24 E	10	30
SOIL-7-1-6		6.1	ND	45	135	7 E	12	36
SOIL-7-1-9		9.1	ND	46	138	7 E	14	42
SOIL-7-1-12		12.2	ND	43	129	23 E	11	33
SOIL-7-1-15		15.2	ND	48	144	12 E	13	39
SOIL-7-1-18		18.3	10 E	34	102	ND	5	15
SOIL-7-1-21		21.3	ND	35	105	ND	5	15
SOIL-7-1-24		24.4	ND	39	117	11 E	7	21
SOIL-7-1-27		27.4	22 E	40	120	ND	6	18
SOIL-7-1-30		30.5	97 E	43	129	6 E	7	21
SOIL-8-1-3	190 feet south of furnace	3.0	17 E	34	102	ND	5	15
SOIL-8-1-6		6.1	16 E	32	96	ND	5	15
SOIL-8-1-9		9.1	ND	36	108	ND	6	18
SOIL-8-1-12		12.2	20 E	36	108	8 E	6	18
SOIL-8-1-15		15.2	52 E	36	108	3 E	5	15
SOIL-8-1-18		18.3	2 E	34	102	ND	5	15
SOIL-8-1-21		21.3	97 E	38	114	18 E	6	18
SOIL-8-1-24		24.4	52 E	36	108	10 E	5	15
SOIL-8-1-27		27.4	21 E	40	120	ND	6	18
SOIL-8-1-30		30.5	ND	41	123	ND	6	18
SOIL-8-1-33		33.5	ND	34	102	14 E	5	15
SOIL-8-1-36		36.6	45 E	35	105	12 E	5	15
SOIL-8-1-39		39.6	21 E	37	111	5 E	5	15
SOIL-8-1-42		42.7	ND	35	105	7 E	5	15

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Barium (ppm)			Bromine (ppm)			Cadmium (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	186 E	307	921	22 E	7	21	ND	24	72
SOIL-5-1-5	498 E	478	1,434	10 E	12	36	17 E	37	111
SOIL-5-1-7	526 E	333	999	21 E	8	24	ND	26	78
SOIL-5-1-10	413 E	301	903	12 E	8	24	ND	27	81
SOIL-5-1-12	646 E	609	1,830	38 E	18	54	ND	47	141
SOIL-5-1-15	ND	1,080	3,240	ND	23	69	ND	55	165
SOIL-5-1-17	370 E	2,390	7,170	117	29	87	ND	94	282
SOIL-5-1-20	ND	1,940	5,820	136	33	99	ND	79	237
SOIL-5-1-22	1,230 E	1,660	4,980	164	25	75	ND	49	147
SOIL-5-1-25	672 E	600	1,800	40 E	12	36	38 E	33	99
SOIL-5-2-33	1,020 E	685	2,060	64	13	39	21 E	32	96
SOIL-5-2-35	1,640 E	659	1,980	50 E	11	33	ND	30	90
SOIL-5-2-38	738	210	630	15 E	6	18	ND	19	57
SOIL-5-2-40	528 E	184	552	11 E	5	15	4 E	18	54
SOIL-5-2-45	463 E	199	597	8 E	5	15	ND	19	57
SOIL-5-2-50	582	181	543	3 E	5	15	ND	18	54
SOIL-5-2-55	344 E	242	726	20 E	7	21	ND	24	72
SOIL-5-2-61	521 E	186	558	5 E	5	15	6 E	18	54
SOIL-5-2-66	397 E	194	582	6 E	6	18	4 E	18	54
SOIL-5-3-68	739	196	588	1 E	5	15	ND	18	54
SOIL-5-3-73	35 E	181	543	9 E	5	15	17 E	19	57
SOIL-5-3-78	291 E	184	552	1 E	5	15	ND	18	54
SOIL-5-3-84	450 E	197	591	5 E	6	18	13 E	19	57
SOIL-5-3-88	193 E	179	537	1 E	5	15	20 E	18	54
SOIL-5-3-94	529 E	185	555	3 E	5	15	6 E	18	54
SOIL-6-1-3	492 E	205	615	9 E	6	18	ND	18	54
SOIL-6-1-6	588 E	253	759	14 E	7	21	ND	21	63
SOIL-6-1-9	763 E	272	816	11 E	7	21	4 E	21	63
SOIL-6-1-12	411 E	291	873	14 E	8	24	47 E	22	66
SOIL-6-1-15	928	277	831	19 E	8	24	10 E	21	63
SOIL-6-1-18	738	228	684	8 E	6	18	ND	21	63
SOIL-6-1-21	505 E	286	858	9 E	7	21	14 E	22	66
SOIL-6-1-24	370 E	307	921	7 E	7	21	17 E	24	72
SOIL-6-1-27	493 E	341	1,020	22 E	7	21	4 E	25	75
SOIL-6-1-30	483 E	371	1,110	21 E	8	24	5 E	25	75
SOIL-7-1-3	1,150	359	1,080	9 E	8	24	29 E	24	72
SOIL-7-1-6	ND	341	1,020	29 E	8	24	ND	25	75
SOIL-7-1-9	1,330	404	1,210	15 E	10	30	ND	26	78
SOIL-7-1-12	673 E	320	960	ND	9	27	33 E	24	72
SOIL-7-1-15	703 E	333	999	ND	8	24	ND	26	78
SOIL-7-1-18	329 E	172	516	3 E	5	15	7 E	19	57
SOIL-7-1-21	340 E	180	540	18 E	5	15	ND	19	57
SOIL-7-1-24	239 E	233	699	1 E	6	18	ND	22	66
SOIL-7-1-27	826	251	753	ND	7	21	ND	22	66
SOIL-7-1-30	287 E	232	696	ND	6	18	21 E	24	72
SOIL-8-1-3	321 E	175	525	4 E	5	15	14 E	19	57
SOIL-8-1-6	301 E	179	537	3 E	6	18	13 E	18	54
SOIL-8-1-9	686	215	645	10 E	5	15	36 E	20	60
SOIL-8-1-12	428 E	220	660	ND	6	18	ND	20	60
SOIL-8-1-15	632 E	230	690	1 E	6	18	ND	20	60
SOIL-8-1-18	889	222	666	10 E	5	15	19 E	19	57
SOIL-8-1-21	232 E	229	687	15 E	7	21	ND	22	66
SOIL-8-1-24	625 E	233	699	8 E	6	18	ND	20	60
SOIL-8-1-27	764 E	260	780	10 E	7	21	29 E	22	66
SOIL-8-1-30	1,080 E	267	801	7 E	7	21	ND	23	69
SOIL-8-1-33	543 E	195	585	2 E	6	18	10 E	19	57
SOIL-8-1-36	555 E	215	645	13 E	6	18	ND	19	57
SOIL-8-1-39	303 E	207	621	6 E	6	18	ND	21	63
SOIL-8-1-42	690	213	639	13 E	6	18	10 E	20	60

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Chromium (ppm)			Cobalt (ppm)			Copper (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	135 E	86	258	1,010	231	693	76	17	51
SOIL-5-1-5	ND	113	339	1,350	345	1,040	93	28	84
SOIL-5-1-7	48 E	87	261	773	236	708	132	21	63
SOIL-5-1-10	ND	72	216	625	202	606	141	22	66
SOIL-5-1-12	ND	150	450	1,110 E	426	1,280	150	39	117
SOIL-5-1-15	ND	283	849	3,710	1,000	3,000	190	56	168
SOIL-5-1-17	ND	663	2,000	3,320 E	2,300	6,900	ND	79	237
SOIL-5-1-20	ND	551	1,650	1,450 E	1,920	5,760	71 E	80	240
SOIL-5-1-22	ND	488	1,460	2,480 E	1,620	4,860	93 E	61	183
SOIL-5-1-25	ND	165	495	79 E	527	1,580	62 E	27	81
SOIL-5-2-33	67 E	190	570	1,400 E	596	1,790	168	33	99
SOIL-5-2-35	ND	174	522	2,480	563	1,690	73 E	27	81
SOIL-5-2-38	23 E	49	147	174 E	100	300	24 E	11	33
SOIL-5-2-40	81 E	44	132	217 E	73	219	26 E	10	30
SOIL-5-2-45	ND	45	135	380	97	291	18 E	11	33
SOIL-5-2-50	68 E	43	129	450	74	222	ND	9	27
SOIL-5-2-55	24 E	56	168	138 E	99	297	ND	13	39
SOIL-5-2-61	80 E	44	132	307	77	231	10 E	10	30
SOIL-5-2-66	137	49	147	215 E	88	264	11 E	10	30
SOIL-5-3-68	17 E	42	126	350	78	234	24 E	11	33
SOIL-5-3-73	64 E	45	135	242 E	81	243	26 E	11	33
SOIL-5-3-78	120 E	46	138	345	81	243	13 E	10	30
SOIL-5-3-84	66 E	45	135	341	85	255	7 E	10	30
SOIL-5-3-88	15 E	41	123	199 E	78	234	26 E	11	33
SOIL-5-3-94	ND	39	117	221 E	78	234	42 E	11	33
SOIL-6-1-3	163 E	58	174	928	134	402	47 E	12	36
SOIL-6-1-6	83 E	64	192	773	160	480	93	15	45
SOIL-6-1-9	344	75	225	1,060	171	513	99	15	45
SOIL-6-1-12	106 E	75	225	745	192	576	104	17	51
SOIL-6-1-15	106 E	69	207	754	173	519	189	18	54
SOIL-6-1-18	22 E	56	168	296 E	129	387	53 E	13	39
SOIL-6-1-21	8 E	70	210	626	186	558	107	17	51
SOIL-6-1-24	109 E	79	237	673	204	612	162	20	60
SOIL-6-1-27	176 E	93	279	330 E	238	714	107	19	57
SOIL-6-1-30	ND	93	279	830 E	285	855	106	20	60
SOIL-7-1-3	112 E	85	255	866	221	663	150	20	60
SOIL-7-1-6	391	104	312	393 E	256	768	148	21	63
SOIL-7-1-9	639	124	372	ND	279	837	131	22	66
SOIL-7-1-12	417	96	288	194 E	204	612	139	20	60
SOIL-7-1-15	379	97	291	253 E	198	594	84	19	57
SOIL-7-1-18	73 E	43	129	25 E	61	183	16 E	10	30
SOIL-7-1-21	72 E	44	132	287	67	201	22 E	11	33
SOIL-7-1-24	23 E	56	168	272 E	128	384	67	15	45
SOIL-7-1-27	12 E	54	162	273 E	105	315	ND	12	36
SOIL-7-1-30	63 E	56	168	168 E	104	312	34 E	14	42
SOIL-8-1-3	57 E	44	132	238	77	231	28 E	11	33
SOIL-8-1-6	26 E	43	129	253	83	249	34 E	11	33
SOIL-8-1-9	ND	46	138	141 E	94	282	22 E	12	36
SOIL-8-1-12	88 E	54	162	544	112	336	48 E	13	39
SOIL-8-1-15	112 E	56	168	560	122	366	16 E	12	36
SOIL-8-1-18	51 E	50	150	537	103	309	38 E	12	36
SOIL-8-1-21	91 E	55	165	260 E	104	312	8 E	12	36
SOIL-8-1-24	21 E	52	156	222 E	110	330	25 E	12	36
SOIL-8-1-27	70 E	61	183	258 E	128	384	14 E	13	39
SOIL-8-1-30	ND	56	168	362 E	127	381	43 E	14	42
SOIL-8-1-33	99 E	48	144	328	91	273	31 E	11	33
SOIL-8-1-36	100 E	51	153	339	93	279	24 E	11	33
SOIL-8-1-39	24 E	48	144	318	93	279	18 E	12	36
SOIL-8-1-42	51 E	48	144	390	92	276	18 E	11	33

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Gold (ppm)			Iron (ppm)			Lead (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	15 E	4	12	127,000	2,290	6,870	117	11	33
SOIL-5-1-5	16 E	7	21	112,000	3,150	9,450	120	17	51
SOIL-5-1-7	18 E	5	15	118,000	2,270	6,810	174	13	39
SOIL-5-1-10	13 E	5	15	72,100	1,550	4,650	143	13	39
SOIL-5-1-12	24 E	11	33	113,000	3,940	11,800	423	37	111
SOIL-5-1-15	38 E	10	30	450,000	18,200	54,600	385	46	138
SOIL-5-1-17	85	18	54	868,000	59,600	179,000	293	69	207
SOIL-5-1-20	118	16	48	871,000	51,600	155,000	359	62	186
SOIL-5-1-22	216	16	48	>900,000	63,100	190,000	ND	47	141
SOIL-5-1-25	51 E	8	24	387,000	9,220	27,700	157	20	60
SOIL-5-2-33	65	7	21	530,000	12,100	36,300	201	22	66
SOIL-5-2-35	65	7	21	521,000	11,100	33,300	208	22	66
SOIL-5-2-38	ND	3	9	40,500	606	1,820	15 E	5	15
SOIL-5-2-40	2 E	3	9	23,000	357	1,070	12 E	4	12
SOIL-5-2-45	2 E	3	9	38,100	567	1,700	23 E	5	15
SOIL-5-2-50	4 E	3	9	22,400	346	1,040	16 E	4	12
SOIL-5-2-55	ND	3	9	23,900	495	1,490	10 E	5	15
SOIL-5-2-61	5 E	3	9	24,200	375	1,130	14 E	4	12
SOIL-5-2-66	ND	3	9	31,200	481	1,440	16 E	5	15
SOIL-5-3-68	ND	3	9	24,400	382	1,150	13 E	4	12
SOIL-5-3-73	ND	3	9	25,200	407	1,220	6 E	4	12
SOIL-5-3-78	5 E	3	9	27,500	415	1,250	12 E	4	12
SOIL-5-3-84	6 E	3	9	29,500	450	1,350	27 E	5	15
SOIL-5-3-88	5 E	3	9	25,100	392	1,180	20 E	5	15
SOIL-5-3-94	3 E	3	9	25,200	391	1,170	19 E	5	15
SOIL-6-1-3	9 E	3	9	68,900	980	2,940	153	9	27
SOIL-6-1-6	10 E	4	12	84,300	1,300	3,900	207	11	33
SOIL-6-1-9	12 E	4	12	97,900	1,470	4,410	166	10	30
SOIL-6-1-12	16 E	5	15	105,000	1,740	5,220	198	12	36
SOIL-6-1-15	15 E	5	15	97,200	1,510	4,530	89	9	27
SOIL-6-1-18	7 E	3	9	55,900	894	2,680	30 E	6	18
SOIL-6-1-21	15 E	4	12	99,100	1,650	4,950	48 E	8	24
SOIL-6-1-24	15 E	4	12	105,000	1,860	5,580	90	10	30
SOIL-6-1-27	12 E	4	12	135,000	2,470	7,410	35 E	8	24
SOIL-6-1-30	18 E	4	12	189,000	3,450	10,400	78	11	33
SOIL-7-1-3	10 E	4	12	127,000	2,190	6,570	84	10	30
SOIL-7-1-6	22 E	5	15	156,000	2,850	8,550	133	12	36
SOIL-7-1-9	17 E	5	15	170,000	3,270	9,810	175	14	42
SOIL-7-1-12	15 E	5	15	101,000	1,870	5,610	110	11	33
SOIL-7-1-15	16 E	5	15	81,800	1,650	4,950	147	12	36
SOIL-7-1-18	3 E	3	9	14,700	265	795	26 E	5	15
SOIL-7-1-21	2 E	3	9	15,200	278	834	29 E	5	15
SOIL-7-1-24	5 E	4	12	47,500	832	2,500	43 E	7	21
SOIL-7-1-27	3 E	4	12	31,100	573	1,720	31 E	6	18
SOIL-7-1-30	6 E	4	12	28,500	555	1,670	34 E	7	21
SOIL-8-1-3	6 E	3	9	22,200	370	1,110	45 E	6	18
SOIL-8-1-6	1 E	3	9	27,100	429	1,290	45 E	6	18
SOIL-8-1-9	2 E	3	9	29,900	512	1,540	46 E	6	18
SOIL-8-1-12	4 E	3	9	42,100	673	2,020	26 E	6	18
SOIL-8-1-15	2 E	3	9	51,400	797	2,390	27 E	6	18
SOIL-8-1-18	7 E	3	9	37,400	585	1,760	34 E	6	18
SOIL-8-1-21	3 E	4	12	31,500	572	1,720	13 E	5	15
SOIL-8-1-24	8 E	4	12	40,200	668	2,000	18 E	5	15
SOIL-8-1-27	6 E	4	12	46,500	824	2,470	25 E	6	18
SOIL-8-1-30	5 E	4	12	43,600	789	2,370	27 E	6	18
SOIL-8-1-33	2 E	3	9	32,300	497	1,490	14 E	5	15
SOIL-8-1-36	ND	3	9	30,500	496	1,490	23 E	5	15
SOIL-8-1-39	4 E	3	9	27,800	481	1,440	22 E	5	15
SOIL-8-1-42	ND	3	9	30,200	489	1,470	16 E	5	15

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Manganese (ppm)			Mercury (ppm)			Molybdenum (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	1,370	132	396	ND	7	21	16 E	5	15
SOIL-5-1-5	2,150	226	678	ND	12	36	1 E	7	21
SOIL-5-1-7	1,710	146	438	ND	8	24	8 E	5	15
SOIL-5-1-10	1,430	136	408	ND	8	24	3 E	5	15
SOIL-5-1-12	1,770	266	798	ND	15	45	ND	9	27
SOIL-5-1-15	2,120	484	1,450	ND	22	66	39 E	12	36
SOIL-5-1-17	2,560 E	1,080	3,240	ND	18	54	51 E	20	60
SOIL-5-1-20	3,610	947	2,840	ND	31	93	23 E	16	48
SOIL-5-1-22	4,680	763	2,290	ND	26	78	41 E	9	27
SOIL-5-1-25	1,300	254	762	ND	12	36	17 E	6	18
SOIL-5-2-33	2,800	304	912	ND	12	36	13 E	6	18
SOIL-5-2-35	3,960	305	915	ND	11	33	ND	6	18
SOIL-5-2-38	3,180	116	348	4 E	5	15	ND	4	12
SOIL-5-2-40	2,330	93	279	2 E	5	15	4 E	4	12
SOIL-5-2-45	2,600	104	312	2 E	5	15	ND	4	12
SOIL-5-2-50	2,100	87	261	3 E	5	15	ND	3	9
SOIL-5-2-55	2,110	119	357	4 E	6	18	2 E	5	15
SOIL-5-2-61	1,220	71	213	ND	5	15	ND	4	12
SOIL-5-2-66	922	69	207	7 E	5	15	ND	4	12
SOIL-5-3-68	843	63	189	8 E	5	15	ND	4	12
SOIL-5-3-73	1,240	75	225	ND	4	12	ND	4	12
SOIL-5-3-78	487	55	165	7 E	5	15	2 E	4	12
SOIL-5-3-84	444	55	165	6 E	5	15	ND	4	12
SOIL-5-3-88	304	49	147	3 E	5	15	ND	4	12
SOIL-5-3-94	654	58	174	ND	5	15	5 E	4	12
SOIL-6-1-3	1,260	87	261	ND	6	18	10 E	4	12
SOIL-6-1-6	2,000	114	342	1 E	7	21	12 E	4	12
SOIL-6-1-9	2,150	119	357	ND	7	21	3 E	4	12
SOIL-6-1-12	2,060	130	390	6 E	8	24	8 E	4	12
SOIL-6-1-15	1,900	116	348	15 E	8	24	ND	4	12
SOIL-6-1-18	1,130	89	267	3 E	6	18	4 E	4	12
SOIL-6-1-21	2,180	131	393	3 E	7	21	2 E	4	12
SOIL-6-1-24	2,090	139	417	ND	8	24	1 E	5	15
SOIL-6-1-27	2,300	157	471	ND	7	21	6 E	5	15
SOIL-6-1-30	2,170	167	501	ND	8	24	2 E	5	15
SOIL-7-1-3	2,920	159	477	4 E	8	24	11 E	5	15
SOIL-7-1-6	4,220	201	603	ND	7	21	12 E	5	15
SOIL-7-1-9	3,920	209	627	10 E	10	30	10 E	5	15
SOIL-7-1-12	4,400	193	579	8 E	9	27	12 E	5	15
SOIL-7-1-15	3,740	188	564	ND	9	27	ND	5	15
SOIL-7-1-18	1,500	79	237	1 E	5	15	ND	4	12
SOIL-7-1-21	232	45	135	ND	5	15	5 E	4	12
SOIL-7-1-24	686	81	243	2 E	6	18	4 E	4	12
SOIL-7-1-27	1,470	96	288	10 E	7	21	11 E	5	15
SOIL-7-1-30	575	73	219	ND	6	18	ND	4	12
SOIL-8-1-3	720	62	186	2 E	5	15	ND	4	12
SOIL-8-1-6	850	66	198	9 E	6	18	4 E	4	12
SOIL-8-1-9	828	72	216	ND	5	15	ND	4	12
SOIL-8-1-12	1,750	96	288	10 E	6	18	8 E	4	12
SOIL-8-1-15	615	73	219	13 E	6	18	ND	4	12
SOIL-8-1-18	1,260	81	243	ND	5	15	5 E	4	12
SOIL-8-1-21	887	80	240	ND	6	18	2 E	4	12
SOIL-8-1-24	1,510	93	279	ND	6	18	ND	4	12
SOIL-8-1-27	1,600	105	315	5 E	7	21	2 E	4	12
SOIL-8-1-30	1,350	99	297	2 E	6	18	2 E	4	12
SOIL-8-1-33	627	62	186	6 E	5	15	ND	4	12
SOIL-8-1-36	1,560	87	261	3 E	5	15	ND	4	12
SOIL-8-1-39	722	69	207	ND	5	15	ND	4	12
SOIL-8-1-42	687	66	198	2 E	5	15	3 E	4	12

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Nickel (ppm)			Rubidium (ppm)			Selenium (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	ND	42	126	30 E	3	9	ND	3	9
SOIL-5-1-5	ND	64	192	36 E	5	15	ND	4	12
SOIL-5-1-7	ND	43	129	33 E	4	12	ND	3	9
SOIL-5-1-10	ND	40	120	24 E	3	9	ND	3	9
SOIL-5-1-12	ND	83	249	28 E	6	18	ND	7	21
SOIL-5-1-15	ND	163	489	38 E	9	27	ND	8	24
SOIL-5-1-17	ND	388	1,160	34 E	16	48	ND	15	45
SOIL-5-1-20	ND	297	891	9 E	12	36	ND	9	27
SOIL-5-1-22	ND	258	774	ND	11	33	ND	8	24
SOIL-5-1-25	ND	88	264	38 E	5	15	ND	4	12
SOIL-5-2-33	ND	105	315	44 E	5	15	ND	4	12
SOIL-5-2-35	ND	99	297	54 E	5	15	ND	4	12
SOIL-5-2-38	42 E	23	69	73	3	9	1 E	2	6
SOIL-5-2-40	34 E	20	60	63	3	9	ND	2	6
SOIL-5-2-45	ND	21	63	69	3	9	3 E	2	6
SOIL-5-2-50	38 E	20	60	68	3	9	ND	2	6
SOIL-5-2-55	73 E	28	84	73	4	12	2 E	2	6
SOIL-5-2-61	23 E	20	60	73	3	9	ND	2	6
SOIL-5-2-66	40 E	22	66	80	4	12	2 E	2	6
SOIL-5-3-68	34 E	21	63	76	3	9	1 E	2	6
SOIL-5-3-73	69	22	66	65	3	9	ND	2	6
SOIL-5-3-78	27 E	21	63	88	4	12	ND	2	6
SOIL-5-3-84	64 E	22	66	88	4	12	1 E	2	6
SOIL-5-3-88	41 E	20	60	80	3	9	ND	2	6
SOIL-5-3-94	19 E	20	60	89	4	12	3 E	2	6
SOIL-6-1-3	7 E	28	84	36 E	3	9	ND	2	6
SOIL-6-1-6	2 E	33	99	50 E	3	9	ND	2	6
SOIL-6-1-9	34 E	35	105	45 E	3	9	6 E	3	9
SOIL-6-1-12	ND	37	111	47 E	3	9	ND	3	9
SOIL-6-1-15	55 E	36	108	48E	3	9	5 E	3	9
SOIL-6-1-18	18 E	28	84	31 E	3	9	ND	2	6
SOIL-6-1-21	ND	36	108	70	4	12	ND	3	9
SOIL-6-1-24	15 E	41	123	45 E	4	12	ND	3	9
SOIL-6-1-27	ND	44	132	55 E	4	12	4 E	3	9
SOIL-6-1-30	ND	51	153	55 E	4	12	3 E	3	9
SOIL-7-1-3	ND	42	126	28 E	3	9	5 E	3	9
SOIL-7-1-6	ND	47	141	25 E	3	9	ND	3	9
SOIL-7-1-9	34 E	52	156	31 E	4	12	ND	3	9
SOIL-7-1-12	5 E	40	120	37 E	4	12	2 E	3	9
SOIL-7-1-15	ND	38	114	41 E	4	12	ND	3	9
SOIL-7-1-18	21 E	18	54	78	4	12	ND	2	6
SOIL-7-1-21	6 E	19	57	83	4	12	1 E	2	6
SOIL-7-1-24	28 E	29	87	64	4	12	1 E	2	6
SOIL-7-1-27	12 E	25	75	78	4	12	5 E	3	9
SOIL-7-1-30	21 E	26	78	77	4	12	ND	2	6
SOIL-8-1-3	6 E	20	60	63	3	9	ND	2	6
SOIL-8-1-6	13 E	21	63	76	3	9	ND	2	6
SOIL-8-1-9	25 E	23	69	86	4	12	ND	2	6
SOIL-8-1-12	23 E	26	78	131	5	15	ND	2	6
SOIL-8-1-15	16 E	27	81	156	5	15	1 E	2	6
SOIL-8-1-18	17 E	24	72	101	4	12	2 E	2	6
SOIL-8-1-21	34 E	26	78	101	5	15	6 E	3	9
SOIL-8-1-24	45 E	26	78	114	5	15	ND	2	6
SOIL-8-1-27	54 E	30	90	116	5	15	5 E	3	9
SOIL-8-1-30	ND	28	84	162	6	18	1E	2	6
SOIL-8-1-33	25 E	22	66	92	4	12	ND	2	6
SOIL-8-1-36	36 E	23	69	99	4	12	2 E	2	6
SOIL-8-1-39	35 E	24	72	84	4	12	ND	2	6
SOIL-8-1-42	15 E	23	69	84	4	12	1 E	2	6

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Silver (ppm)			Strontium (ppm)			Tin (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	ND	19	57	37 E	3	9	ND	39	117
SOIL-5-1-5	60 E	30	90	44 E	6	18	ND	61	183
SOIL-5-1-7	14 E	21	63	43 E	4	12	ND	43	129
SOIL-5-1-10	ND	22	66	55 E	4	12	ND	44	132
SOIL-5-1-12	42 E	38	114	40 E	7	21	ND	77	231
SOIL-5-1-15	12 E	45	135	41 E	8	24	200 E	90	270
SOIL-5-1-17	66 E	81	243	48 E	14	42	252 E	159	477
SOIL-5-1-20	180 E	68	204	18 E	9	27	151 E	136	408
SOIL-5-1-22	ND	40	120	22 E	6	18	ND	81	243
SOIL-5-1-25	34 E	27	81	35 E	4	12	25 E	55	165
SOIL-5-2-33	9 E	26	78	39 E	4	12	16 E	53	159
SOIL-5-2-35	2 E	25	75	49 E	5	15	16 E	53	159
SOIL-5-2-38	8 E	15	45	51 E	3	9	ND	31	93
SOIL-5-2-40	ND	15	45	46 E	3	9	ND	30	90
SOIL-5-2-45	ND	15	45	47 E	3	9	48 E	31	93
SOIL-5-2-50	ND	14	42	44 E	3	9	2 E	29	87
SOIL-5-2-55	ND	20	60	44 E	3	9	40 E	40	120
SOIL-5-2-61	15 E	15	45	45 E	3	9	28 E	30	90
SOIL-5-2-66	ND	15	45	36 E	3	9	ND	31	93
SOIL-5-3-68	10 E	15	45	41 E	3	9	ND	31	93
SOIL-5-3-73	16 E	16	48	37 E	3	9	31 E	32	96
SOIL-5-3-78	46 E	15	45	46 E	3	9	13 E	30	90
SOIL-5-3-84	32 E	15	45	43E	3	9	8 E	32	96
SOIL-5-3-88	25 E	15	45	39 E	3	9	22 E	30	90
SOIL-5-3-94	ND	15	45	45 E	3	9	ND	30	90
SOIL-6-1-3	12 E	15	45	51 E	3	9	8 E	31	93
SOIL-6-1-6	ND	17	51	74	4	12	25 E	34	102
SOIL-6-1-9	ND	17	51	73	4	12	52 E	35	105
SOIL-6-1-12	ND	18	54	64	4	12	110 E	37	111
SOIL-6-1-15	ND	17	51	71	4	12	58 E	36	108
SOIL-6-1-18	ND	17	51	50 E	3	9	4 E	34	102
SOIL-6-1-21	18 E	18	54	111	5	15	34 E	37	111
SOIL-6-1-24	8 E	19	57	65	4	12	ND	39	117
SOIL-6-1-27	ND	20	60	109	5	15	15 E	41	123
SOIL-6-1-30	ND	20	60	113	5	15	72 E	41	123
SOIL-7-1-3	9 E	19	57	186	7	21	ND	39	117
SOIL-7-1-6	5 E	20	60	177	7	21	57 E	42	126
SOIL-7-1-9	ND	21	63	176	7	21	ND	43	129
SOIL-7-1-12	15 E	20	60	162	6	18	ND	40	120
SOIL-7-1-15	ND	22	66	141	6	18	86 E	44	132
SOIL-7-1-18	1 E	16	48	47 E	3	9	47 E	31	93
SOIL-7-1-21	ND	16	48	45 E	3	9	ND	32	96
SOIL-7-1-24	30 E	18	54	44 E	3	9	ND	36	108
SOIL-7-1-27	ND	18	54	103	5	15	74 E	37	111
SOIL-7-1-30	7 E	19	57	41 E	3	9	89 E	39	117
SOIL-8-1-3	ND	15	45	27 E	2	6	35 E	31	93
SOIL-8-1-6	ND	15	45	34 E	3	9	36 E	30	90
SOIL-8-1-9	ND	16	48	31 E	3	9	1 E	34	102
SOIL-8-1-12	ND	16	48	37 E	3	9	28 E	33	99
SOIL-8-1-15	1 E	16	48	39 E	3	9	35 E	33	99
SOIL-8-1-18	ND	15	45	36 E	3	9	76 E	32	96
SOIL-8-1-21	2 E	18	54	41 E	3	9	4 E	36	108
SOIL-8-1-24	ND	17	51	42 E	3	9	34 E	34	102
SOIL-8-1-27	24 E	18	54	31 E	3	9	ND	37	111
SOIL-8-1-30	ND	18	54	42 E	3	9	1 E	38	114
SOIL-8-1-33	ND	15	45	44 E	3	9	ND	31	93
SOIL-8-1-36	ND	16	48	43 E	3	9	83 E	32	96
SOIL-8-1-39	36 E	17	51	40 E	3	9	ND	35	105
SOIL-8-1-42	13 E	16	48	42 E	3	9	26 E	33	99

Table G. Results of analyses by X-ray fluorescence spectroscopy of soil samples from Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Analyses by Cynthia Hall and Martin Helmke of West Chester University and Michael Degnan of the U.S. Geological Survey. cm, centimeters; ppm, parts per million; E, estimated value below the level of detection; ND, not detected; >, greater than]

Sample number	Titanium (ppm)			Zinc (ppm)			Zirconium (ppm)		
	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
SOIL-5-1-2	4,640	847	2,540	270	17	51	116	5	15
SOIL-5-1-5	4,420	1,310	3,930	271	27	81	143	9	27
SOIL-5-1-7	4,340	906	2,720	311	20	60	166	7	21
SOIL-5-1-10	2,080 E	793	2,380	198	17	51	105	6	18
SOIL-5-1-12	4,330 E	1,650	4,950	242	32	96	151	11	33
SOIL-5-1-15	11,800	3,090	9,270	351	47	141	152	14	42
SOIL-5-1-17	2,550 E	6,110	18,300	842	126	378	65	18	54
SOIL-5-1-20	11,800 E	5,370	16,100	451	78	234	41 E	13	39
SOIL-5-1-22	ND	4,130	12,400	676	58	174	32 E	7	21
SOIL-5-1-25	1,650 E	1,520	4,560	392	29	87	90	7	21
SOIL-5-2-33	6,620	1,800	5,400	532	33	99	112	7	21
SOIL-5-2-35	7,050	1,730	5,190	601	32	96	140	7	21
SOIL-5-2-38	5,300	598	1,790	77	8	24	346	7	21
SOIL-5-2-40	5,190	535	1,610	47 E	6	18	310	6	18
SOIL-5-2-45	5,840	585	1,760	105	8	24	311	7	21
SOIL-5-2-50	4,510	514	1,540	66	7	21	303	6	18
SOIL-5-2-55	5,760	725	2,180	56 E	9	27	314	9	27
SOIL-5-2-61	5,110	540	1,620	62	7	21	330	7	21
SOIL-5-2-66	5,510	570	1,710	51 E	6	18	313	7	21
SOIL-5-3-68	5,350	563	1,690	46 E	6	18	306	6	18
SOIL-5-3-73	6,000	561	1,680	55 E	7	21	295	7	21
SOIL-5-3-78	6,190	555	1,670	53 E	6	18	338	7	21
SOIL-5-3-84	6,730	593	1,780	40 E	6	18	321	7	21
SOIL-5-3-88	6,020	550	1,650	46 E	6	18	287	6	18
SOIL-5-3-94	4,840	535	1,610	31 E	5	15	227	5	15
SOIL-6-1-3	1,970	530	1,590	366	15	45	180	5	15
SOIL-6-1-6	5,320	708	2,120	357	17	51	184	6	18
SOIL-6-1-9	7,070	770	2,310	378	17	51	173	5	15
SOIL-6-1-12	7,520	846	2,540	342	18	54	219	7	21
SOIL-6-1-15	6,010	770	2,310	245	14	42	201	6	18
SOIL-6-1-18	2,710	602	1,810	92	9	27	128	5	15
SOIL-6-1-21	6,680	820	2,460	214	14	42	209	6	18
SOIL-6-1-24	7,470	893	2,680	267	17	51	185	6	18
SOIL-6-1-27	6,490	957	2,870	198	15	45	203	7	21
SOIL-6-1-30	6,520	1,030	3,090	288	18	54	199	7	21
SOIL-7-1-3	11,300	1,050	3,150	257	16	48	107	5	15
SOIL-7-1-6	8,600	1,010	3,030	372	21	63	155	6	18
SOIL-7-1-9	3,530	1,030	3,090	396	23	69	168	7	21
SOIL-7-1-12	4,830	869	2,610	342	20	60	203	7	21
SOIL-7-1-15	5,180	915	2,750	282	19	57	182	7	21
SOIL-7-1-18	3,470	488	1,460	62	7	21	145	5	15
SOIL-7-1-21	3,990	519	1,560	34 E	6	18	199	5	15
SOIL-7-1-24	5,400	684	2,050	83	9	27	240	7	21
SOIL-7-1-27	6,270	730	2,190	54 E	8	24	374	9	27
SOIL-7-1-30	5,480	692	2,080	62	9	27	220	7	21
SOIL-8-1-3	3,020	487	1,460	72	7	21	137	4	12
SOIL-8-1-6	3,850	510	1,530	69	7	21	164	5	15
SOIL-8-1-9	4,270	603	1,810	78	8	24	166	5	15
SOIL-8-1-12	6,130	647	1,940	94	9	27	203	6	18
SOIL-8-1-15	6,040	662	1,990	100	9	27	182	5	15
SOIL-8-1-18	5,660	632	1,900	56 E	7	21	228	6	18
SOIL-8-1-21	7,170	707	2,120	64	8	24	239	7	21
SOIL-8-1-24	6,330	682	2,050	69	8	24	198	6	18
SOIL-8-1-27	6,040	746	2,240	64	9	27	185	6	18
SOIL-8-1-30	5,050	743	2,230	73	9	27	164	6	18
SOIL-8-1-33	4,380	550	1,650	75	7	21	281	6	18
SOIL-8-1-36	6,890	644	1,930	74	8	24	276	6	18
SOIL-8-1-39	5,700	621	1,860	56 E	7	21	261	7	21
SOIL-8-1-42	5,820	620	1,860	69	8	24	279	6	18

[1] The 1 sigma error represents the uncertainty of each analysis.

[2] The 3 sigma error is the level of detection. Values less than the 3 sigma error are estimated.

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Antimony (ppm)			Arsenic (ppm)			Barium (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	128 E	84	252	472	78	234	2,060 E	2,140	6,420
Stove 1	Ash lip	6	8 E	91	273	ND	80	240	2,320 E	2,430	7,290
Stove 1	Ash lip	7	50 E	79	237	500	78	234	ND	1,800	5,400
Stove 1	Top	8	ND	78	234	411	71	213	1,340 E	1,970	5,910
Stove 1	Top	9	99 E	83	249	565	71	213	2,300 E	2,070	6,210
Stove 1	Top	10	5 E	81	243	497	75	225	1,580 E	2,040	6,120
Stove 2	Ash lip	11	ND	92	276	1,330	116	348	ND	2,240	6,720
Stove 2	Ash lip	12	57 E	99	297	845	107	321	2,140 E	2,640	7,920
Stove 2	Ash lip	13	ND	71	213	995	108	324	299 E	1,570	4,710
Stove 2	Top	14	ND	89	267	1,080	123	369	ND	2,180	6,540
Stove 2	Top	15	ND	96	288	958	138	414	1,770 E	2,320	6,960
Stove 2	Top	16	70 E	77	231	992	116	348	ND	1,790	5,370
Stove 3	Ash lip	17	ND	100	300	407	92	276	4,250 E	2,650	7,950
Stove 3	Ash lip	18	ND	104	312	583	91	273	327 E	2,860	8,580
Stove 3	Ash lip	19	ND	94	282	533	79	237	ND	2,430	7,290
Stove 3	Top	20	ND	91	273	659	84	252	908 E	2,410	7,230
Stove 3	Top	21	10 E	87	261	410	77	231	3,760 E	2,300	6,900
Stove 3	Top	22	ND	89	267	229	68	204	3,810 E	2,300	6,900
Stove 4 [3]	Ash lip	23	26 E	96	288	738	100	300	ND	2,440	7,320
Stove 4 [3]	Ash lip	24	ND	95	285	709	92	276	2,860 E	2,470	7,410
Stove 4 [3]	Ash lip	25	ND	102	306	820	100	300	5,530 E	2,760	8,280
Stove 4 [3]	Top	26	75 E	89	267	394	77	231	ND	2,240	6,720
Stove 4 [3]	Top	27	ND	92	276	607	86	258	3,500 E	2,320	6,960
Stove 4 [3]	Top	28	ND	82	246	549	71	213	1,820 E	2,000	6,000
Stove 5	Ash lip	29	ND	83	249	341	52	156	3,430 E	2,030	6,090
Stove 5	Ash lip	30	3 E	87	261	223	54	162	2,100 E	1,950	5,850
Stove 5	Ash lip	31	ND	85	255	239	51	153	3,140 E	1,970	5,910
Stove 5	Top	32	ND	84	252	436	62	186	193 E	2,030	6,090
Stove 5	Top	33	43 E	86	258	328	60	180	2,550 E	2,150	6,450
Stove 5	Top	34	69 E	83	249	416	59	177	2,370 E	2,010	6,030
Stove 6	Ash lip	36	32 E	60	180	462	60	180	1,740 E	1,020	3,060
Stove 6	Ash lip	37	ND	69	207	298	58	174	945 E	1,240	3,720
Stove 6	Ash lip	38	ND	66	198	386	59	177	1,350 E	1,210	3,630
Stove 6	Top	39	66 E	73	219	440	64	192	1,020 E	1,590	4,770
Stove 6	Top	40	ND	77	231	711	90	270	2,680 E	1,780	5,340
Stove 6	Top	41	ND	79	237	759	86	258	ND	1,720	5,160
Stove 7	Ash lip	42	ND	88	264	562	75	225	3,950 E	2,300	6,900
Stove 7	Ash lip	43	ND	91	273	622	80	240	3,750 E	2,300	6,900
Stove 7	Ash lip	44	ND	97	291	549	83	249	ND	2,530	7,590
Stove 7	Top	45	ND	87	261	512	82	246	2,530 E	2,220	6,660
Stove 7	Top	46	ND	103	309	681	97	291	1,840 E	2,780	8,340
Stove 7	Top	47	ND	86	258	446	73	219	2,470 E	2,200	6,600
Stove 8	Ash lip	48	ND	90	270	382	84	252	925 E	2,150	6,450
Stove 8	Ash lip	49	66 E	87	261	640	94	282	3,290 E	2,150	6,450
Stove 8	Ash lip	50	105 E	83	249	208	48	144	ND	1,830	5,490
Stove 8	Top	52	39 E	75	225	316	59	177	1,320 E	1,690	5,070
Stove 8	Top	53	ND	76	228	243	51	153	ND	1,730	5,190
Stove 8	Top	54	0 E	75	225	175	58	174	ND	1,720	5,160
Stove 9	Ash lip	55	85 E	85	255	334	60	180	ND	2,050	6,150
Stove 9	Ash lip	56	ND	82	246	285	59	177	ND	1,890	5,670
Stove 9	Ash lip	57	59 E	87	261	380	65	195	684 E	2,160	6,480
Stove 9	Top	58	45 E	102	306	420	82	246	505 E	2,620	7,860
Stove 9	Top	59	88 E	87	261	356	64	192	6,100 E	2,320	6,960
Stove 9	Top	60	48 E	95	285	341	71	213	1,260 E	2,530	7,590
Footed pot	Outside	61	ND	143	429	1,050	178	534	100 E	3,840	11,500
Footed pot	Outside	62	ND	102	306	607	100	300	4,050 E	2,800	8,400
Footed pot	Inside	63	26 E	89	267	1,180	149	447	3,850 E	2,200	6,600
Footed pot	Inside	64	105 E	130	390	1,440	242	726	6,160 E	3,100	9,300
Footed pot	Outside	65	12 E	89	267	795	134	402	3,660 E	2,130	6,390
Footed pot	Outside	66	ND	129	387	922	155	465	553 E	3,410	10,200
Kettle	Outside	67	ND	95	285	ND	42	126	6,940 E	2,360	7,080
Kettle	Outside	68	43 E	103	309	ND	45	135	2,120 E	2,210	6,630
Kettle	Outside	69	140 E	94	282	ND	45	135	3,420 E	2,190	6,570

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Bromine (ppm)			Cadmium (ppm)			Chromium (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	265	35	105	ND	49	147	ND	611	1,830
Stove 1	Ash lip	6	238	41	123	ND	54	162	ND	684	2,050
Stove 1	Ash lip	7	233	36	108	ND	46	138	ND	522	1,570
Stove 1	Top	8	345	35	105	ND	47	141	346 E	588	1,760
Stove 1	Top	9	246	37	111	50 E	48	144	ND	582	1,750
Stove 1	Top	10	315	37	111	ND	47	141	ND	573	1,720
Stove 2	Ash lip	11	180	41	123	ND	52	156	ND	650	1,950
Stove 2	Ash lip	12	291	46	138	ND	57	171	ND	763	2,290
Stove 2	Ash lip	13	220	39	117	ND	43	129	ND	455	1,370
Stove 2	Top	14	222	42	126	131 E	52	156	ND	638	1,910
Stove 2	Top	15	201	48	144	3 E	56	168	ND	663	1,990
Stove 2	Top	16	172	41	123	ND	47	141	ND	532	1,600
Stove 3	Ash lip	17	415	42	126	ND	56	168	ND	758	2,270
Stove 3	Ash lip	18	404	47	141	1 E	60	180	ND	829	2,490
Stove 3	Ash lip	19	301	39	117	ND	53	159	ND	715	2,150
Stove 3	Top	20	386	40	120	6 E	53	159	ND	706	2,120
Stove 3	Top	21	333	35	105	16 E	52	156	ND	640	1,920
Stove 3	Top	22	374	34	102	ND	51	153	ND	651	1,950
Stove 4 [3]	Ash lip	23	349	48	144	ND	56	168	ND	718	2,150
Stove 4 [3]	Ash lip	24	287	43	129	ND	54	162	326 E	739	2,220
Stove 4 [3]	Ash lip	25	362	47	141	126 E	60	180	ND	798	2,390
Stove 4 [3]	Top	26	367	42	126	ND	52	156	369 E	675	2,030
Stove 4 [3]	Top	27	340	42	126	ND	51	153	ND	680	2,040
Stove 4 [3]	Top	28	257	34	102	ND	47	141	ND	560	1,680
Stove 5	Ash lip	29	297	33	99	69 E	47	141	590 E	602	1,810
Stove 5	Ash lip	30	301	35	105	ND	49	147	ND	557	1,670
Stove 5	Ash lip	31	324	32	96	ND	48	144	ND	556	1,670
Stove 5	Top	32	328	35	105	25 E	47	141	507 E	614	1,840
Stove 5	Top	33	344	35	105	ND	51	153	ND	622	1,870
Stove 5	Top	34	336	31	93	ND	48	144	ND	590	1,770
Stove 6	Ash lip	36	89	27	81	57 E	36	108	1 E	290	870
Stove 6	Ash lip	37	161	26	78	83 E	40	120	ND	351	1,050
Stove 6	Ash lip	38	186	27	81	ND	38	114	ND	342	1,030
Stove 6	Top	39	225	30	90	ND	43	129	ND	454	1,360
Stove 6	Top	40	223	35	105	ND	46	138	ND	514	1,540
Stove 6	Top	41	193	33	99	5 E	46	138	ND	489	1,470
Stove 7	Ash lip	42	341	39	117	66 E	52	156	ND	666	2,000
Stove 7	Ash lip	43	322	36	108	34 E	52	156	ND	668	2,000
Stove 7	Ash lip	44	405	46	138	5 E	56	168	ND	751	2,250
Stove 7	Top	45	270	37	111	ND	50	150	ND	642	1,930
Stove 7	Top	46	406	45	135	ND	58	174	ND	809	2,430
Stove 7	Top	47	311	38	114	ND	52	156	ND	617	1,850
Stove 8	Ash lip	48	344	37	111	116 E	52	156	69 E	641	1,920
Stove 8	Ash lip	49	228	40	120	ND	51	153	941 E	640	1,920
Stove 8	Ash lip	50	278	28	84	ND	47	141	ND	553	1,660
Stove 8	Top	52	207	30	90	6 E	42	126	ND	493	1,480
Stove 8	Top	53	269	28	84	ND	44	132	602 E	536	1,610
Stove 8	Top	54	251	29	87	67 E	44	132	ND	505	1,520
Stove 9	Ash lip	55	332	38	114	ND	51	153	ND	596	1,790
Stove 9	Ash lip	56	285	34	102	115 E	49	147	ND	556	1,670
Stove 9	Ash lip	57	311	35	105	54 E	51	153	ND	640	1,920
Stove 9	Top	58	429	42	126	26 E	59	177	ND	760	2,280
Stove 9	Top	59	333	36	108	ND	50	150	ND	639	1,920
Stove 9	Top	60	382	45	135	ND	54	162	ND	720	2,160
Footed pot	Outside	61	290	63	189	70 E	82	246	ND	1,150	3,450
Footed pot	Outside	62	396	44	132	ND	57	171	ND	793	2,380
Footed pot	Inside	63	142	46	138	ND	53	159	ND	631	1,890
Footed pot	Inside	64	157 E	69	207	5 E	76	228	ND	871	2,610
Footed pot	Outside	65	183	43	129	ND	52	156	ND	616	1,850
Footed pot	Outside	66	296	55	165	44 E	73	219	ND	992	2,980
Kettle	Outside	67	353	34	102	ND	57	171	ND	641	1,920
Kettle	Outside	68	357	34	102	ND	59	177	ND	639	1,920
Kettle	Outside	69	373	31	93	ND	56	168	ND	626	1,880

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Cobalt (ppm)			Copper (ppm)			Gold (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	11,900	2,150	6,450	1,590	127	381	252	19	57
Stove 1	Ash lip	6	12,100	2,440	7,320	2,270	165	495	327	21	63
Stove 1	Ash lip	7	17,200	1,920	5,760	1,510	115	345	215	20	60
Stove 1	Top	8	13,300	2,000	6,000	1,810	130	390	267	20	60
Stove 1	Top	9	12,000	2,070	6,210	1,430	120	360	266	21	63
Stove 1	Top	10	11,300	2,030	6,090	1,870	135	405	236	20	60
Stove 2	Ash lip	11	16,000	2,360	7,080	2,210	159	477	234	25	75
Stove 2	Ash lip	12	16,200	2,690	8,070	4,240	254	762	341	29	87
Stove 2	Ash lip	13	17,700	1,700	5,100	2,060	126	378	160	23	69
Stove 2	Top	14	12,500	2,280	6,840	3,310	200	600	214	24	72
Stove 2	Top	15	11,000	2,320	6,960	2,060	165	495	193	29	87
Stove 2	Top	16	13,100	1,900	5,700	2,070	138	414	170	23	69
Stove 3	Ash lip	17	16,700	2,700	8,100	4,440	263	789	372	28	84
Stove 3	Ash lip	18	5,600 E	2,870	8,610	4,790	292	876	400	30	90
Stove 3	Ash lip	19	12,200	2,480	7,440	4,750	264	792	341	24	72
Stove 3	Top	20	14,400	2,450	7,350	2,900	189	567	306	24	72
Stove 3	Top	21	9,280	2,270	6,810	2,620	173	519	305	21	63
Stove 3	Top	22	8,090	2,240	6,720	2,850	180	540	321	21	63
Stove 4 [3]	Ash lip	23	10,200	2,520	7,560	ND	78	234	296	26	78
Stove 4 [3]	Ash lip	24	5,120 E	2,440	7,320	ND	71	213	334	27	81
Stove 4 [3]	Ash lip	25	8,810	2,680	8,040	ND	84	252	349	29	87
Stove 4 [3]	Top	26	10,500	2,270	6,810	ND	70	210	301	23	69
Stove 4 [3]	Top	27	8,360	2,280	6,840	ND	73	219	290	23	69
Stove 4 [3]	Top	28	4,870 E	1,950	5,850	ND	67	201	248	20	60
Stove 5	Ash lip	29	8,720	1,980	5,940	1,580	124	372	261	18	54
Stove 5	Ash lip	30	7,030	1,930	5,790	1,460	120	360	256	18	54
Stove 5	Ash lip	31	9,790	1,940	5,820	1,360	116	348	247	16	48
Stove 5	Top	32	8,940	2,040	6,120	1,850	136	408	264	20	60
Stove 5	Top	33	13,800	2,160	6,480	1,930	143	429	311	22	66
Stove 5	Top	34	9,590	2,010	6,030	1,180	112	336	263	19	57
Stove 6	Ash lip	36	11,300	1,010	3,030	215	45	135	81	15	45
Stove 6	Ash lip	37	8,930	1,230	3,690	99 E	48	144	115	13	39
Stove 6	Ash lip	38	13,700	1,240	3,720	267	52	156	96	13	39
Stove 6	Top	39	8,000	1,590	4,770	52 E	56	168	190	16	48
Stove 6	Top	40	10,200	1,760	5,280	53 E	61	183	174	19	57
Stove 6	Top	41	11,400	1,830	5,490	ND	58	174	203	21	63
Stove 7	Ash lip	42	7,960	2,270	6,810	2,700	177	531	319	24	72
Stove 7	Ash lip	43	10,200	2,280	6,840	2,240	160	480	294	23	69
Stove 7	Ash lip	44	9,740	2,610	7,830	3,480	223	669	334	24	72
Stove 7	Top	45	8,540	2,190	6,570	1,670	135	405	295	23	69
Stove 7	Top	46	8,520	2,750	8,250	1,750	159	477	380	29	87
Stove 7	Top	47	12,300	2,220	6,660	1,970	145	435	277	20	60
Stove 8	Ash lip	48	17,100	2,250	6,750	2,140	152	456	289	23	69
Stove 8	Ash lip	49	13,200	2,120	6,360	3,810	212	636	257	23	69
Stove 8	Ash lip	50	7,090	1,880	5,640	1,860	129	387	271	17	51
Stove 8	Top	52	10,700	1,710	5,130	1,310	103	309	213	17	51
Stove 8	Top	53	11,000	1,800	5,400	1,970	129	387	256	17	51
Stove 8	Top	54	7,900	1,770	5,310	4,560	218	654	241	17	51
Stove 9	Ash lip	55	14,600	2,180	6,540	1,030	108	324	281	21	63
Stove 9	Ash lip	56	17,300	2,050	6,150	929	99	297	243	18	54
Stove 9	Ash lip	57	13,700	2,220	6,660	1,030	109	327	299	22	66
Stove 9	Top	58	10,100	2,680	8,040	1,730	154	462	392	29	87
Stove 9	Top	59	12,600	2,280	6,840	1,490	129	387	306	21	63
Stove 9	Top	60	9,250	2,550	7,650	1,610	145	435	350	24	72
Footed pot	Outside	61	1,760 E	3,850	11,600	ND	105	315	373	44	132
Footed pot	Outside	62	ND	2,750	8,250	ND	79	237	381	29	87
Footed pot	Inside	63	7,640	2,160	6,480	ND	64	192	193	29	87
Footed pot	Inside	64	5,390 E	2,960	8,880	ND	90	270	178	45	135
Footed pot	Outside	65	4,310 E	2,080	6,240	ND	64	192	222	28	84
Footed pot	Outside	66	ND	3,420	10,300	ND	98	294	385	43	129
Kettle	Outside	67	ND	2,130	6,390	ND	61	183	259	21	63
Kettle	Outside	68	ND	2,120	6,360	ND	59	177	323	21	63
Kettle	Outside	69	ND	2,080	6,240	ND	54	162	264	19	57

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Iron (ppm)			Lead (ppm)			Manganese (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	>900,000	96,700	290,000	574	88	264	ND	858	2,570
Stove 1	Ash lip	6	>900,000	119,000	357,000	1,120	102	306	ND	958	2,870
Stove 1	Ash lip	7	>900,000	75,500	227,000	1,090	89	267	ND	751	2,250
Stove 1	Top	8	>900,000	85,000	255,000	560	80	240	ND	795	2,390
Stove 1	Top	9	>900,000	90,600	272,000	230	76	228	ND	815	2,450
Stove 1	Top	10	>900,000	88,000	264,000	596	83	249	ND	817	2,450
Stove 2	Ash lip	11	>900,000	109,000	327,000	1,350	115	345	226 E	954	2,860
Stove 2	Ash lip	12	>900,000	135,000	405,000	838	115	345	ND	1,080	3,240
Stove 2	Ash lip	13	>900,000	60,200	181,000	3,150	142	426	1,870 E	687	2,060
Stove 2	Top	14	>900,000	105,000	315,000	2,330	146	438	ND	935	2,810
Stove 2	Top	15	>900,000	98,600	296,000	2,960	180	540	ND	933	2,800
Stove 2	Top	16	>900,000	77,000	231,000	3,090	153	459	1,850 E	795	2,390
Stove 3	Ash lip	17	>900,000	135,000	405,000	577	110	330	ND	1,020	3,060
Stove 3	Ash lip	18	>900,000	159,000	477,000	ND	108	324	ND	1,170	3,510
Stove 3	Ash lip	19	>900,000	122,000	366,000	4 E	91	273	ND	981	2,940
Stove 3	Top	20	>900,000	118,000	354,000	217 E	92	276	ND	959	2,880
Stove 3	Top	21	>900,000	108,000	324,000	355	89	267	ND	927	2,780
Stove 3	Top	22	>900,000	107,000	321,000	166 E	85	255	ND	930	2,790
Stove 4 [3]	Ash lip	23	>900,000	127,000	381,000	806	110	330	1,730 E	1,070	3,210
Stove 4 [3]	Ash lip	24	>900,000	124,000	372,000	464	100	300	177 E	1,040	3120
Stove 4 [3]	Ash lip	25	>900,000	141,000	423,000	447	105	315	5,110	1,200	3600
Stove 4 [3]	Top	26	>900,000	107,000	321,000	401	89	267	8,040	1,080	3240
Stove 4 [3]	Top	27	>900,000	109,000	327,000	535	94	282	10,700	1,150	3450
Stove 4 [3]	Top	28	>900,000	86,300	259,000	325	76	228	6,900	937	2,810
Stove 5	Ash lip	29	>900,000	86,000	258,000	ND	63	189	2,840	864	2,590
Stove 5	Ash lip	30	>900,000	83,100	249,000	35 E	66	198	2,590	844	2,530
Stove 5	Ash lip	31	>900,000	82,100	246,000	ND	63	189	1,510 E	823	2,470
Stove 5	Top	32	>900,000	90,600	272,000	ND	71	213	2,620 E	887	2,660
Stove 5	Top	33	>900,000	96,100	288,000	ND	72	216	2,200 E	911	2,730
Stove 5	Top	34	>900,000	86,900	261,000	ND	67	201	1,860 E	859	2,580
Stove 6	Ash lip	36	>750,000	25,100	75,300	1,490	68	204	3,220	451	1,350
Stove 6	Ash lip	37	>900,000	37,400	112,000	1,060	65	195	2,430	541	1,620
Stove 6	Ash lip	38	>900,000	35,300	106,000	1,150	66	198	1,190 E	501	1,500
Stove 6	Top	39	>900,000	60,500	182,000	700	69	207	ND	642	1,930
Stove 6	Top	40	>900,000	69,900	210,000	1,700	104	312	895 E	739	2,220
Stove 6	Top	41	>900,000	73,700	221,000	1,210	92	276	877 E	759	2,280
Stove 7	Ash lip	42	>900,000	108,000	324,000	67 E	83	249	2,330 E	981	2,940
Stove 7	Ash lip	43	>900,000	107,000	321,000	279	86	258	7,000	1,060	3,180
Stove 7	Ash lip	44	>900,000	135,000	405,000	7 E	96	288	4,050	1,150	3450
Stove 7	Top	45	>900,000	101,000	303,000	626	92	276	1,590 E	935	2,810
Stove 7	Top	46	>900,000	148,000	444,000	282 E	108	324	5,340	1,240	3,720
Stove 7	Top	47	>900,000	101,000	303,000	253	83	249	1,790 E	934	2,800
Stove 8	Ash lip	48	>900,000	98,100	294,000	950	99	297	700 E	908	2,720
Stove 8	Ash lip	49	>900,000	92,200	277,000	1,360	107	321	2,080 E	895	2,690
Stove 8	Ash lip	50	>900,000	80,000	240,000	ND	63	189	1,570 E	806	2,420
Stove 8	Top	52	>900,000	66,300	199,000	468	67	201	ND	685	2,060
Stove 8	Top	53	>900,000	72,200	216,000	1 E	62	186	ND	728	2,180
Stove 8	Top	54	>900,000	71,800	215,000	370	69	207	ND	732	2,200
Stove 9	Ash lip	55	>900,000	95,700	287,000	ND	73	219	193 E	882	2,650
Stove 9	Ash lip	56	>900,000	83,500	251,000	117 E	69	207	254 E	815	2,450
Stove 9	Ash lip	57	>900,000	99,600	299,000	ND	76	228	ND	898	2,690
Stove 9	Top	58	>900,000	140,000	420,000	54 E	99	297	ND	1,110	3,330
Stove 9	Top	59	>900,000	106,000	318,000	ND	80	240	2,240 E	966	2,900
Stove 9	Top	60	>900,000	130,000	390,000	ND	91	273	ND	1,050	3,150
Footed pot	Outside	61	>900,000	217,000	651,000	1,550	198	594	2,620 E	1,690	5,070
Footed pot	Outside	62	>900,000	152,000	456,000	469	112	336	3,380 E	1,220	3,660
Footed pot	Inside	63	>900,000	97,300	292,000	4,410	221	663	1,620 E	926	2,780
Footed pot	Inside	64	>900,000	135,000	405,000	6,270	415	1,250	ND	1,250	3,750
Footed pot	Outside	65	>900,000	92,800	278,000	3,890	200	600	725 E	889	2,670
Footed pot	Outside	66	>900,000	19,000	57,000	1,550	177	531	1,220 E	1,490	4,470
Kettle	Outside	67	>900,000	97,000	291,000	401	54	162	6,120	1,040	3,120
Kettle	Outside	68	>900,000	96,000	288,000	536	60	180	5,480	1,020	3,060
Kettle	Outside	69	>900,000	93,100	279,000	540	59	177	5,230	988	2,960

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Mercury (ppm)			Molybdenum (ppm)			Nickel (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	ND	31	93	66	10	30	ND	313	939
Stove 1	Ash lip	6	ND	35	105	83	11	33	ND	366	1,100
Stove 1	Ash lip	7	ND	32	96	69	10	30	ND	275	825
Stove 1	Top	8	ND	27	81	52	10	30	ND	290	870
Stove 1	Top	9	ND	36	108	65	10	30	ND	311	933
Stove 1	Top	10	ND	31	93	69	10	30	ND	307	921
Stove 2	Ash lip	11	ND	36	108	91	11	33	ND	345	1,040
Stove 2	Ash lip	12	ND	42	126	76	11	33	ND	396	1,190
Stove 2	Ash lip	13	ND	31	93	51	9	27	ND	248	744
Stove 2	Top	14	ND	35	105	84	11	33	ND	341	1,020
Stove 2	Top	15	ND	41	123	79	12	36	ND	350	1,050
Stove 2	Top	16	ND	35	105	85	10	30	ND	294	882
Stove 3	Ash lip	17	ND	34	102	104	12	36	ND	390	1,170
Stove 3	Ash lip	18	ND	41	123	102	13	39	ND	427	1,280
Stove 3	Ash lip	19	ND	37	111	76	11	33	ND	371	1,110
Stove 3	Top	20	ND	30	90	77	11	33	ND	358	1,070
Stove 3	Top	21	ND	30	90	79	11	33	ND	343	1,030
Stove 3	Top	22	ND	28	84	61	10	30	ND	339	1,020
Stove 4 [3]	Ash lip	23	ND	42	126	92	12	36	ND	378	1,130
Stove 4 [3]	Ash lip	24	ND	40	120	92	12	36	ND	374	1,120
Stove 4 [3]	Ash lip	25	ND	40	120	100	13	39	ND	421	1,260
Stove 4 [3]	Top	26	ND	35	105	88	11	33	ND	361	1,080
Stove 4 [3]	Top	27	ND	35	105	79	11	33	ND	381	1,140
Stove 4 [3]	Top	28	ND	30	90	68	10	30	ND	324	972
Stove 5	Ash lip	29	ND	29	87	61	10	30	ND	313	939
Stove 5	Ash lip	30	ND	30	90	74	10	30	ND	306	918
Stove 5	Ash lip	31	ND	26	78	50	10	30	ND	307	921
Stove 5	Top	32	ND	29	87	70	10	30	ND	319	957
Stove 5	Top	33	ND	30	90	94	11	33	ND	337	1,010
Stove 5	Top	34	ND	23	69	78	11	33	ND	323	969
Stove 6	Ash lip	36	ND	24	72	54	8	24	ND	156	468
Stove 6	Ash lip	37	ND	22	66	54	9	27	ND	191	573
Stove 6	Ash lip	38	ND	21	63	59	8	24	ND	185	555
Stove 6	Top	39	ND	26	78	52	9	27	ND	248	744
Stove 6	Top	40	ND	28	84	52	9	27	ND	271	813
Stove 6	Top	41	ND	29	87	65	10	30	ND	276	828
Stove 7	Ash lip	42	ND	33	99	77	11	33	ND	344	1,030
Stove 7	Ash lip	43	ND	30	90	76	11	33	ND	348	1,040
Stove 7	Ash lip	44	ND	39	117	91	12	36	ND	396	1,190
Stove 7	Top	45	ND	35	105	85	11	33	ND	332	996
Stove 7	Top	46	ND	37	111	101	13	39	ND	421	1,260
Stove 7	Top	47	ND	33	99	75	11	33	ND	334	1,000
Stove 8	Ash lip	48	ND	33	99	112	12	36	ND	330	990
Stove 8	Ash lip	49	ND	37	111	81	11	33	ND	328	984
Stove 8	Ash lip	50	ND	26	78	53	9	27	ND	289	867
Stove 8	Top	52	ND	28	84	37	9	27	ND	258	774
Stove 8	Top	53	ND	26	78	72	10	30	ND	270	810
Stove 8	Top	54	ND	27	81	66	10	30	ND	269	807
Stove 9	Ash lip	55	ND	33	99	83	11	33	ND	325	975
Stove 9	Ash lip	56	ND	30	90	71	10	30	ND	298	894
Stove 9	Ash lip	57	ND	30	90	80	11	33	ND	329	987
Stove 9	Top	58	ND	35	105	112	13	39	ND	403	1,210
Stove 9	Top	59	ND	31	93	58	10	30	ND	346	1,040
Stove 9	Top	60	ND	40	120	83	12	36	ND	389	1,170
Footed pot	Outside	61	ND	57	171	108	18	54	ND	608	180
Footed pot	Outside	62	ND	36	108	97	13	39	ND	430	1,290
Footed pot	Inside	63	ND	40	120	74	11	33	ND	336	1,010
Footed pot	Inside	64	ND	55	165	94	17	51	ND	461	1,380
Footed pot	Outside	65	ND	38	114	69	11	33	ND	334	1,000
Footed pot	Outside	66	ND	51	153	90	16	48	ND	547	1,640
Kettle	Outside	67	ND	28	84	50	12	36	ND	348	1,040
Kettle	Outside	68	ND	30	90	70	12	36	ND	349	1,050
Kettle	Outside	69	ND	23	69	41	11	33	ND	334	1,000

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Rubidium (ppm)			Selenium (ppm)			Silver (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	ND	16	48	ND	12	36	21 E	42	126
Stove 1	Ash lip	6	258	21	63	ND	13	39	ND	45	135
Stove 1	Ash lip	7	ND	14	42	ND	12	36	111 E	39	117
Stove 1	Top	8	ND	15	45	ND	11	33	17 E	39	117
Stove 1	Top	9	ND	15	45	ND	12	36	95 E	40	120
Stove 1	Top	10	ND	15	45	ND	13	39	105 E	40	120
Stove 2	Ash lip	11	ND	18	54	ND	14	42	86 E	45	135
Stove 2	Ash lip	12	ND	21	63	ND	15	45	98 E	47	141
Stove 2	Ash lip	13	ND	12	36	8 E	14	42	57 E	36	108
Stove 2	Top	14	ND	17	51	ND	15	45	109 E	43	129
Stove 2	Top	15	ND	18	54	9 E	19	57	31 E	48	144
Stove 2	Top	16	ND	14	42	ND	14	42	29 E	39	117
Stove 3	Ash lip	17	ND	22	66	ND	16	48	90 E	48	144
Stove 3	Ash lip	18	ND	23	69	ND	18	54	9 E	48	144
Stove 3	Ash lip	19	ND	19	57	ND	13	39	ND	44	132
Stove 3	Top	20	ND	19	57	ND	15	45	29 E	45	135
Stove 3	Top	21	ND	17	51	ND	12	36	12 E	44	132
Stove 3	Top	22	ND	17	51	ND	12	36	49 E	43	129
Stove 4 [3]	Ash lip	23	ND	20	60	8 E	17	51	63 E	47	141
Stove 4 [3]	Ash lip	24	ND	19	57	ND	16	48	ND	45	135
Stove 4 [3]	Ash lip	25	ND	21	63	ND	16	48	58 E	49	147
Stove 4 [3]	Top	26	ND	17	51	ND	13	39	42 E	44	132
Stove 4 [3]	Top	27	ND	17	51	ND	12	36	86 E	43	129
Stove 4 [3]	Top	28	ND	15	45	ND	11	33	90 E	41	123
Stove 5	Ash lip	29	ND	15	45	ND	11	33	1 E	39	117
Stove 5	Ash lip	30	ND	14	42	ND	11	33	35 E	41	123
Stove 5	Ash lip	31	ND	14	42	ND	9	27	ND	40	120
Stove 5	Top	32	ND	16	48	ND	13	39	34 E	39	117
Stove 5	Top	33	ND	15	45	ND	12	36	ND	42	126
Stove 5	Top	34	ND	14	42	ND	11	33	17 E	41	123
Stove 6	Ash lip	36	60	8	24	ND	9	27	45 E	30	90
Stove 6	Ash lip	37	40	8	24	ND	8	24	20 E	34	102
Stove 6	Ash lip	38	ND	9	27	ND	8	24	1 E	32	96
Stove 6	Top	39	ND	12	36	ND	9	27	27 E	36	108
Stove 6	Top	40	ND	13	39	ND	12	36	ND	38	114
Stove 6	Top	41	ND	13	39	ND	13	39	57 E	39	117
Stove 7	Ash lip	42	ND	17	51	ND	12	36	64 E	43	129
Stove 7	Ash lip	43	ND	18	54	ND	12	36	112 E	44	132
Stove 7	Ash lip	44	ND	20	60	ND	14	42	58 E	48	144
Stove 7	Top	45	ND	17	51	ND	13	39	30 E	42	126
Stove 7	Top	46	ND	22	66	ND	16	48	113 E	50	150
Stove 7	Top	47	ND	17	51	ND	12	36	13 E	43	129
Stove 8	Ash lip	48	ND	16	48	ND	13	39	21 E	43	129
Stove 8	Ash lip	49	ND	15	45	ND	12	36	ND	42	126
Stove 8	Ash lip	50	ND	14	42	ND	9	27	ND	39	117
Stove 8	Top	52	ND	12	36	ND	10	30	40 E	36	108
Stove 8	Top	53	ND	13	39	ND	8	24	ND	38	114
Stove 8	Top	54	ND	13	39	ND	10	30	97 E	37	111
Stove 9	Ash lip	55	ND	16	48	ND	12	36	87 E	43	129
Stove 9	Ash lip	56	ND	14	42	ND	12	36	56 E	40	120
Stove 9	Ash lip	57	ND	16	48	ND	12	36	110 E	43	129
Stove 9	Top	58	ND	20	60	ND	16	48	86 E	51	153
Stove 9	Top	59	ND	18	54	ND	12	36	64 E	42	126
Stove 9	Top	60	ND	21	63	ND	14	42	35 E	46	138
Footed pot	Outside	61	ND	29	87	ND	25	75	10 E	69	207
Footed pot	Outside	62	ND	21	63	ND	15	45	70 E	48	144
Footed pot	Inside	63	ND	16	48	ND	17	51	99 E	44	132
Footed pot	Inside	64	ND	19	57	ND	26	78	ND	64	192
Footed pot	Outside	65	ND	15	45	ND	15	45	76 E	45	135
Footed pot	Outside	66	ND	25	75	14 E	26	78	182 E	62	186
Kettle	Outside	67	30 E	13	39	ND	9	27	25 E	48	144
Kettle	Outside	68	29 E	13	39	ND	11	33	36 E	48	144
Kettle	Outside	69	16 E	12	36	ND	11	33	58 E	45	135

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Strontium (ppm)			Tin (ppm)			Titanium (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	103	11	33	ND	81	243	ND	5,350	16,100
Stove 1	Ash lip	6	97	11	33	166 E	87	261	ND	6,070	18,200
Stove 1	Ash lip	7	90	10	30	9 E	76	228	12,400 E	4,720	14,100
Stove 1	Top	8	60	8	24	38 E	76	228	ND	4,860	14,600
Stove 1	Top	9	53	8	24	179 E	79	237	ND	5,180	15,500
Stove 1	Top	10	68	9	27	ND	78	234	5,860 E	5,190	15,600
Stove 2	Ash lip	11	96	11	33	ND	87	261	ND	5,620	16,900
Stove 2	Ash lip	12	95	12	36	ND	92	276	ND	6,580	19,700
Stove 2	Ash lip	13	79	9	27	18 E	68	204	ND	3,840	11,500
Stove 2	Top	14	54	9	27	173 E	85	255	ND	5,490	16,500
Stove 2	Top	15	58	10	30	ND	88	264	ND	5,790	17,400
Stove 2	Top	16	67	9	27	43 E	74	222	ND	4,420	13,300
Stove 3	Ash lip	17	44	9	27	60 E	91	273	ND	6,430	19,300
Stove 3	Ash lip	18	56	10	30	ND	98	294	ND	7,140	21,400
Stove 3	Ash lip	19	57	9	27	45 E	85	255	763 E	6,130	18,400
Stove 3	Top	20	67	9	27	84 E	88	264	905 E	6,050	18,200
Stove 3	Top	21	60	9	27	56 E	82	246	ND	5,580	16,800
Stove 3	Top	22	47	8	24	170 E	84	252	ND	5,640	16,900
Stove 4 [3]	Ash lip	23	44	9	27	ND	90	270	ND	5,970	17,900
Stove 4 [3]	Ash lip	24	42	8	24	60 E	89	267	ND	5,990	18,000
Stove 4 [3]	Ash lip	25	47	9	27	116 E	94	282	ND	6,660	20,000
Stove 4 [3]	Top	26	47	8	24	166 E	85	255	1,340 E	5,640	16,900
Stove 4 [3]	Top	27	58	9	27	87 E	87	261	ND	5,640	16,900
Stove 4 [3]	Top	28	54	8	24	4 E	78	234	118 E	5,030	15,100
Stove 5	Ash lip	29	30	7	21	31 E	78	234	ND	4,940	14,800
Stove 5	Ash lip	30	52	8	24	ND	80	240	ND	4,760	14,300
Stove 5	Ash lip	31	31	7	21	ND	78	234	ND	4,820	14,500
Stove 5	Top	32	41	7	21	79 E	80	240	ND	5,080	15,200
Stove 5	Top	33	41	8	24	ND	81	243	ND	5,300	15,900
Stove 5	Top	34	52	8	24	27 E	80	240	ND	4,910	14,700
Stove 6	Ash lip	36	233	12	36	43 E	58	174	210 E	2,520	7,560
Stove 6	Ash lip	37	128	10	30	5 E	66	198	798 E	3,110	9,340
Stove 6	Ash lip	38	72	7	21	ND	62	186	1,520 E	3,030	9,100
Stove 6	Top	39	44	7	21	ND	68	204	ND	3,990	12,000
Stove 6	Top	40	58	8	24	63 E	74	222	ND	4,330	13,000
Stove 6	Top	41	44	7	21	64 E	76	228	ND	4,310	12,900
Stove 7	Ash lip	42	67	9	27	ND	84	252	ND	5,550	16,700
Stove 7	Ash lip	43	107	11	33	8 E	87	261	ND	5,530	16,600
Stove 7	Ash lip	44	74	10	30	9 E	92	276	ND	6,380	19,100
Stove 7	Top	45	50	8	24	72 E	82	246	ND	5,470	16,400
Stove 7	Top	46	53	9	27	43 E	96	288	ND	6,960	20,900
Stove 7	Top	47	38	8	24	5 E	82	246	ND	5,420	16,300
Stove 8	Ash lip	48	102	11	33	17 E	84	252	ND	5,330	16,000
Stove 8	Ash lip	49	112	11	33	46 E	83	249	ND	5,320	16,000
Stove 8	Ash lip	50	50	8	24	87 E	77	231	ND	4,480	13,400
Stove 8	Top	52	110	10	30	32 E	70	210	ND	4,190	12,600
Stove 8	Top	53	82	9	27	1 E	72	216	ND	4,230	12,700
Stove 8	Top	54	69	8	24	70 E	72	216	ND	4,340	13,000
Stove 9	Ash lip	55	85	10	30	177 E	84	252	14,400 E	5,410	16,200
Stove 9	Ash lip	56	68	9	27	49 E	79	237	2,540 E	4,820	14,500
Stove 9	Ash lip	57	108	11	33	103 E	83	249	ND	5,340	16,000
Stove 9	Top	58	69	10	30	146 E	97	291	ND	6,480	19,400
Stove 9	Top	59	53	8	24	ND	81	243	ND	5,560	16,700
Stove 9	Top	60	51	9	27	ND	89	267	ND	6,280	18,800
Footed pot	Outside	61	40	12	36	293 E	133	399	ND	9,460	28,400
Footed pot	Outside	62	31	8	24	47 E	98	294	ND	6,730	20,200
Footed pot	Inside	63	30	8	24	82 E	86	258	ND	5,300	15,900
Footed pot	Inside	64	23 E	11	33	ND	124	372	ND	7,210	21,600
Footed pot	Outside	65	28	8	24	13 E	85	255	ND	5,100	15,300
Footed pot	Outside	66	41	11	33	ND	122	366	ND	8,350	25,100
Kettle	Outside	67	18 E	7	21	ND	92	276	ND	5,720	17,200
Kettle	Outside	68	45	9	27	ND	93	279	ND	5,480	16,400
Kettle	Outside	69	33	8	24	56 E	89	267	ND	5,370	16,100

Table H. Results of analysis by X-ray fluorescence spectroscopy of cast iron artifacts in the Hopewell Furnace National Historic Site museum, Pennsylvania.—Continued

[Artifacts are shown on figure 9; analyses by Martin Helmke of West Chester University. All concentrations are in parts per million (ppm); E, estimated value below detection limit; ND, not detected; >, greater than]

Artifact number	Sample location	Reading number	Zinc (ppm)			Zirconium (ppm)		
			Concentration	1 sigma error[1]	3 sigma error[2]	Concentration	1 sigma error[1]	3 sigma error[2]
Stove 1	Ash lip	5	675	67	201	21 E	8	24
Stove 1	Ash lip	6	495	65	195	20 E	9	27
Stove 1	Ash lip	7	1,010	75	225	26	8	24
Stove 1	Top	8	2,420	130	390	25	8	24
Stove 1	Top	9	4,850	222	666	29	8	24
Stove 1	Top	10	2,330	129	387	25	8	24
Stove 2	Ash lip	11	865	79	237	28	9	27
Stove 2	Ash lip	12	836	87	261	17 E	9	27
Stove 2	Ash lip	13	2,650	127	381	26	7	21
Stove 2	Top	14	1,260	96	288	21 E	8	24
Stove 2	Top	15	2,780	169	507	36	10	30
Stove 2	Top	16	912	73	219	19 E	8	24
Stove 3	Ash lip	17	887	90	270	29	9	27
Stove 3	Ash lip	18	320	71	213	9 E	9	27
Stove 3	Ash lip	19	656	77	231	10 E	8	24
Stove 3	Top	20	318	59	177	36	9	27
Stove 3	Top	21	467	62	186	19 E	8	24
Stove 3	Top	22	292	55	165	18 E	8	24
Stove 4 [3]	Ash lip	23	1,500	108	324	18 E	8	24
Stove 4 [3]	Ash lip	24	766	74	222	17 E	8	24
Stove 4 [3]	Ash lip	25	1,140	97	291	27	9	27
Stove 4 [3]	Top	26	676	67	201	33	8	24
Stove 4 [3]	Top	27	612	65	195	35	9	27
Stove 4 [3]	Top	28	461	53	159	21 E	8	24
Stove 5	Ash lip	29	120 E	41	123	13 E	7	21
Stove 5	Ash lip	30	583	61	183	24	8	24
Stove 5	Ash lip	31	248	46	138	27	8	24
Stove 5	Top	32	872	74	222	16 E	7	21
Stove 5	Top	33	850	75	225	40	8	24
Stove 5	Top	34	591	61	183	30	8	24
Stove 6	Ash lip	36	1,950	84	252	43	7	21
Stove 6	Ash lip	37	1,010	62	186	43	7	21
Stove 6	Ash lip	38	1,060	62	186	35	7	21
Stove 6	Top	39	832	61	183	20 E	7	21
Stove 6	Top	40	770	62	186	22	7	21
Stove 6	Top	41	519	53	159	32	8	24
Stove 7	Ash lip	42	826	78	234	21 E	8	24
Stove 7	Ash lip	43	650	70	210	41	9	27
Stove 7	Ash lip	44	812	85	255	17 E	9	27
Stove 7	Top	45	1,930	119	357	20 E	8	24
Stove 7	Top	46	1,110	98	294	25 E	9	27
Stove 7	Top	47	952	80	240	20 E	8	24
Stove 8	Ash lip	48	8,220	360	1,080	35	9	27
Stove 8	Ash lip	49	3,330	171	513	25	8	24
Stove 8	Ash lip	50	730	65	195	19 E	7	21
Stove 8	Top	52	2,360	119	357	35	8	24
Stove 8	Top	53	2,950	142	426	19 E	7	21
Stove 8	Top	54	1,480	93	279	18 E	7	21
Stove 9	Ash lip	55	478	58	174	47	9	27
Stove 9	Ash lip	56	592	60	180	46	9	27
Stove 9	Ash lip	57	376	54	162	16 E	8	24
Stove 9	Top	58	548	72	216	39	9	27
Stove 9	Top	59	366	56	168	15 E	8	24
Stove 9	Top	60	230	55	165	28	9	27
Footed pot	Outside	61	674	105	315	34 E	13	39
Footed pot	Outside	62	348	61	183	13 E	9	27
Footed pot	Inside	63	1,530	105	315	22 E	9	27
Footed pot	Inside	64	2,450	203	609	44	14	42
Footed pot	Outside	65	1,250	93	279	28	9	27
Footed pot	Outside	66	676	96	288	33 E	12	36
Kettle	Outside	67	376	56	168	18 E	9	27
Kettle	Outside	68	785	77	231	17 E	9	27
Kettle	Outside	69	1,270	98	294	22 E	9	27

[1] The 1 sigma error represents the uncertainty of each analysis.

[2] The 3 sigma error is the level of detection. Values less than the 3 sigma error are estimated.

[3] Stove cast at Rock Furnace in Lancaster County.

Table I. Results of field and laboratory analysis for groundwater samples, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by USGS, National Water Quality Laboratory, Denver, Colo. USGS, U.S. Geological Survey; mg/L, milligrams per liter; µg/L, micrograms per liter; N, nitrogen; P, phosphorus; <, less than; E, estimated concentration]

Well and USGS identifier	Date collected	pH (units)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen (mg/L)	Temperature (degrees Celsius)	Acid neutralizing capacity, as $CaCO_3$, total (mg/L)	Ammonia, dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)
Supply well BE-523	10/27/2008	7.2	209	6.7	11.4	82	<0.02	<0.002
Slag pile well BE-1784	10/28/2008	7.0	87	9.6	14.7	66	0.213	0.02

Well and USGS identifier	Ammonia + organic nitrogen, dissolved (mg/L as N)	Ammonia + organic nitrogen, total (mg/L as N)	Nitrite + nitrate (NO_2+NO_3), dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Orthophosphate, dissolved (PO_4) (mg/L as P)	Calcium, total (mg/L)	Magnesium, total (mg/L)	Sodium, total (mg/L)
Supply well BE-523	0.1 E	<0.1	0.10	0.089	0.084	23.5	6.42	6.2
Slag pile well BE-1784	3.1	0.98	0.15	0.031	0.004 E	14	3.21	5.7

Well and USGS identifier	Potassium, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Aluminum, total (µg/L)	Antimony, total (µg/L)	Arsenic, total (µg/L)
Supply well BE-523	0.81	3.27	8.74	<0.08	18.9	24.3	<0.4	3.4
Slag pile well BE-1784	3.92	8.43	3.19	0.05 E	12.4	570	<0.4	0.8

Table I. Results of field and laboratory analysis for groundwater samples, Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by USGS, National Water Quality Laboratory, Denver, Colo. USGS, U.S. Geological Survey; mg/L, milligrams per liter; µg/L, micrograms per liter; N, nitrogen; P, phosphorus; <, less than; E, estimated concentration]

Well and USGS identifier	Barium, total (µg/L)	Beryllium, total (µg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Cobalt, total (µg/L)	Copper, total (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)
Supply well BE-523	129	0.03	<0.06	0.73	<0.1	<4	32	0.35
Slag pile well BE-1784	141	0.06	0.03 E	1.2	3.9	3.4 E	1,740	13.7

Well and USGS identifier	Lithium, total (µg/L)	Manganese, total (µg/L)	Molybdenum, total (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Silver, total (µg/L)	Strontium, total (µg/L)	Thallium, total (µg/L)
Supply well BE-523	6.8	0.9	0.60	0.3	0.24	<0.06	91.3	<0.12
Slag pile well BE-1784	2.3	2,430	0.30	2.5	0.11 E	<0.06	66.1	<0.12

Well and USGS identifier	Uranium, total (µg/L)	Zinc, total (µg/L)
Supply well BE-523	1.76	6.1
Slag pile well BE-1784	0.145	11.6

Table J. Results of laboratory analysis for surface-water base-flow samples, Hopewell Furnace National Historic Site, Pennsylvania.

[Laboratory analyses by USGS, National Water Quality Laboratory, Denver, Colo. mg/L, milligrams per liter; µg/L, micrograms per liter; N, nitrogen; P, phosphorus; <, less than; E, estimated concentration]

Site number	Station number	Date sampled	pH (units)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Dissolved oxygen (mg/L)	Temperature (degrees Celsius)	Acid neutralizing capacity, as $CaCO_3$, total (mg/L)	Ammonia, dissolved (mg/L as N)	Nitrite, dissolved (mg/L as N)
HF-1	014721245	11/14/2008	7.5	65	11.1	10.8	13	0.076	0.004
HF-2	0147212511	11/12/2008	6.8	74	11.1	10.7	25	0.036	0.006
HF-3	014721253	11/12/2008	7.4	72	12.3	8.3	22	0.021	0.003
HF-4	014721259	11/10/2008	7.3	48	11.2	8.3	14	<0.02	<0.002
HF-5	014721265	11/10/2008	7.2	87	11.5	9.3	24	<0.02	0.002

Site number	Ammonia + organic nitrogen, dissolved (mg/L as N)	Ammonia + organic nitrogen, total (mg/L as N)	Nitrite + nitrate (NO_2+NO_3), dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)	Phosphorus, total (mg/L as P)	Orthophosphate, dissolved (PO_4) (mg/L as P)	Calcium, total (mg/L)	Magnesium, total (mg/L)	Sodium, total (mg/L)
HF-1	0.40	0.35	0.04	0.007	0.017	0.005 E	4.97	1.74	3.8
HF-2	0.93	0.28	0.13	0.010	0.020	<0.008	6.10	2.24	3.8
HF-3	0.32	0.25	0.12	0.006	0.011	<0.008	6.06	1.99	4.1
HF-4	0.23	0.11	<0.04	0.015	0.017	<0.008	2.95	1.31	3.9
HF-5	0.27	0.20	0.14	0.009	0.013	0.004 E	7.14	2.27	4.6

Site number	Potassium, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L)	Aluminum, total (µg/L)	Antimony, total (µg/L)	Arsenic, total (µg/L)	Barium, total (µg/L)
HF-1	0.90	5.00	5.33	<0.08	0.7	29	<0.4	0.39	35.1
HF-2	1.09	4.54	5.87	<0.08	3.3	36	<0.4	0.36	40.6
HF-3	0.95	4.68	6.04	<0.08	2.9	17	<0.4	0.32	37.6
HF-4	0.74	1.98	3.99	<0.08	20.3	37	<0.4	0.26	33.6
HF-5	0.93	6.02	6.17	<0.08	9.7	23	<0.4	0.31	44.1

Table J. Results of laboratory analysis for surface-water base-flow samples, Hopewell Furnace National Historic Site, Pennsylvania.—Continued

[Laboratory analyses by USGS, National Water Quality Laboratory, Denver, Colo. mg/L, milligrams per liter; µg/L, micrograms per liter; N, nitrogen; P, phosphorus; <, less than; E, estimated concentration]

Site number	Beryllium, total (µg/L)	Cadmium, total (µg/L)	Chromium, total (µg/L)	Cobalt, total (µg/L)	Copper, total (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Lithium, total (µg/L)	Manganese, total (µg/L)
HF-1	<0.02	< 0.06	<0.4	0.05 E	<4	162	0.2	0.6 E	41
HF-2	0.02	< 0.06	<0.4	0.20	<4	346	0.61	0.6	51.4
HF-3	<0.02	< 0.06	<0.4	0.10	<4	196	0.23	0.7	47.7
HF-4	0.02	< 0.06	<0.4	0.05 E	<4	78	0.24	1	8.4
HF-5	0.01 E	< 0.06	<0.4	0.12	<4	257	0.15	1	50.8

Site number	Molybdenum, total (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Silver, total (µg/L)	Strontium, total (µg/L)	Thallium, total (µg/L)	Uranium, total (µg/L)	Zinc, total (µg/L)
HF-1	0.1	0.43	0.11 E	<0.06	27.2	<0.12	0.017 E	<2
HF-2	0.1 E	0.39	0.14	<0.06	29.9	<0.12	0.018 E	1.2 E
HF-3	0.1 E	0.35	0.10 E	<0.06	34.1	<0.12	0.011 E	5.5
HF-4	<0.1	0.60	0.08 E	<0.06	11.7	<0.12	0.011 E	1.6 E
HF-5	0.1 E	0.41	0.09 E	<0.06	34	<0.12	0.019 E	1.4 E

Table K. Benthic macroinvertebrates identified from 300 organism subsamples collected from sites at Hopewell Furnace National Historical Site, November 2008.

[Macroinvertebrate identication by Andrew G. Rief of the U.S. Geological Survey; PTV, Pollution tolerance value from Chalfant (2007)]

Station number		014721245	0147212511	0147212511	014721253	014721259	014721265
Site number		HF-1	HF-2	HF-2 replicate	HF-3	HF-4	HF-5
Date sampled		11/14/08	11/12/08	11/12/08	11/12/08	11/10/08	11/10/08
Grids		8	9	10	10	12	28
Total count		317	336	302	302	330	93
Organism	**PTV**	**Count**					
Platyhelminthes							
Turbellaria (flatworms)							
Tricladida							
Planariidae	9	4		1			
Nemertea (probosas worms)							
Enopla							
Hoplonemertea							
Tetrastemmatidae							
Prostoma	6	3			1		
Mollusca							
Gastropoda (snails)							
Basommatophora							
Planorbidae							
Planorbella	6			1			
Neotaenioglaas							
Hydrobiidae							
Amnicola	8		3	2			
Bivalvia (clams)							
Veneroida							
Corbiculidae							
Corbicula fluminea	4	15	7	7	5		2
Pisidiidae							
Pisidium	8			1			
Sphaerium	8		4	1	2		
Annelida (segmented worms)							
Clitellata							
Oligochaeta							
Lumbriculida							
Lumbriculidae	8	3	18	25	8		
Haplotaxida							
Enchytraeidae	10			1			
Naididae	8	4	8	2	3		9
Arthropoda							
Arachnida							
Acariformes (water mites)	7	1	1		5	4	3

Table K. Benthic macroinvertebrates identified from 300 organism subsamples collected from sites at Hopewell Furnace National Historical Site, November 2008.—Continued

[Macroinvertebrate identication by Andrew G. Rief of the U.S. Geological Survey; PTV, Pollution tolerance value from Chalfant (2007)]

Station number		014721245	0147212511	0147212511	014721253	014721259	014721265
Site number		HF-1	HF-2	HF-2 replicate	HF-3	HF-4	HF-5
Date sampled		11/14/08	11/12/08	11/12/08	11/12/08	11/10/08	11/10/08
Grids		8	9	10	10	12	28
Total count		317	336	302	302	330	93
Organism	**PTV**	**Count**					
Crustacea							
Cladocera							
Daphniidae							
Daphnia	5		1	2			
Copepoda							
Cyclopoida							
Cyclopidae	8			1			
Amphipoda (scuds)							
Crangonyctidae							
Crangonyx	4	1	2	4	1		
Talitridae							
Hyalella	8		4	1			
Isopoda (sow bugs)							
Asellidae							
Caecidotea	6						1
Podocopa (seed shrimp)	8		3				
Insecta							
Ephemeroptera (mayflies)							
Baetidae							
Baetis	6					3	
Caenidae							
Caenis	7		1	1			
Ephemerellidae							
Eurylophella	4	1	1		9	1	
Serratella	2			1	1	79	3
Heptageniidae							
Epeorus	0					1	
Stenacron	4	1	1				
Stenonema (Maccaffertium)	3	64	29	12	33	28	12
Leptophlebiidae							
Paraleptophlebia	1			1		1	
Odonata (dragonflies and damselflies)							
Aeshnidae							
Boyeria	2						1
Coenagrionidae							

Table K. Benthic macroinvertebrates identified from 300 organism subsamples collected from sites at Hopewell Furnace National Historical Site, November 2008.—Continued

[Macroinvertebrate identication by Andrew G. Rief of the U.S. Geological Survey; PTV, Pollution tolerance value from Chalfant (2007)]

Station number		014721245	0147212511	0147212511	014721253	014721259	014721265
Site number		HF-1	HF-2	HF-2 replicate	HF-3	HF-4	HF-5
Date sampled		11/14/08	11/12/08	11/12/08	11/12/08	11/10/08	11/10/08
Grids		8	9	10	10	12	28
Total count		317	336	302	302	330	93
Organism	**PTV**	**Count**					
Argia	6		1	2			
Gomphidae							
Arigomphus	4		1				
Gomphus	5		1	2			
Lanthus	5					1	
Plecoptera (stoneflies)							
Capniidae	3					3	
Allocapnia	3				3		2
Chloroperlidae	0			1			
Peltoperlidae							
Peltoperla	2					2	
Nemouridae	2				2	2	1
Perlidae							
Perlesta	4					1	
Taeniopterygidae							
Strophopteryx	3				1	5	
Taeniopteryx	2				2	3	2
Megaloptera							
Corydalidae (fishflies and dobsonflies)							
Corydalus	4	1					
Nigronia	2	3			2		
Trichoptera (caddisflies)							
Glossosomatidae							
Glossosoma	0					12	
Hydropsychidae							
Cheumatopsyche	6	179	25	24	35	27	20
Hydropsyche	5	6	21	13	8	3	
Hydroptilidae							
Hydroptila	6	1					1
Lepidostomatidae							
Lepidostoma	1					2	
Leptoceridae							
Oecetis	8		2	3			
Philopotamidae							
Chimarra	4				3	1	

Table K. Benthic macroinvertebrates identified from 300 organism subsamples collected from sites at Hopewell Furnace National Historical Site, November 2008.—Continued

[Macroinvertebrate identication by Andrew G. Rief of the U.S. Geological Survey; PTV, Pollution tolerance value from Chalfant (2007)]

Station number		014721245	0147212511	0147212511	014721253	014721259	014721265
Site number		HF-1	HF-2	HF-2 replicate	HF-3	HF-4	HF-5
Date sampled		11/14/08	11/12/08	11/12/08	11/12/08	11/10/08	11/10/08
Grids		8	9	10	10	12	28
Total count		317	336	302	302	330	93
Organism	**PTV**	**Count**					
Psychomyiidae							
Lype	2					1	
Rhyacophilidae							
Rhyacophila	1					2	
Uenoidae							
Neophylax	3					5	
Coleoptera (beetles)							
Elmidae (riffle beetles)							
Ancyronyx	2						1
Dubiraphia	6			1			1
Optioservus	4	1	1	1	3	3	2
Oulimnius	5					24	
Promoresia	2				1	4	3
Stenelmis	5					2	
Psephenidae (water pennies)							
Ectopria	5					1	
Diptera (true flies)							
Ceratopogonidae							
Probezzia	6		2	1	1	1	1
Chironomidae (midges)	6	19	178	173	142	102	26
Empididae (dance flies)							
Chelifera	6				5		
Hemerodromia	6	2	17	15	17		2
Simuliidae (black flies)							
Simulium	6	5	3	2	9	2	
Tipulidae (crane flies)							
Antocha	3	2	1			1	
Diranota	3					2	
Hexatoma	2					1	
Tipula	4	1		1			

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