The History of Leather Industry Waste Contamination in the Aberjona Watershed: A Mass Balance Approach

Performing a mass balance analysis is an important step in determining the amount of hazardous materials discharged within a given area.

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There is concern that leather industry wastes that were discarded into the Aberjona watershed in eastern Massachusetts may constitute a potential human health risk. Chemicals used in hide- and skin-tanning processes, as well as chemicals found in tannery wastes (in particular, chromium, which is a common tanning agent), have been shown to be toxic to aquatic organisms and humans,[1,2] mutagenic and carcinogenic in animal assays,[3-5] and carcinogenic in human epidemiology studies.[4] The Aberjona watershed, a 25-square-mile area ten miles north of Boston (see Figure 1), was once a major center for tanning, leather finishing, and hide and leather rendering. Between 1838 and 1988 approximately 100 tanneries, leather-finishing companies, and rendering factories operated at over 67 sites in Woburn, Winchester, and Stoneham (see Figure 2 and Table 1[6-24]).

Records from as early as 1871 to the mid-1930s indicate that the Aberjona River and its tributaries were the main conduits by which tannery and rendering factory wastewater was discarded. Tannery and rendering factory sludges were commonly disposed of on site or at centrally located dumping areas.[11,20,25-44]

At present, there are six sites in the watershed that are being investigated for the presence of leather industry wastes.[8,17,18,22,45,46] Five sites are being investigated by the Massachusetts Department of Environmental Protection (DEP) under the provisions of Massachu-

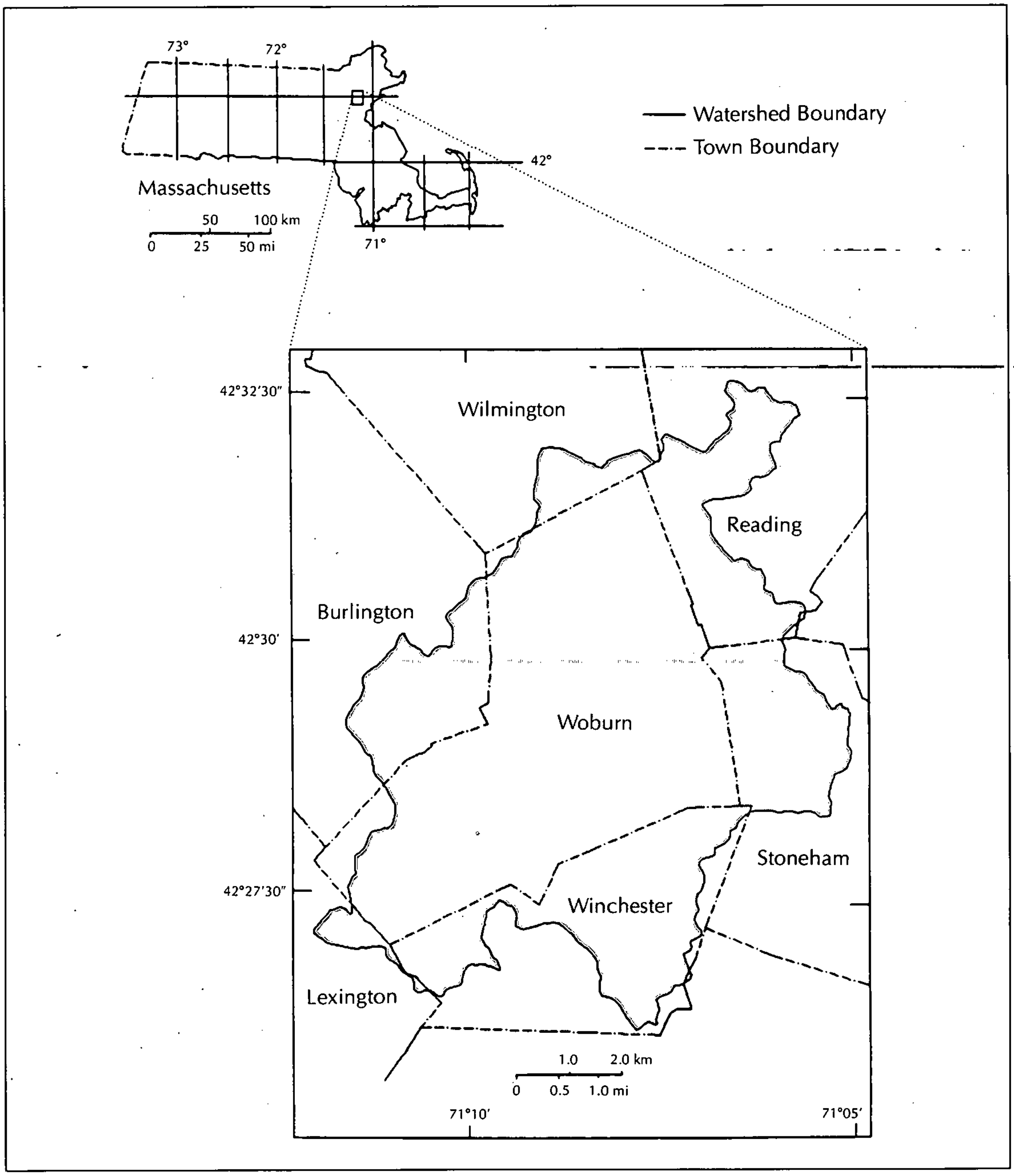

FIGURE 1. Study area location map.

setts General Law, Chapter 21E, section 3(A)b and the Massachusetts Contingency Plan (310 CMR 40.00). The sixth site, the "Industriplex" Superfund site, is being investigated by the United States Environmental Protection Agency (EPA) under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and is currently ranked fifth on the "National Priorities List."

Possible links between environmental contaminants and human health effects in the Aberjona River watershed are being investigated. Work is being done to determine how hazardous chemical wastes are distributed in

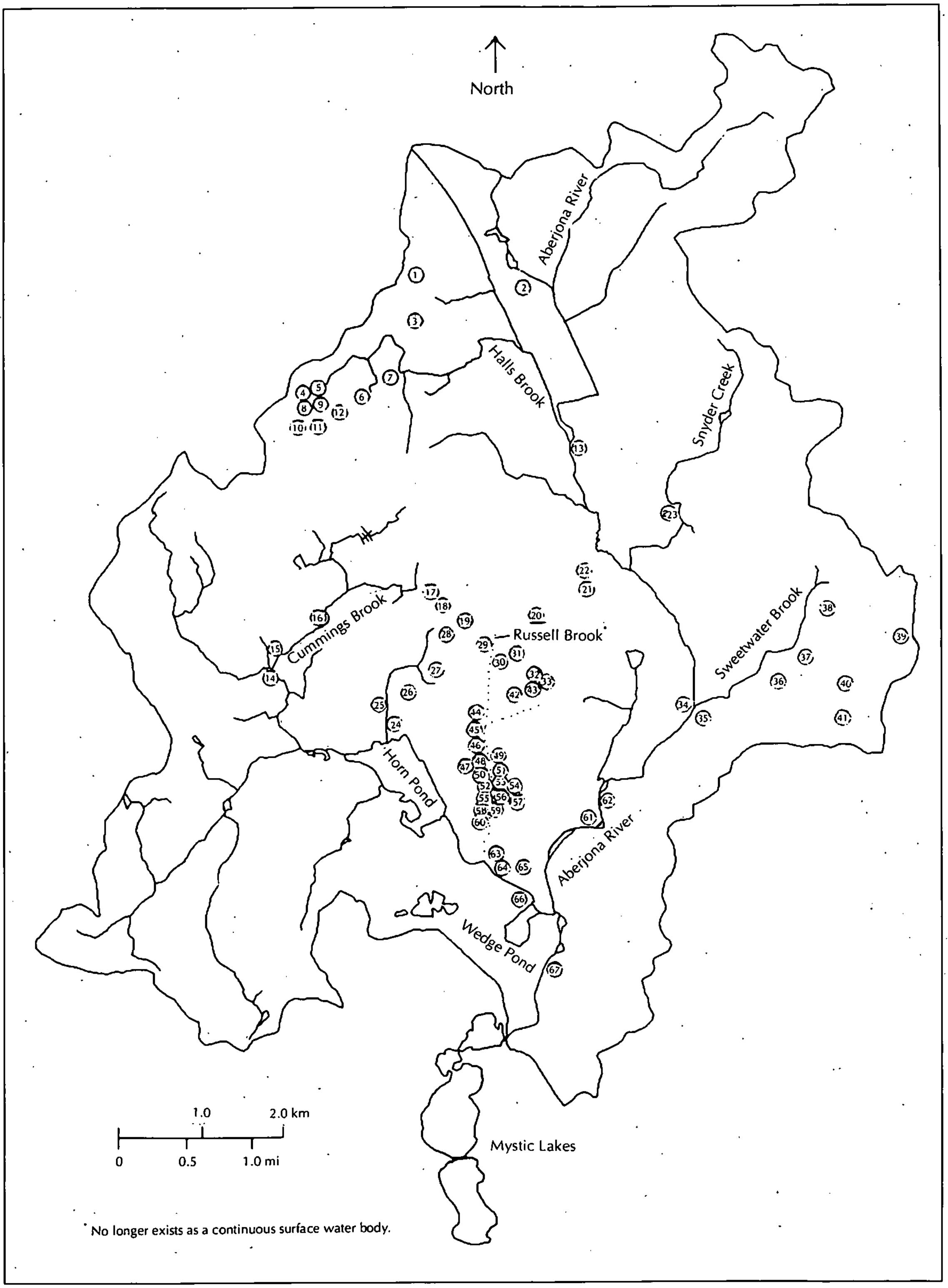

FIGURE 2. Location of tanneries, leather-finishing companies and renderers in the Aberjona watershed between 1838 and 1988.

TABLE 1
Tanneries, Leather-Finishing Companies & Rendering Factories in the Aberjona Watershed (1838-1988)

Site	Last Company to Operate at the Site	Type of Operation	Approximate Dates	Reference(s)
1	Woburn Hide & Leather Co.	Tanning	1957-1960	6,7
2	Stauffer Chemical Co.	Rendering	1934-1968	8
3	Algonquin Leather Co.	Tanning	1918-1926	9
4	Foucar Leather Co.	Finishing	1918-1926	9
5	Rathburn Leather	Tanning	1875-1939	9,10
6	Eaton, Winn & Co.	Tanning	1875- ?	10
7	North Star Japanning Co.	Finishing	1926- ?	9
8	Porter Japanning Factory 2	Finishing	1918-1939	9
9	Porter Japanning Factory 1	Finishing	1894-1939	9
10	Linscott Heel Manufacturers	Tanning	1888-1926	9
11	Bond & Tidd	Tanning	1875- ?	10
12	Bond Leather Specialists	Tanning	1918-1926	9
13	H.W. Clark Patent Leather	Finishing	1904- ?	9
14	Woburn Degreasing Co.	Rendering	1871-1977	11,12
15	Bacon's Patent Leather Co.	Finishing	1871- ?	11
16	Colgate & Son Tannery	Tanning	1871- ?	11
17	E.G. Place Split Leather	Tanning	1888- ?	9
18	W.P. Fox Grain & Split	Tanning	1888-1904	9
19	Kinney & Murphy	Tanning	1875-1894	9,10
20	Paterson Patent Leather	Finishing	1926- ?	9
21	Murray Leather Co.	Finishing	1918-1979	9,13
22	J.J. Riley Co.	Tanning	1918-1988	9,13
23	Crescent Tanning Co.	Tanning	1918-1940	9,14
24	Morocco Manufactory	Tanning	1871- ?	11
25	Stephen Dow & Co.	Tanning	1875-1894	9,10
26	Prime Tanning Co.	Tanning	1888-1926	9
27	Bay State Japanning Co.	Finishing	1913-1926	9,13
28	Amer. Hide & Leather Fact. H	Tanning	1875-1904	9,10
29	Winn Tannery	Tanning	1875- ?	10
30	J.H. Connolly	Tanning	1875- ?	10
31	Murray Leather Co.	Finishing	1875-1961	9,10,15
32	Woburn Japanning Co.	Finishing	1875-1961	9,10,15
33	Griffin Place Curry Shop*	Tanning	1894-1918	9
34	Tanners Degreasing Co.	Rendering	1939-1977	9,12
35	Atlantic Gelatin	Rendering	1875-Present	9,10,16
36	A. Buckman Co.	Tanning	1924- ?	9
37	J.H. Murphy Curriers	Tanning	1924- ?	9
38	Blank Brothers Curry Shop	Tanning	1887-1903	9
39	Best Leather Nut Co.	Tanning	1924- ?	9
40	W.H. Tidd	Tanning	1840-1903	9
41	Van Tassel Co.	Tanning	1897-1924	9
42	Ballard Japanning Co.	Finishing	1904-1926	9
43	J. Kendall Chrome Tannery*	Tanning	1888-1918	9
44	Prime Tanning Co.	Tanning	1875-1934	9,10,17
45	Tolman-Fox Corp.	Tanning	1875-1938	9,10,18
46	W.P. Fox Leather**	Tanning	1875-1918	9,10
47	Dorrington Leather Co.	Tanning	1888-1939	9
48	Amer. Hide & Leather Fact. D	Tanning	1875-1939	9,10
49	E. Cummings Leather Co.	Tanning	1888-1926	9
50	E.C. Cottle***	Tanning	1888-1894	9
51	Watauga Tanning Co.	Tanning	1888-1894	9
52	Middlesex Leather Co.***	Tanning	1888-1904	9
53	Cottle Leather Co.	Tanning	1888-1918	9
54	American Hide & Leather	Rendering	1918-1926	9
55	B.H. Nichols Grease Factory	Rendering	1888-1904	9
56	Beggs & Cobb Factory 1	Finishing	1888-1926	9
57	Beggs & Cobb Factory 2	Finishing	1888-1926	9
58	Kean Brothers & Bedell	Finishing	1926- ?	9
59	Amer. Hide & Leather Fact. E	Tanning	1875-1926	9,10
60	Amer. Hide & Leather Fact. S	Tanning	1875-1939	9,10
61	J.O. Whitten Co.	Rendering	1872-1980	19,20,21,22
62	A.H. McLatchy Co.	Finishing	1916-1929	9,20
63	Pantasote Leather Co.	Tanning	1899- ?	9
64	Haley Patent Leather Co.	Finishing	1904-1916	9
65	Beggs & Cobb	Tanning	1871-1957	11,20,21,23
66	Blank Brothers Tannery	Tanning	1876-1910	19,21,24
67	Waldmyer Tannery	Tanning	1838-1894	21

* In 1918 incorporated into Woburn Japanning at Site 32. ** In 1918 incorporated into Fox & Sons at Site 45. *** In 1904 incorporated into Amer. Hide & Leather Fact. D at Site 48.

and move through the watershed, and how humans may be exposed to and affected by particular waste chemicals. In order to help identify which hazardous chemicals are most widely distributed in the wastershed, mass balance techniques are being employed to quantify chemical consumption and waste generation by specific industries in the watershed, with special emphasis here on the area's major industry. The mass balance approach is employed to estimate the amounts of four metals — chromium, copper, lead and zinc — produced as by-products of tanning and leather finishing. (Since there were insufficient records to properly characterize the rendering industry, wastes generated by rendering operations were not included in the mass balance).

The Rise of the Leather Industry in the Aberjona Watershed

The history of tanning in the Aberjona River watershed spans over 320 years. The first tannery was built in Woburn in 1666.[47] During the 1700s several more tanneries were constructed in Woburn, but it was not until after the Middlesex Canal was completed in 1803 that the tanning industry became firmly established. Built to facilitate the exchange of raw materials and manufactured goods between Boston and the city of Lowell to the north, the canal had a significant impact on the economies of the smaller communities that developed along its banks. The canal ran through what is now Woburn center, providing Woburn's tanneries direct access to markets from which they could acquire new hides and skins, and to which they could distribute finished leather products. By 1837 there were four tanneries in Woburn employing over 75 workers.[48]

The early development of the leather industry in the watershed was helped considerably by the concurrent development of machine making, chemical production, and shoe and boot manufacturing. Machinists produced new and innovative tanning machinery; chemical companies both supplied chemicals to, and derived raw materials from, tanning operations; and, shoe and boot manufacturers provided a steady market for finished leather. Although all three support industries were important to the early success and growth of the tanning industry, the making of shoes and boots had perhaps the most significant impact. Along with Philadelphia and Lynn, Massachusetts, the Aberjona watershed was one of the nation's largest manufacturing centers for leather footwear. In 1850, there were 26 shoe and boot manufacturing shops in Woburn alone.[48]

By the 1860s the production of leather had become the dominant industry in the watershed. The construction of the Woburn branchline to the Boston & Maine Railroad in 1844, the increasing supply of skilled tannery workers, the continued demand for finished leather by local shoe and boot manufacturers, and the growing reputation of the quality of Woburn leather goods all contributed to the prosperity of the leather industry. In explaining the dominance of the leather industry in the watershed, historians also suggest that the quality and supply of water was an important factor. In 1920, one historian wrote:

> From the beginning of tanning in this city [Woburn], it has become a well known fact that the opportunities here presented for tanning were unexcelled, and that better results could be obtained here because of the water properties, than in any other known locality.[47]

Not only were there abundant supplies of surface water from which to draw water for production and in which to discharge wastes, but there were considerable groundwater reservoirs as well. According to the United States Geological Survey, the Aberjona watershed has some of the most transmissive aquifers in the northeast Massachusetts coastal drainage basin.[49]

Peak Years of the Leather Industry

The most productive period in the history of the leather industry lasted from the late 1870s to the 1920s. During that period, from 15 to 20 tanneries and leather-finishing companies were consistently in business, nearly 55 percent of all wage earners in the area were employed in the leather industry, and the value of tanned and finished leather products accounted for over half of the total annual value of goods produced in the watershed.[50]

Two factors that had a significant impact on the growth and success of the industry in this period were the introduction of chrome-tanning methods and the increased specialization of the industry in the production of "upper" leather (*i.e.*, the leather from which the upper parts of shoes are made). Prior to 1900, most tanning was performed using tanning agents that were derived from plants — principally, tannins from wood, leaf and bark extracts. "Vegetable" tanning, as it is known, was performed in vats of tannin solution in which hides and skins were soaked for as long as several weeks, depending on the thickness of the leather and the desired qualities of the tanned product. The introduction of chrome-tanning methods to the watershed around the turn of the century, however, revolutionized the production of light leathers by greatly reducing the time necessary for tanning. Chrome tanning, in which chromium salts — usually basic chromium sulfate — are used as the principal tanning agents, is completed within six to 24 hours, and produces a leather that has greater heat and abrasion resistance than vegetable-tanned leather.

The specialization of the tanning industry in the production of upper leather was influenced not only by the development of chrome-tanning methods, but also by technological innovations and market demand. Such inventions as the belt knife splitting machine (used to separate the grain side of the leather from the flesh side or "split"), the staking machine (used to soften leather), the shaving machine, and embossing and buffing machines improved the productivity of upper leather tanneries greater than tenfold.[47] Likewise, the use of trucks instead of railroad cars and horse-drawn wagons to deliver leather to market both increased the speed of distribution and allowed access to new distribution centers.

In response to market demands for new types and styles of finished leather goods, tanneries and leather finishers produced patent leather for shoes, and special grades of upper leather such as glove grain, pebble grain and crimping splits. By the 1920s, tanneries and finishers had markets in England, Europe and South America. In the United States, the cities of Woburn and Winchester were referred to as the nation's "home of upper leather manufacturing."[51] In order to keep up with demand, it was estimated that in the late 1920s tanneries in Woburn were producing approximately 30,000 sides of leather per day, or seven million sides annually.[47]

The Decline of the Leather Industry

The finished leather industry had its best years in 1927 and 1928, and then experienced significant losses as a result of the stock market crash in 1929 and the depressed national economy in the early 1930s. In 1928, the value of leather goods produced in Woburn was just over $10 million, 1,299 wage earners were employed in the leather industry, and 24 tanneries and leather-finishing companies were in business. By 1932, however, the value of leather goods produced in Woburn had decreased by two-thirds to just over $3.2 million, the number of employees had been reduced to 759, and the number of tanning and leather-finishing businesses had fallen to 16. The leather industry hit bottom in 1940 when only six tanneries remained and the value of goods produced was $380,000.[50]

Despite the downturn in the finished leather economy in the 1930s, other sectors of the leather industry — specifically, leather and hide rendering — still managed to post modest gains. Rendering companies took advantage of the cheap surpluses of hides and unfinished leather, and built large factories to manufacture grease, gelatin and glue. By 1939, five rendering plants were operating in the watershed.

In 1940 there were eleven tanneries, leather-finishing companies, and rendering factories in the watershed. Between 1940 and 1948, the industry posted modest gains as the value of products sold reached its highest levels since 1929. By the 1950s, however, it was clear that the industry was stagnating. No new establishments were going into business, and industry profits were not keeping pace with growth in other sectors of the local economy. Increasing competition from foreign companies for market share, fluctuations in wholesale prices and rising production costs also contributed to the slow demise of the industry. The remaining companies began going out of business one by one in the late 1950s. The last company to go out of business closed in January 1988, thus ending the long tenure of the leather industry in the watershed.

Surface Water Contamination

There is a substantial historical record documenting leather industry waste contamination of surface water bodies in the watershed. Much of this history was documented by the Massachusetts State Board of Health and later by the body that replaced it, the State Department of Public Health. In one of its first investigations of the relationship between industrial and municipal waste disposal practices and the contamination of drinking water supplies, the Board of Health studied the problems in the Upper Mystic Lake watershed. In 1871 a report was issued on the condition of Upper Mystic Lake (which then provided drinking water to Charlestown, Somerville and East Boston), its main tributary, the Aberjona River, and other water bodies in the watershed. Although no industrial or municipal waste contamination was found in Upper Mystic Lake, the report indicated that tannery wastes were present in Horn Pond (which was then part of Woburn's water supply) and its tributaries.[11] Subsequent reports by the Board of Health in 1874 and 1875 described the extent of tannery waste contamination in Russell Brook, a tributary to Horn Pond Brook.[25,26] Investigators identified eight tanneries that were directly discharging effluent to the brook. Sewage from nearby homes and coal degassing wastes were also adding to the foul condition of the brook, leading Board of Health officials to speculate that the contaminated water had contributed to the recent increase in mortality rates in the community:

> Within the last ten years, there has been a large number of deaths in this district, especially from consumption, typhoid fever, diphtheria and scarlet fever. During the past summer and fall, when the brook [Russell Brook] was in its worst condition, there was sickness in most of the houses. It is fair to infer that the prevalence of disease was influenced, if not caused, by the polluted stream . . . .[26]

In 1876, just five years after declaring Upper Mystic Lake water "unquestionably good and wholesome," Board of Health investigators returned to the watershed to assess conditions in the Aberjona River. Fueled by growing concerns that discharges of municipal and industrial wastes would lead to the contamination of Upper Mystic Lake, investigators found that a 1.5-mile-long section of the river directly upstream of Upper Mystic Lake received inputs of glue manufacturing wastes, "putrescent animal matter and lime" from tanneries, and sewage.[27] Fifty-five factories (of which twenty were "leather-works") were identified on tributaries to Upper Mystic Lake, and it was estimated that "about seven percent of the water that flows in upper Mystic Pond is drainage from [these] factories."[27] In their report, Board of Health investigators also observed that "[f]ish have been killed in this pond, and cattle have refused to drink the water of the 'Abajonna' River."[27]

The Board of Health (and later the Department of Public Health) continued to make examinations of surface water conditions in the watershed between the late 1870s and the 1950s. During that period, health officials focused much of their attention on promoting the establishment of legislation that would prevent further pollution of surface waters in the watershed, and on the construction of a sewer system that could meet both municipal and industrial waste disposal needs. Particular emphasis was given to Russell Brook and the Aberjona River, where tannery and rendering wastes were frequently found. Investigations of Russell Brook in 1904 and 1907 (and again in 1915 and 1921) revealed widespread contamination by tannery effluent discharges.[20,28,29,31] Likewise, leather industry waste contamination was reported in the Aberjona River in 1912, 1915, 1922, 1927 through 1929, 1931 through 1934, 1936 and 1939.[20,30-35,37-42]

Development of the Sewer System

The development of the sewer system in the watershed has a complex and interesting history. The first major sewer line in the watershed was constructed in Winchester in 1878, along the course of the Aberjona River. Fearing that discharges of industrial wastes and raw sewage would contaminate drinking water supplies in

Upper Mystic Lake, the city of Boston built the "Old Mystic Valley Sewer," complete with a precipitation facility to separate liquid and settleable wastes. Sewage and industrial effluent from Winchester center and factories operating on the Aberjona River were treated in settling tanks and mixers before being discharged into Lower Mystic Lake. From its inception the Old Mystic Valley sewer system proved to be inadequate to handle the volume of wastes generated by its users. Also, the water quality of Lower Mystic Lake rapidly deteriorated, leading the Board of Health to write in its 1884 annual report that the sewer provided "but a partial remedy for the evil of the Mystic Valley."[52] The Old Mystic Valley sewer was used until 1895 when connections were finally completed to sewer lines that discharged at Deer Island into Boston Harbor.[6]

After the turn of the century, worsening pollution problems in the watershed prompted area residents to issue complaints against Woburn and Winchester companies that were found to be discharging waste into surface waters.[48] In addition, Board of Health investigators continued to document the extent of contamination in Russell Brook and in the Aberjona River, and made concerted efforts to identify the offending dischargers.[28,29] In response to increasing public pressure to take action, the Massachusetts General Court passed two pieces of pollution control legislation. One piece of legislation (Chapter 235), passed in 1907, prohibited the pollution of Horn Pond Brook and its tributaries. The other law (Chapter 291), passed in 1911, prohibited the pollution of the Aberjona River.[6] The Chapter 291 Acts were intended to prohibit:

> [T]he entrance or discharge of sewage into any part of the Aberjona River, or its tributaries, and to prevent the entrance or discharge therein of any substance which might be injurious to public health or might tend to create a public nuisance.

The Acts established a maximum fine of $500 for each offense. In addition, the Board of Health was instructed to provide technical advice to assist companies in reducing discharges to the Aberjona River or its tributaries.[53]

Despite the clear mandate of the 1907 and 1911 legislation, their implementation and enforcement were made difficult because many tanneries and rendering companies were either unable or unwilling to comply with the pollution control laws. Prior to the passage of the Acts, leather industry firms that were not sewered typically stored their wastewater in lagoons to permit solids to settle before discharging the effluent to surface waters. Because the Metropolitan District Commission (MDC) sewer system (formerly the Old Mystic Valley sewer system) did not extend into north Woburn where many leather industry firms were located, companies had no alternative but to discharge their wastes into surface waters. Furthermore, with pressure mounting at both the local and state levels to prevent further pollution of the Aberjona River from sources in north Woburn, leather industry firms recognized that the extension of the MDC sewer was inevitable, and they were therefore reluctant to invest in expensive waste treatment technology.

Although there was almost universal support for the development of the Woburn extension sewer, conflicts over the allocation of costs significantly delayed its construction. Between 1921 and 1923, several bills were introduced in the state legislature to provide for the construction of the sewer as part of the MDC system, but in each case the bills were defeated because other communities felt the cost of the sewer extension should be borne by the city of Woburn and not the state. After considerable debate, a compromise was reached in which the legislature agreed to share the costs of constructing the sewer extension.[48] Work on the sewer line finally began in 1927, but due to problems caused by excessive groundwater infiltration, the sewer was not put into operation until 1932.[6]

Land Disposal of Waste Sludge

The disposal of waste sludges presented an additional problem for tanneries and rendering factories in the watershed. Tanning and rendering wastewater contains high concentrations of solids — mainly hide and leather residues such as fleshings, hair, trimmings, shavings, buffing dust, *etc.* — that readily settle and create dense sludges. Because these sludges frequently caused sewer lines to become clogged and to eventually overflow, tanneries and rendering factories in the watershed were required to pretreat their wastewater in settling lagoons before discharging it to the sewer. Sludges were then removed from the lagoons and placed in either on-site dumps or in public landfills.

Several problems caused by these sludge dumps were reported by the Department of Public Health and other investigators. For example, in 1915, the Department of Health observed in its annual report that:

> In the course of many years large quantities of organic matter, chiefly from tanneries, have been deposited upon the ground at many places in this valley, and the natural effect of the rainfall is to carry matters from these deposits, partly in solution and partly in suspension, into the streams.[31]

In 1920, a Red Cross investigator reporting on health and sanitary conditions in Woburn noted:

> Because of the fact that chrome-tanning sludge is not allowed to flow into the Metropolitan Sewerage system, this material is kept in catch basins for two months and then piled upon a dump which is near Russell Brook. From this material a very irritating, obnoxious odor goes forth.[43]

Also, between 1921 and 1922, while conducting a survey of the watershed to assess the condition of fish populations in the Aberjona River and its tributaries, State Department of Fisheries and Wildlife biologists identified three tanning sludge dumps that were draining into either Russell Brook or its tributaries.[20] Similarly, in 1970 a Department of Public Health investigator found that leachate emanating from rendering residue dumps on the Stauffer Chemical Company property was draining into Halls Brook.[44]

Even though tanneries and rendering companies in the watershed were required to perform primary treatment to remove settleable materials prior to discharging wastewater into sewer lines, solids were invariably introduced into the sewerage. As a result, the deposition and accumulation of solids in the sewers contributed to several incidents of sewer line overflow. Between 1927 and 1929, for example, the MDC sewer in Winchester regularly overflowed, causing raw sewage and industrial wastes to drain directly into the Aberjona River.[33-35] Also, for several years after it went on line, the Woburn extension sewer repeatedly overflowed, and, as a result, tanning and rendering wastes from companies in north Woburn spilled into the river.[41,54-56] In order to reduce the frequency of sewage overflows, the Department of Public Health tried to institute a program of periodic sewer cleaning.[41,56] The program successfully decreased the incidence of overflowing; however, in its report on sanitary conditions in the Aberjona River and the Mystic Lakes in 1957, the Department of Public Health noted that material removed from sewer lines during cleaning was often left in piles near the manholes from which it was removed and, therefore, was a potential source of surface water pollution.[6]

Leather Industry Waste Sites

There are currently six sites in the watershed that are being investigated for the presence of leather industry waste contamination. The Massachusetts DEP is investigating two former rendering factory sites and three former tannery sites under the Oil and Hazardous Materials Release Prevention and Response Act of 1983 (*i.e.*, MGL c.21(E)). The federal EPA is directing the investigation and remediation of the "Industriplex" site — where a large rendering factory once operated — under CERCLA (*i.e.*, Superfund).

60 South Bedford Street. Tanning and rendering wastes were first discovered at 60 South Bedford Street (Site 14 on Figure 2) in October 1984. Water from a brick vault uncovered during the installation of a swimming pool in a residential area was found to contain low concentrations of metals and volatile organic compounds. A second vault was later found that contained "a red sludge with animal hairs." Sludge samples were analyzed and found to be contaminated with high concentrations of chromium and lead. A title search revealed that from the mid-1830s until the turn of the century a tannery operated on the site, and that between the 1900s and 1977, the site was used by a hide and leather degreasing company.

Following the discovery of the vaults, emergency measures were taken to reduce risks posed by the contaminants present on the site. A trench was excavated from which contaminated groundwater was pumped, the sludge materials and vaults were removed, and wells were installed to monitor the migration of pollutants in the groundwater. A Phase II "Comprehensive Site Investigation" has been planned to determine whether additional waste materials are present on the site and whether contaminant migration in groundwater could impact local drinking water supplies.[45] The site was placed on the state DEP's list of "confirmed" hazardous materials sites in January 1987.[57]

5 Green Street. An assessment of the 5 Green Street Site (Site 45 on Figure 2) was performed in October 1984 to determine whether petroleum products or other hazardous materials were present on the property. Six test pits were excavated and soil samples from one of the test pits were found to contain elevated concentrations of chromium. Site investigators attributed the chromium to tanneries that had operated on the site from before 1875 until 1938. Although other metals including beryllium, thallium and barium were also detected in soil samples, investigators concluded that the contamination does not pose a threat of off-site migration, and it was recommended that no further action be taken on the site.[18] The DEP placed the site on its "Remedial Sites List" in January 1987.[57]

8 Green Street. The results of an investigation of the 8 Green Street site (Site 44 on Figure 2), performed in December 1986, indicate that groundwater beneath the property is contaminated with petroleum products and metals. Both oil and grease were detected, as well as low concentrations of arsenic, cadmium, mercury and lead. Historical records indicate that tanneries operated on the site from around 1875 until 1934. A number of filled pits were also discovered on the property. Investigators speculated that "the pits contain materials associated with the tanning business such as leather scraps, wood, animal remains, minor amounts of grease and solvents, *etc.*"[17] As a result of the investigation, the DEP was notified, and in October 1988 the site was placed on the DEP's list of "Locations to Be Investigated."[57]

J.O. Whitten Company Site. An evaluation of the former J.O. Whitten Company property in Winchester (Site 61 on Figure 2) was performed in December 1984. A total of 33 test pits were excavated, eight monitoring wells were installed and numerous soil, soil gas, sludge and groundwater samples were collected. In addition, surface water and sediment samples were taken from the Aberjona River that abuts the eastern edge of the property. It was found that the soils and sediment samples were contaminated with arsenic, chromium and mercury, the groundwater and surface water samples contained arsenic, barium, cyanide, toluene and benzene, and the soil gas samples had concentrations of mercury vapor. Historical records indicate that a tannery operated on the site from 1872 until around the turn of the century. The property was then purchased by the J.O. Whitten Company which operated a gelatin, and later a glue, manufactory there until 1980.[22] The DEP placed the site on its list of confirmed sites in January 1987. In January 1989, the site was given "Phase III" status, indicating that the development of the remedial response plan was underway.[57]

J.J. Riley Company Site. The J.J. Riley Company tannery (Site 22 on Figure 2) was first investigated by the EPA in 1980 to determine whether waste disposal practices at the site had resulted in violations of Resource Conservation and Recovery Act or Clean Water Act standards. During a site inspection, EPA investigators were told by company officials that two lagoons had been used until 1970 for the separation of settleable solids from chrome-tanning wastewater prior to discharging the wastewater to the MDC sewer. Although the lagoons were no longer in use, the investigators noted that materials leaching from the lagoons could pose a threat to groundwater. The investigators were also told that waste sludge from an existing sedimentation tank was routinely piled on the ground near the lagoons.[58] In 1983, officials from the DEP inspected the tannery. In their report, the state inspectors wrote:

With reference to non-hazardous sludges, John J. Riley Co. appears to be in violation of M.G.L. c.24 section 43 which prohibits the discharge of pollutants to the waters of the Commonwealth without a valid permit.... The Company also appears to be in violation of Chapter III, section 150A, of the Solid Waste Disposal Act.[59]

As a result of the EPA and the DEP investigations, the site was placed on the state's "Locations to Be Investigated" list in January 1987.[57]

Industriplex Site. The "Industriplex" site (Site 2 on Figure 2) is one of the oldest industrial sites in the watershed. It was first developed in 1853 by the Chemical Works Company, which made acids and other chemicals for textiles, paper and leather producers. In 1863, the Chemical Works Company was acquired by Merrimac Chemical, which used the site to manufacture arsenic- and lead-based insecticides and explosives such as trinitrotoluene (TNT). By the turn of the century, Merrimac Chemical had developed over 400 acres of the site and it soon became one of the largest chemical producers in New England. Between 1927 and 1936, ownership of the chemical works changed three more times as the Monsanto Company (from 1927 to 1934), the New England Chemical Company (from 1934 to 1936) and Consolidated Chemical Industries rebuilt the facility into a rendering factory. The companies used hides and leather scraps from tanneries in the watershed as raw materials to make glue and grease. Consolidated Chemical used the site until 1960, when it was purchased by Stauffer Chemical Company. Stauffer maintained the glue manufactory until it went out of business in 1968.

Shortly after Stauffer abandoned the glue works, the property was acquired by the Mark Phillip Realty Trust. The trust wanted to develop the entire 400-acre site into an industrial park. As development proceeded in the northern end of the site, workers began to uncover piles of waste materials that the chemical companies had buried. In June 1979, the Army Corps of Engineers took action against the realty trust when it was discovered that dredging spoils and fill material were being dumped into the Aberjona River and adjacent wetlands. Acting under the authority of section 404 of the Federal Water Pollution Control Act, the Corps served a cease and desist order to the developer, thereby temporarily barring work on the site. In its preliminary assessment of wetlands violations by the developer, the Corps noted that there were increased levels of heavy metals, biochemical oxygen demand (BOD), bacteria and sedimentation in the Aberjona River. Suspecting that additional waste materials were also present on the site, state DEP and federal EPA officials conducted their own investigations. These investigations revealed sludge lagoons contaminated with high levels of chromium, an earthen pit filled with lead- and arsenic-laden soil, twenty acres of rendering residue piles that were generating large quantities of hydrogen sulfide and methane gas, and plumes of benzene and toluene in the groundwater. As a result of these discoveries, the EPA obtained a court order to prevent further development on the property. In October 1981, the site was named to the EPA "Superfund Interim Priorities List" of sites eligible for federal clean-up funding. In December 1982, the site was added to the final EPA "National Priorities List."[60]

Mass Balance Analysis of Leather Industry Wastes

Taking into account the chemical characteristics of the wastes produced by tanning, leather-finishing and rendering operations, as well as historical manufacturing records, mass balance techniques can be used to estimate the amounts of waste chemicals produced by tanning operations. Because much of the tanning industry in the watershed specialized in making chrome-tanned upper leather for shoes, special focus is given to chrome tanning of cattlehide.

Cattlehide Tanning & Leather Finishing

Tanning is the chemical process by which hides and skins are converted into non-putrescible leather. Tanning is accomplished by first removing the epidermal layer and subcutaneous flesh layer of the hide, followed by chemically stabilizing the remaining middle layer that is composed mainly of the protein collagen. Leather finishing involves any of several chemical processes such as bleaching, fat-liquoring and coloring, or mechanical operations such as

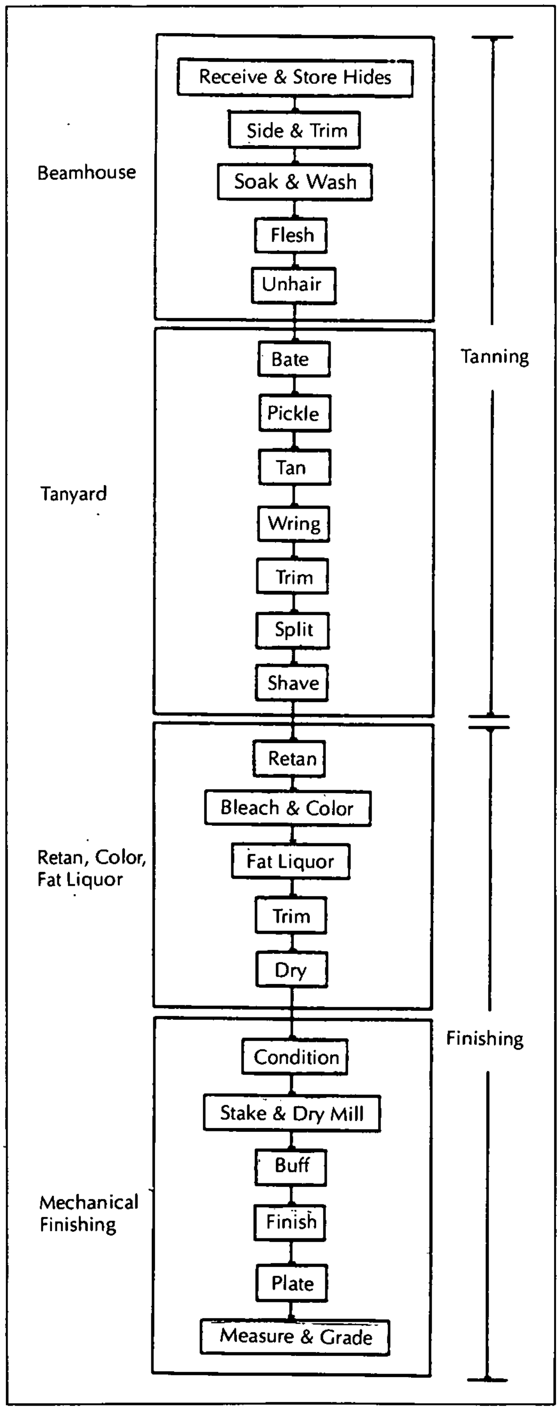

FIGURE 3. Process flow diagram for a "complete" chrome tannery.

drying, staking and buffing. Finishing is performed to alter the surface characteristics of leather, such as thickness, texture, feel, *etc.*, for making specific leather goods. While there are basic steps to produce finished, chrome-tanned leather from raw cattlehide, there was perhaps wide variation in tanning practices among the many tanneries in the watershed. In the absence of a complete record of each company's methods, the general practices of the industry as a whole are reviewed.

When hides are removed from freshly slaughtered cattle, they are typically salt-cured to prevent bacterial decay. As a result, upon arriving at a tannery, cattlehides are often dehydrated and contain large amounts of undissolved salt, dirt, blood, manure and non-fibrous protein. In order to prepare the hides for tanning, new hides are first processed in what is called a "beamhouse" where they are rehydrated and cleaned (see Figure 3). After being "sided," or cut in half along the backbone, new hides are soaked to restore lost moisture and then washed to remove extraneous matter. The flesh layer is then cut away to allow easier penetration and more effective action of the tanning agents. Finally, the hair and epidermis are removed from the hide. Unhairing is frequently done by soaking hides in a series of successively stronger lime baths. Lime causes collagen fibers to separate, thereby allowing the dissolution of non-fibrous proteins. Lime-softened hides are then immersed in solutions of sodium sulfide, the strength of which can be controlled either to loosen hair for subsequent hair recovery or to pulp hair if hair recovery is not desired.

Once hides have been prepared in the beamhouse, they are transferred to the "tanyard" where tanning is performed. In the first tanyard process, called "bating," the surface properties of the lime-soaked hides are adjusted to facilitate tanning. Hides are soaked in solutions of buffering salts, such as ammonium sulfate or ammonium chloride, and proteolytic enzymes, such as trypsin and chymotrypsin. Bating reduces the pH and swelling of the hide, peptizes protein fibers and removes protein degradation products. It also softens the hide texture by removing unhairing chemicals and non-fibrous proteins. After bating, hides are typically immersed in pickling solutions of salts and acids to reduce the pH of the hides so that chrome-tanning salts do not precipitate on the protein fibers during tanning.

Once bating and pickling have been completed, the hide is ready for tanning. Tanning is accomplished by milling the hides in baths containing chrome liquor (*i.e.*, high concentrations of chromium salts dissolved in water). Trivalent chromium in the liquor binds with the carboxyl groups (–COOH) on different peptide chains, thus increasing the chemical stability of collagen molecules. In chrome tanning, the most widely used process is the "one-bath" method, in which basic chromium sulfate is the tanning agent. Following tanning, hides are split into two distinct layers: the upper layer or grain layer, and the lower layer or split. The grain layer is more valuable than the split and, thus, many tanneries process only the grain layer, selling the splits to split-finishers or rendering factories. In the final tanyard step, the grain layer is shaved on a shaving machine to uniform thickness.

After tanning, most cattlehide leather requires considerable finishing work before it can be made into leather goods. Typical finishing processes include vegetable retanning, bleaching, coloring and fat-liquoring. Vegetable retanning, in which chrome-tanned leather is given short baths in weak solutions of vegetable tannins, results in leather that is in general fuller, plumper, more easily tooled and more water resistant than non-retanned leather. In bleaching and coloring processes, pigments and synthetic dyes — many of which contain cadmium, chromium, iron, lead, titanium and zinc[61] — are used to give leather its desired appearance. Fat-liquoring is a procedure in which oils, greases and waxes are applied to leather to keep it soft and pliable, and to increase the strength and tear resistance of the leather fibers.

A number of mechanical operations are also performed during leather finishing. The most common are trimming, drying, staking, dry milling and buffing. Trimming removes the rough edges and improves the appearance of the leather and makes the sides easier to handle for subsequent finishing steps. Trimming is often repeated several times during leather finishing; as a result, trimming scraps can become a sizeable fraction of the solid waste stream. Because unfinished leather typically contains a significant amount of water, sides are dryed until the desired residual moisture content is achieved. In drying processes, sides are either stretched on metal frames, pasted on large plates or hung on racks and then placed in low-temperature ovens, heated rooms or outdoors in direct sunlight. Buffing, or light sanding, of the grain side is typically performed to improve the final appearance of the leather.

Characterization of Chrome-Tanning & Finishing Wastes

The chemical properties of chrome-tanning and leather-finishing wastes have been well characterized. In studies by the New England Interstate Water Pollution Control Commission[62] and the EPA,[63,64] which were conducted in order to assist the leather industry and pollution abatement agencies in their efforts to reduce waste pollution, tanning and finishing wastes were chemically analyzed. The results of these analyses indicate that tanning and finishing wastes are composed of complex mixtures of dissolved chemicals as well as settleable and nonsettleable solids. Wastewater samples were found to contain dirt, blood, manure, bactericides, salt, fleshings, grease, lime, acids, enzymes, hair, unfixed tanning agents, dyes, pigments, oils and buffing dust. Waste solids were shown to be composed mainly of protein and fat from fleshings, trimmings, shavings and buffing dust, in addition to undissolved tanning and finishing chemicals. A list of tanning and finishing chemicals used in a typical complete chrome tannery is presented in Figure 4. The figure also shows the amounts of waste solids produced in each tanning and finishing component process.

Efforts have been made to identify the hazardous chemicals in tanning and finishing wastes that pose the greatest risks to human health and the environment. In assessing the chemical composition of tanning and finishing wastes, EPA-contracted investigators classified wastes as "potentially hazardous" if hazardous constituents were present at levels exceeding a selected threshold. Potentially hazardous waste was defined as:

> [W]aste or combinations of waste which pose a substantial present or potential haz-

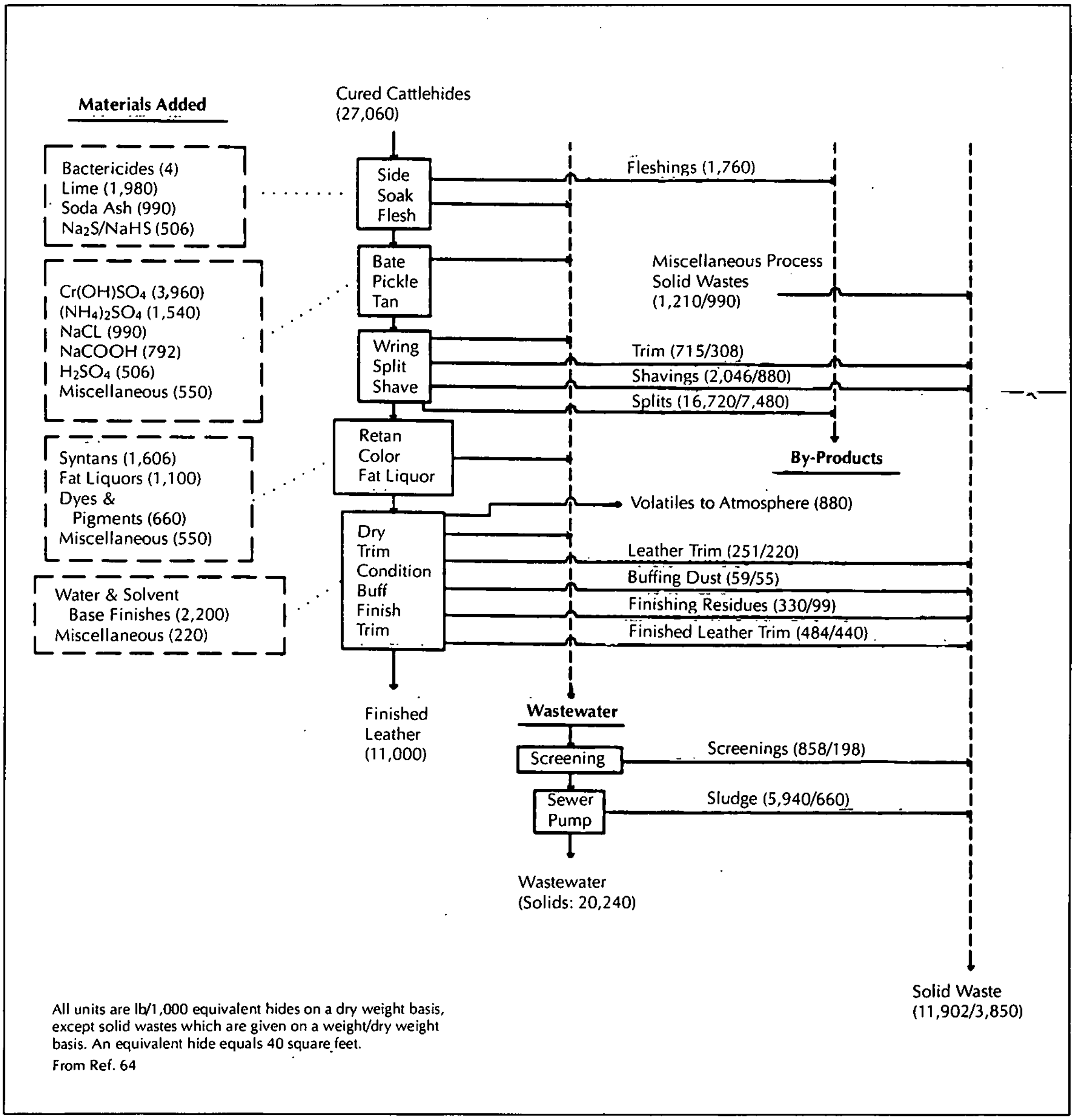

FIGURE 4. Materials used and wastes generated by a "complete" chrome tannery.

ard to human health or living organisms because such waste is lethal, non-degradable, or persistent in nature; may be biologically magnified; or otherwise cause or tend to cause detrimental cumulative effects.[64]

Waste constituents were considered hazardous if they were radioactive, infectious, explosive, flammable, irritants or strong sensitizers, corrosive or toxic. The hazardous concentration threshold for various constituent chemicals was selected as the mean of background concentrations in soils in the United States.

In their study, the investigators analyzed waste samples collected at different points in the solid waste streams of 28 tanneries in the United States. It was found that chromium (trivalent), copper, lead and zinc were present in several waste samples at levels that exceeded their hazard thresholds. Citing the well-established toxic properties of chromium, copper, lead and zinc, the investigators concluded that

TABLE 2
Concentrations of Metals in Complete[*] Chrome Tannery Wastes

Metal[***]	Concentration Range (lb/1,000lb)[§]	Weighted Mean Concentration (lb/1,000lb)	Concentration Range (mg/l)	Weighted Mean Concentration (mg/l)
Wastewater[**]				
Chromium[§§]	3.3-5.8	4.0	40-120	76
Copper	1.2×10^{-1}	1.2×10^{-1}	2.3	2.3
Lead	7.7×10^{-2}-1.4×10^{-1}	1.3×10^{-1}	1.5-1.7	2.5
Zinc	4.2×10^{-2}-6.7×10^{-2}	6.2×10^{-2}	0.8-1.3	1.2
Waste Solids[§§§]				
			(mg/kg)	(mg/kg)
Chromium	1.2×10^{-1}-3.2	8.9×10^{-1}	7.5×10^{2}-2.0×10^{4}	5.4×10^{3}
Copper	4.6×10^{-5}-7.7×10^{-1}	3.5×10^{-2}	4.8×10^{-1}-7.9×10^{3}	3.6×10^{2}
Lead	8.6×10^{-4}-4.0×10^{-1}	5.6×10^{-2}	7.1-3.3×10^{3}	4.6×10^{2}
Zinc	8.6×10^{-4}-2.2×10^{-2}	1.7×10^{-2}	7.3-1.9×10^{2}	1.5×10^{2}

[*] In a "complete" tannery, both tanning and finishing are done.
[**] Includes concentration in settleable suspended solids. In converting units it is assumed that 6,300 gallons of water are used per 1,000 pounds of hide tanned. (From Reference 63.)
[***] Chromium is used primarily in tanning agents; copper is used in bactericides; lead and zinc are used in dyes and pigments.
[§] Units are expressed as pounds of constituent in waste per 1,000 pounds of hide tanned.
[§§] Values for chromium in wastewater are from References 62 and 65.
[§§§] Values from Reference 64. Based on 1.625 lb/ft^2 average hide density.

the solid wastes that contained these metals were potentially hazardous. Other hazardous constituents including arsenic, beryllium, cadmium, mercury, selenium, zirconium, phenols and pesticides were also found in the waste samples, but at concentrations that were below the selected thresholds.[63]

Concentrations of chromium, copper, lead and zinc in wastewater and waste solids samples from "complete" chrome tanneries where both tanning and finishing were performed are presented in Table 2. In general, the average levels of chromium are an order of magnitude greater than the levels of the other metals. Although concentrations of these metals have been shown to be fairly steady in equalized discharges, unequalized effluent can have a widely varying composition. Bailey, for example, found that the chemical properties of tannery effluent fluctuated considerably as a function of discharge rate.[66] Samples that were collected over a 24-hour period from a catch basin in which effluent was held prior to discharge to the sewer showed the following variations:

- Suspended solids: 0 to 8,500 mg/l
- BOD: 100 to 10,000 mg/l
- Sulfide: 0 to 500 mg/l
- pH: 3.0 to 11.0

Samples of equalized effluent, however, showed considerably less variation:

- Suspended solids: 100 to 500 mg/l
- BOD: 600 to 900 mg/l
- Sulfide: 0 to 24 mg/l
- pH: 7.5 to 8.5

The concentrations shown in Table 2 are for equalized discharges of wastewater and waste solids.

In addition to the rate of discharge, chemical interactions in raw tannery wastes can have a large effect on concentrations of dissolved constituents. Chelation by organic matter and dissolution due to the presence of carbonates can cause concentrations of metals — especially chromium — to deviate significantly from predicted levels. In order to compensate for the effect of such interactions, the amounts of metals generated in tannery wastes are normalized by the weight of hide tanned. Normalized concentrations are used in the mass balance analysis to predict the total amounts of metals generated in tanning and finishing wastes.

Hide & Leather Rendering

Rendering is the process by which grease and glue are extracted from animal hides, bones and leather. Rendering is typically performed by cooking raw materials in vats of water in order to liquefy fats and collagen. Grease is recovered by skimming off the fat layer that forms on the water surface. Glue is made by concentrating the dissolved collagen in the glue-stock.

When chrome-tanned leather (*i.e.*, scraps, trim and splits) is used in rendering, it is typically treated with acids so that rendering products are free of chromium. Leather is first placed in lime baths to allow fibers to swell, thereby increasing the surface area over which the detanning agents can act. The limed leather is then washed in solutions of sulfuric acid, which cause the chromium to dissolve from the leather. Because leather contains chromium in concentrations of 1 to 2 grams / ft^2, considerable amounts of dissolved chromium may be present in rendering effluent.

Although it is generally known when and where rendering activities took place in the watershed, detailed records documenting rendering operations could not be located for the majority of rendering companies. The only information that was found was from the Stauffer Chemical Company, which operated a rendering factory at the "Industriplex" site from 1960 to 1968. Records from the late 1960s indicate that chrome-tanned leather accounted for approximately 25 percent (or around 29 tons annually) of the raw materials used by the company, and that nearly 50,000 to 60,000 pounds of rendering wastes (25 percent solids) were generated per day.[8] Information concerning the operations of other rendering companies in the watershed could not be obtained because the companies had either gone out of business or never kept such records. Because there was not enough production or raw materials consumption data to accurately characterize the rendering industry in the watershed, chromium from rendering wastes was not included in the mass balance analysis.

Mass Balance of Metals in Tanning & Leather-Finishing Wastes

Mass balance (or chemical accounting) techniques were used to estimate the amounts of four metals — chromium, copper, lead and zinc — produced in tanning and leather-finishing wastes in the watershed between 1900 and 1936. The 36-year period was selected for three reasons:

- During this period chrome tanning was the dominant tanning method practiced in the watershed;
- It was the period during which the leather industry was most productive; and,
- During this period most tanning and leather-finishing wastes were discharged into surface water bodies and dumps (after 1936, the majority of tanning and leather-finishing companies in the watershed were connected to the sewers, and sewer overflowing was no longer persistently occurring).

Two mass balance methods were used in the analysis. The first method, called the "Value Method," is based on the gross value of finished leather produced by the leather industry. The second method, the "Labor Method," is based on the amount of hide tanned and finished per manhour worked. Data used in the two mass balance methods was obtained from Census of Manufacturers records for the city of Woburn and from national statistics. Manufacturers' records for Winchester and Stoneham were not available for the period of interest.

The two mass balance methods were used to generate independent estimates of the annual amounts of leather produced in Woburn.

In the Value Method, shown in Table 3, the total annual value of products, in dollars, made by tanners and leather finishers in Woburn was compared to the national average unit price of leather ($\$/ft^2$). In the Labor Method, shown in Table 4, the average number of wage earners employed in tanneries and leather-finishing companies in Woburn was compared with national statistics for average number of hours worked per week and production per manhour (ft^2/hr). The amounts of leather, in square feet, predicted by the two methods are shown in column 4 of Table 3 and column 5 of Table 4. In applying both methods, it was assumed that 85 percent of the leather produced was chrome-tanned. The total amounts of chrome-tanned leather estimated by the Value Method and the Labor Method for the 36-year period are 550 million and 1,630 million ft^2, respectively.

In order to predict the amount of metals produced in tanning and leather-finishing wastes, effluent concentrations from Table 2 were used. The amount of chrome-tanned leather (ft^2) produced annually was first multiplied by the average density of an equivalent hide, 1.625 lb/ft^2,[69] to determine the total weight of hide tanned (lb). The weighted mean concentrations of chromium, copper, lead and zinc in wastewater and waste solids (lb/1,000 lb) were then multiplied by the weight of hide tanned to estimate the total amounts of metals (tons) generated in tanning and leather-finishing effluent.

The amount of chromium in tannery wastewater and waste solids estimated by the two mass balance methods is presented in columns 5 and 6 of Table 3 and columns 6 and 7 of Table 4. The two mass balance methods indicate that, between 1900 and 1936, on the order of 2,000 to 4,000 tons of chromium were generated in tannery wastewater, and on the order of 400 to 800 tons of chromium were generated in tannery waste solids. It is further estimated that during this period, tanning and leather-finishing companies produced on the order of 50 to 110 tons of copper, 60 to 120 tons of lead and 30 to 60 tons of zinc in wastewater, and on the order of 15 to 32 tons of copper, 26 to 52 tons of lead and 8 to 16 tons of zinc in waste solids. The results of these estimates are plotted in Figures 5 to 7. The total amounts of the four metals in both wastewater and waste solids predicted by the two mass balance methods are depicted in Figure 8.

Three assumptions were used in applying the mass balance methods. First, it was assumed that the chemical characteristics of chrome-tanning and leather-finishing wastes have not changed significantly since the introduction of chrome-tanning methods. Thus, chemical analyses of tanning and leather-finishing wastes performed in the 1950s and 1970s can be used to characterize wastes generated between 1900 and 1936. This assumption is reasonable for chromium, which is still the most widely used tanning agent; however, because the history of copper, lead and zinc use in tanning and leather finishing is not well documented, it is uncertain whether this assumption leads the mass balance models to overestimate or underestimate the amounts of these metals produced in leather industry wastes. Second, it was assumed that 85 percent of the leather produced in Woburn between 1900 and 1936 was chrome-tanned. This estimate is based on research conducted recently that indicates between 80 and 85 percent of leather produced in the United States is chrome-tanned.[63,68] And third, in using the Value Method, it was assumed that the Census of Manufacturers' value of product data (column 2 in Table 3) represent the value of finished leather. This assumption would result in an overestimation, using the Value Method, of the amount of leather produced if tanners and leather finishers reported profit on the same leather (*i.e.*, if tanners sold unfinished leather to finishers and both reported income on that leather).

Discussion

In the absence of complete historical records documenting the amount of leather produced and describing the chemical characteristics of wastes generated by the leather industry in the watershed between 1900 and 1936, it is difficult to assess the accuracy of the waste metals estimates predicted in the mass balance analysis. Considering the limitations in the data available for the analysis and the uncertainty inherent in the assumptions used, it is possible that the mass balance estimates could be off by as much as a factor of two. Nonetheless, if the results are skewed, then it can be argued that the bias is in favor of underestimation rather than overestimation. Leather industry statistics could not be found in Census of Manufacturers data for Winchester and Stoneham, and, therefore, tanning and leather-finishing wastes generated in these two towns were not included in the analysis (rough estimates suggest that Win-

TABLE 3
Amount of Chromium in Tannery Wastes as a Function of the Total Gross Value of Finished Leather Produced

Year	Total* Value ($1,000)	Cost Per** Square Foot ($/ft²)	Square feet*** Chrome-Tanned Leather (1,000)	Chromium§ in Waste-Water (tons)	Chromium§ in Waste Solids (tons)
1900	3,352	0.299	9,529	31	7
1901	3,252	0.299	9,245	30	7
1902	3,152	0.299	8,961	29	6
1903	3,052	0.299	8,676	28	6
1904	2,952	0.299	8,392	27	6
1905	2,852	0.299	8,108	26	6
1906	2,932	0.299	8,335	27	6
1907	3,012	0.299	8,563	28	6
1908	3,092	0.299	8,790	29	6
1909	3,172	0.299	9,017	29	7
1910	3,252	0.299	9,245	30	7
1911	3,332	0.299	9,472	31	7
1912	3,412	0.299	9,700	32	7
1913	3,567	0.256	11,844	38	9
1914	3,451	0.268	10,945	36	8
1915	6,169	0.278	18,862	61	14
1916	7,397	0.325	19,346	63	14
1917	7,244	0.439	14,026	46	10
1918	7,232	0.412	14,920	48	11
1919	8,465	0.640	11,243	37	8
1920	4,818	0.617	6,637	22	5
1921	2,909	0.312	7,925	26	6
1922	6,409	0.258	21,115	69	15
1923	8,376	0.260	27,383	89	20
1924	8,999	0.264	28,974	94	21
1925	8,561	0.274	26,558	86	19
1926	9,363	0.253	31,457	102	23
1927	10,021	0.320	26,618	87	19
1928	10,019	0.369	23,079	75	17
1929	7,134	0.288	21,055	68	15
1930	5,277	0.238	18,846	61	14
1931	4,341	0.204	18,088	59	13
1932	3,214	0.162	16,864	55	12
1933	3,743	0.194	16,400	53	12
1934	3,631	0.188	16,417	53	12
1935	3,136	0.188	14,179	46	10
1936	3,322	0.196	14,407	47	10
		Totals:	553,219	1,798	400

* Reference 50 (1900-1904, 1906-1913 values interpolated from 1895, 1905 data).
** Reference 67 (values for 1900-1912 are average of 1913-1936 data).
*** It is assumed that 85 percent of the leather produced is chrome-tanned.[63,68]
§ An "equivalent" raw cattle hide is 40 square feet in area. It is assumed that the average weight of an equivalent hide is 65 pounds.[69] The average amount of chromium in wastewater of a complete chrome tannery is 4 lbs/1,000 lbs of raw cattle hide.[62,65]
§§ The average amount of chromium in sludge generated by a complete chrome tannery is 0.891 lbs/1,000 lbs of raw cattle hide tanned.[64]

chester and Stoneham may have produced as much as one-tenth the amount of wastes generated by the leather industry in Woburn). Also, because there was not enough information to adequately characterize the rendering industry in Woburn, it too was excluded from the analysis. In light of recent investigations at former rendering sites in Woburn, the exclusion of ren-

TABLE 4
Amount of Chromium in Tannery Wastes as a Function of the Amount of Finished Leather Produced Per Manhour

Year	Average* Number Wage Earners	Average** Number Hours Per Week	Product*** Per Manhour (ft^2/hr)	Square Feet§ Chrome-Tanned Leather (1,000)	Chromium§§ in Waste-Water (tons)	Chromium§§§ in Waste Solids (tons)
1900	915	39.50	25.56	40,832	133	30
1901	901	39.50	25.56	40,207	131	29
1902	887	39.50	25.56	39,583	129	29
1903	873	39.50	25.56	38,958	127	28
1904	859	39.50	25.56	38,333	125	28
1905	845	39.50	25.56	37,708	123	27
1906	843	39.50	25.56	37,619	122	27
1907	842	39.50	25.56	37,574	122	27
1908	840	39.50	25.56	37,485	122	27
1909	839	39.50	25.56	37,441	122	27
1910	837	39.50	25.56	37,351	121	27
1911	835	39.50	25.56	37,262	121	27
1912	833	39.50	25.56	37,173	121	27
1913	832	39.50	25.56	37,128	121	27
1914	919	39.50	25.56	41,011	133	30
1915	1,274	39.50	25.56	56,853	185	41
1916	1,264	39.50	25.56	56,406	183	41
1917	1,100	39.50	25.56	49,088	160	36
1918	1,040	39.50	25.56	46,410	151	34
1919	1,140	39.50	25.56	50,873	165	37
1920	865	39.50	25.56	38,601	125	28
1921	593	39.50	25.56	26,463	86	19
1922	1,200	39.50	25.56	53,550	174	39
1923	1,568	39.50	25.56	69,972	227	51
1924	1,453	42.54	23.90	65,296	212	47
1925	1,223	43.07	25.81	60,091	195	44
1926	1,259	43.18	24.30	58,390	190	42
1927	1,379	41.19	24.63	61,836	201	45
1928	1,299	41.71	23.53	56,350	183	41
1929	1,105	44.18	23.69	51,118	166	37
1930	911	40.89	24.69	40,652	132	29
1931	795	42.74	26.98	40,520	132	29
1932	759	42.74	24.68	35,387	115	26
1933	842	41.29	27.02	41,521	135	30
1934	916	37.75	27.84	42,550	138	31
1935	814	34.08	28.94	35,485	115	26
1936	762	17.99	26.26	15,911	52	12
			Totals:	1,628,987	3,677	819

* Reference 50 (1900-1904, 1906-1913 values interpolated from 1895, 1905 data).
** Reference 67 (values for 1900-1912 are average of 1913-1936 data).
*** *Ibid.*
§ It is assumed that 85 percent of the leather produced is chrome-tanned.[63,68]
§§ An "equivalent" raw cattle hide is 40 square feet in area. It is assumed that the average weight of an equivalent hide is 65 pounds.[69] The average amount of chromium in wastewater of a complete chrome tannery is 4 lbs/1,000 lbs of raw cattle hide.[62,65]
§§§ The average amount of chromium in sludge generated by a complete chrome tannery is 0.891 lbs/1,000 lbs of raw cattle hide tanned.[64]

dering wastes from the analysis would result in the omission of significant amounts of chromium. At the "Industriplex" site, for example, glue manufacturing wastes are distributed over a 35-acre area, of which approximately half contains chromium at concentrations exceeding 1,000 mg/kg, or 0.1 percent by weight.[60] Using conservative estimates of the

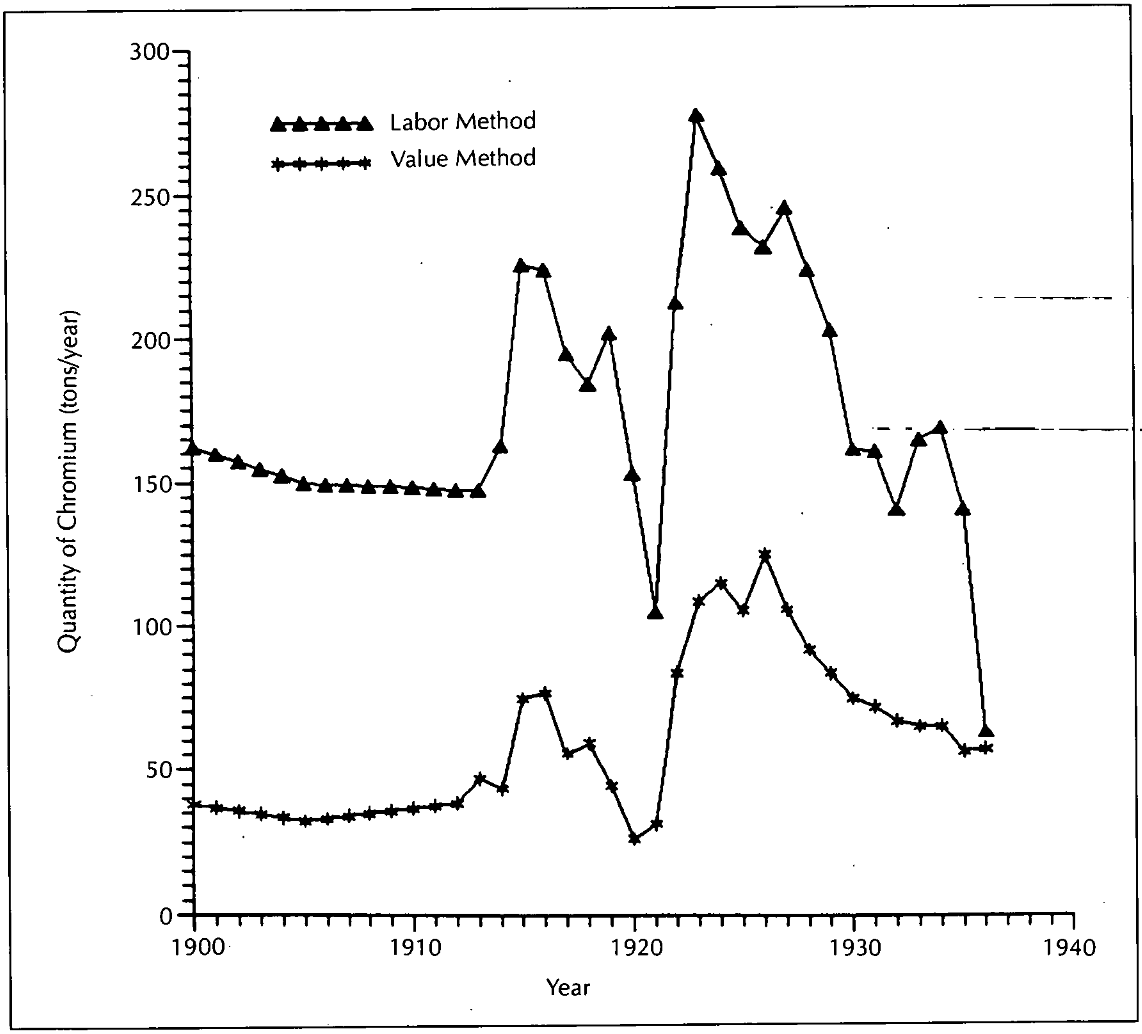

FIGURE 5. Comparison of the total quantity of chromium in tannery wastes as predicted by two mass balance methods.

depth (20 feet) and density (2 g/ml) of the rendering wastes, it is estimated that on the order of 1,000 tons of chromium are present on the site. It follows, therefore, that if wastes from the other rendering companies that operated in the watershed were also included in the analysis, the amount of chromium predicted would be considerably larger.

An important question raised by the results of the analysis is: What has happened to the waste metals generated by the leather industry? It is likely that large amounts of metals discharged in leather industry wastewater are no longer present in the watershed. Wastewater discharged to sewer lines was carried out of the watershed and then either treated at Deer Island or dumped directly into Boston Harbor. Wastewater discharged to the Aberjona River and its tributaries ultimately flowed into the Mystic Lakes. Because leather industry wastewater contains large amounts of solid materials, it is likely that the binding of waste metals to settling solids was a significant transport process. In support of this hypothesis, there is mounting evidence that large quantities of waste metals were deposited in quiescent zones along the course of the Aberjona River and its tributaries, and in the Mystic Lakes.[70,71] Rough estimates suggest that as much as ten percent of the chromium predicted in leather

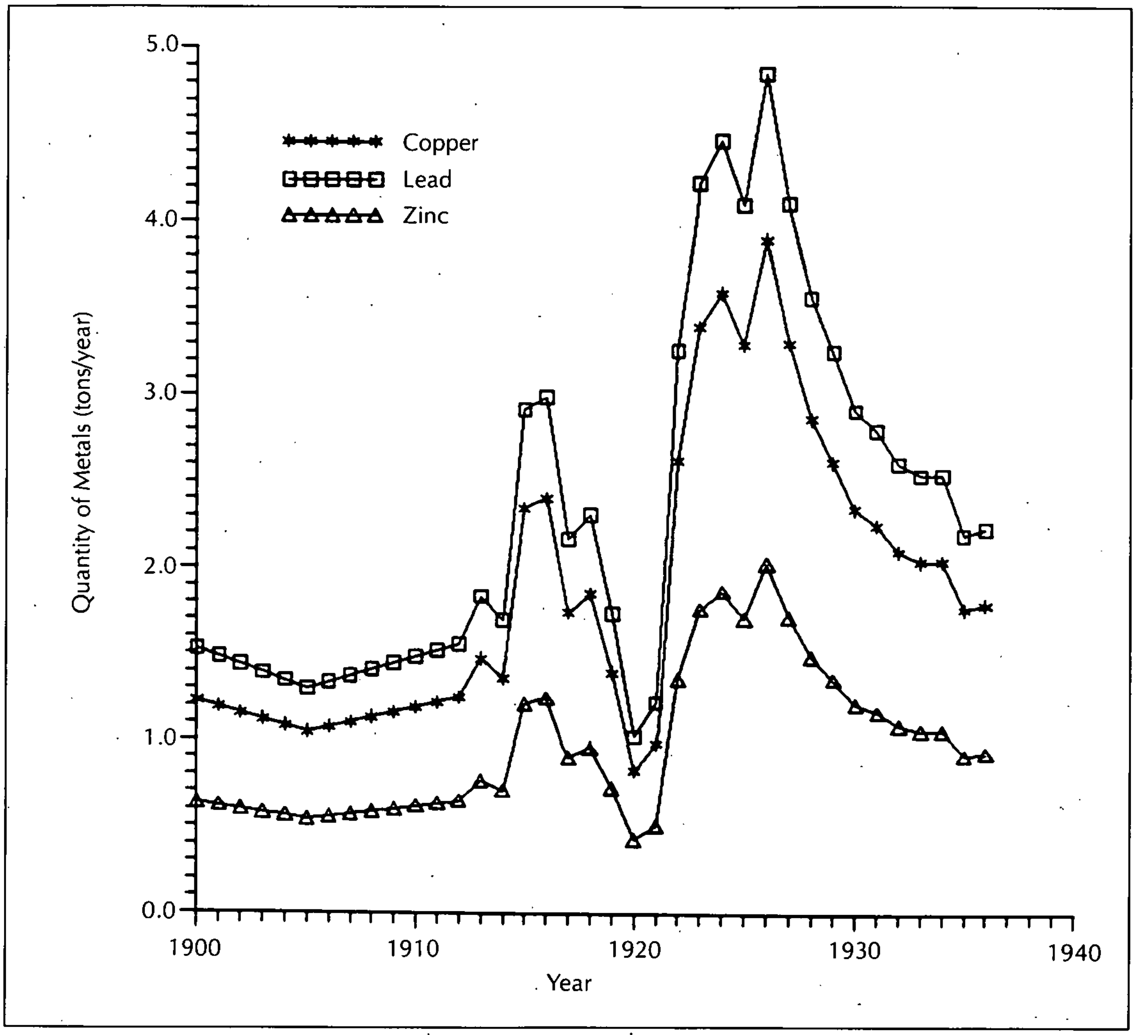

FIGURE 6. The quantity of metals in tannery wastes based on the gross value of the finished leather.

industry wastewater (200 tons) is present in the sediments of the Mystic Lakes. Current research is focused on identifying other surface water bodies where metals may have accumulated.

In addition to finding high concentrations of metals in river and lake sediments, large amounts of waste metals have also been discovered in abandoned lagoons and sludge dumping areas in the watershed. Though efforts have been made to identify the dumping areas that pose the most immediate environmental and human health risks, it is likely that other, less obvious leather industry waste disposal sites are scattered throughout the watershed.

Conclusions

Tanning, leather finishing, and hide and leather rendering were once an important part of the economy in the Aberjona watershed. Records indicate that between 1838 and 1988, approximately 100 tanneries, leather-finishing companies and rendering factories operated at over 67 sites in Woburn, Winchester and Stoneham. For 50 years, between the 1870s and the late 1920s, the leather industry employed nearly 55 percent of all wage earners in the area, and accounted for more than half of the total annual value of goods produced in the watershed. Historical documents and records also indicate

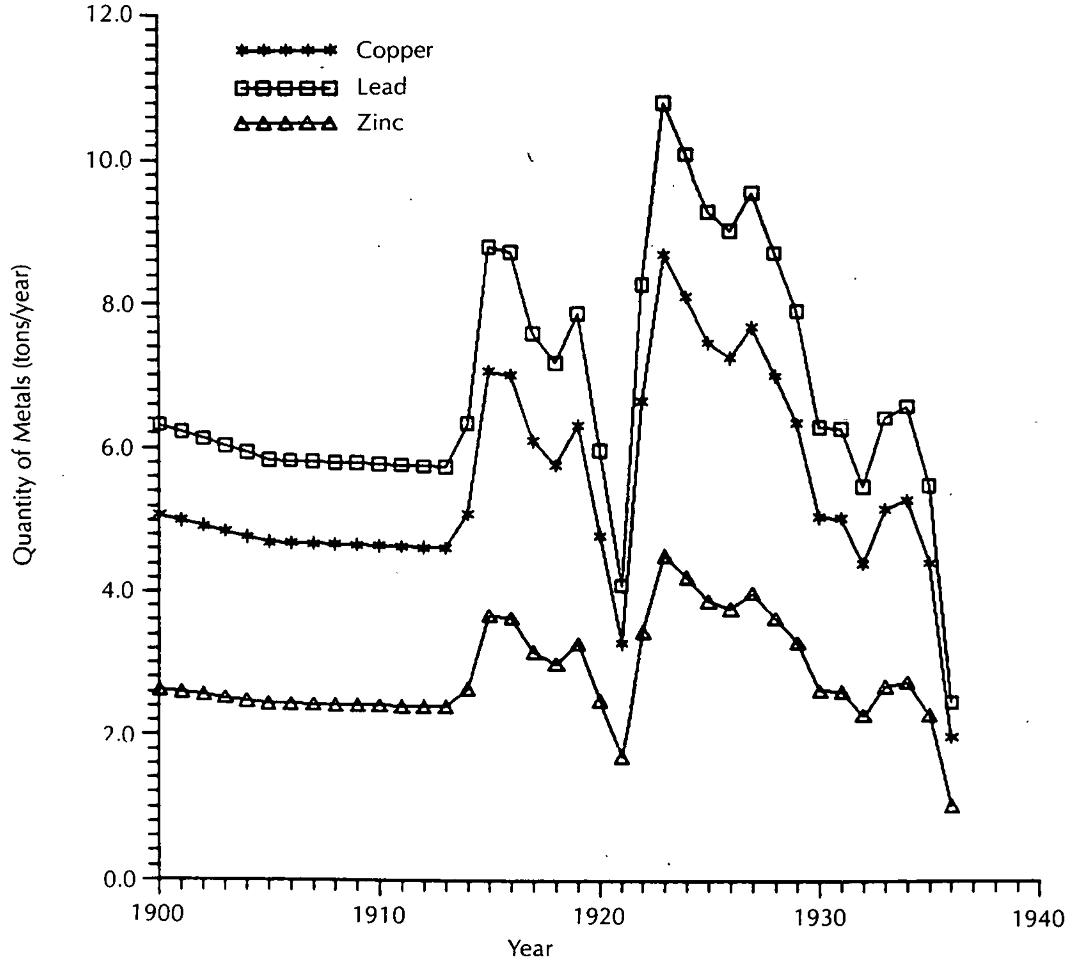

FIGURE 7. The quantity of metals in tannery wastes based on the finished leather produced per manhour.

that the leather industry used considerable amounts of hazardous chemicals, and routinely discharged wastes to surface water bodies, lagoons and dumps throughout the watershed. Mass balance models based on manufacturing statistics estimate that between 1900 and 1936 roughly 2,000 to 4,000 tons of chromium, 65 to 140 tons of copper, 85 to 175 tons of lead and 40 to 75 tons of zinc were generated in leather industry wastes.

Currently, officials from the EPA and Massachusetts DEP are investigating six sites in the watershed that are contaminated with leather industry wastes. On one former rendering site, it is estimated that over 1,000 tons of chromium discharged in leather detanning effluent are distributed over a 35-acre area. Other locations where waste metals have been found in the watershed include depositional areas in ponds, lakes and tributaries.

Pollution problems have been investigated for the past ten years, but not on a watershed-wide basis until the last three years. Surface water, groundwater, sediment, soil and air samples have been collected and analyzed to determine the extent and approximate concentrations of anthropogenic chemicals at sites throughout the watershed. The ultimate goal of this research is to determine how hazardous wastes are distributed in and move through the

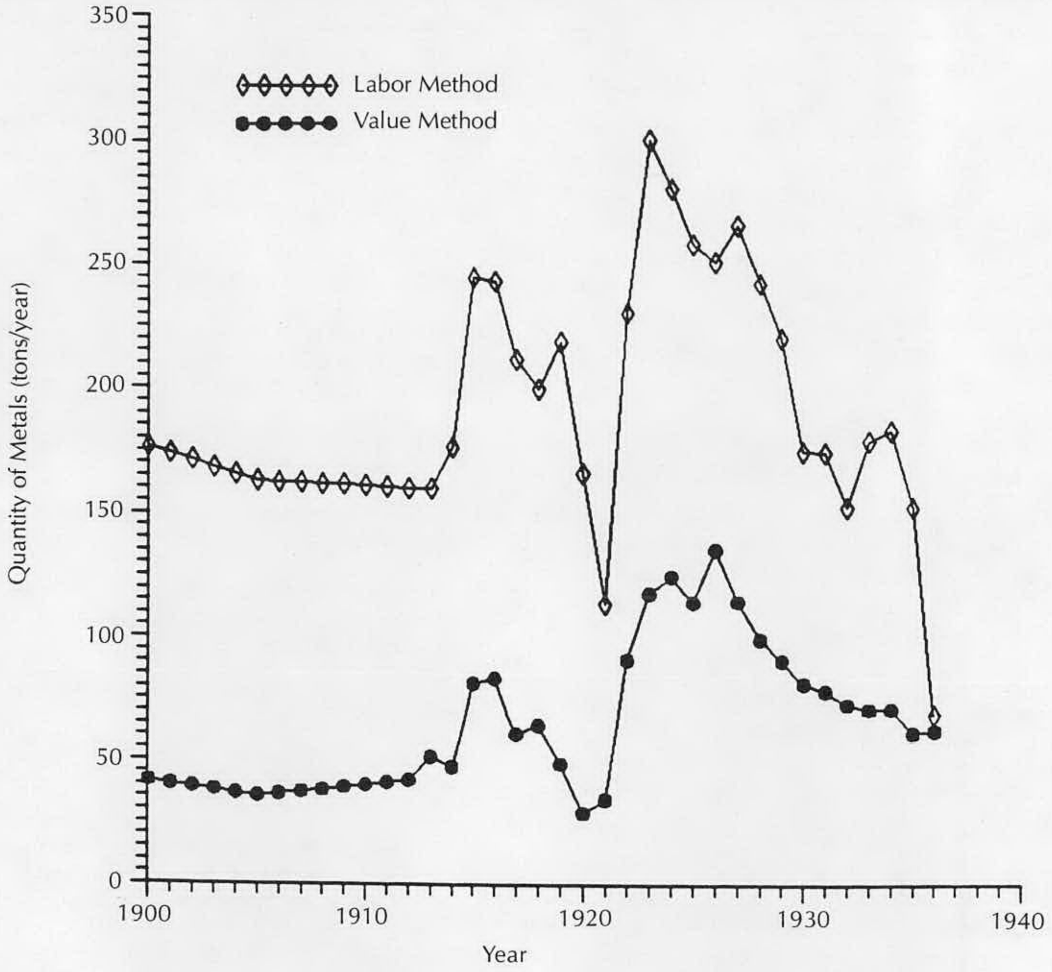

FIGURE 8. Comparison of the total quantities of metals in tannery wastes as predicted by two mass balance methods.

watershed, and how humans may be exposed to, and affected by, particular waste chemicals. An important first step is to identify which hazardous chemicals were most widely used in the watershed, and which are most likely to be present in environmental samples. From the descriptive history of the leather industry, its chemical usage and its waste disposal practices, it is evident that wastes containing hazardous metals — in particular, chromium, copper, lead and zinc — were routinely discharged to surface waters and dumps throughout the watershed. Mass balance analyses indicate that considerable quantities of these metals were present in the wastes. Based on these conclusions, it is hypothesized that a significant fraction of the total amount of metals discharged in the leather industry wastes is still present in the watershed. In testing this hypothesis, researchers have used the historical information to direct sampling and analytical programs toward identifying metals in samples collected in sediment deposition areas and in parts of the watershed where the most active leather industry sites were located.

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