
Asbestos as an Urban Area Pollutant

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Asbestos as an urban area pollutant

Robert Pitt

ABSTRACT: A supplemental investigation of asbestos fibers was conducted in Castro Valley, California, to characterize asbestos fibers in urban stormwater and source area soils and to estimate the fate and movement of asbestos fibers in the urban areas. The study concluded that large numbers of short asbestos fibers can be found throughout an urban area that does not contain any appreciable natural asbestos sources. However, the monitored asbestos fiber abundance varied appreciably for different local source areas and urban area yields were greater than adjacent rural area yields, indicating significant local urban asbestos sources. *J. Water Pollut. Control Fed.*, **60**, 1993 (1988).

KEYWORDS: stormwater, asbestos, nonpoint pollution.

Recent concerns of nonoccupational asbestos exposure, especially for families of asbestos workers and children attending schools having extensive asbestos insulation, increase the importance of studies that have examined typical environmental asbestos fiber characteristics. Moreover, nonoccupational asbestos exposure criteria, especially for very short asbestos fibers, are very limited.[1-3] Most of the nonoccupational environmental asbestos studies conducted have examined asbestos in air[4,5] and drinking water sources.[6] This study examined asbestos fibers in urban stormwater runoff and urban soils. Although it is difficult to evaluate the significance of the asbestos characteristics of these urban sources, this information may be of interest to researchers examining nonoccupational asbestos exposure problems.

The Castro Valley Nationwide Urban Runoff Program (NURP) project was one of 28 similar multi-year projects conducted throughout the country for the U.S. Environmental Protection Agency (EPA).[7] The general objectives for NURP were to obtain a broad data base covering urban stormwater quantity and quality characteristics and to provide actual full-scale performance data for urban runoff pollutant controls. The Castro Valley project was conducted in a 614-ha urban watershed in the San Francisco Bay Area. Detailed urban stormwater quantity and quality data was obtained for about 50 storms in Castro Valley Creek during 1979 and 1980. The Castro Valley project was also one of several NURP projects that investigated the effects of street cleaning on urban runoff quality. The project therefore also involved the collection and analysis of many street surface particulate samples. Street surface particulate loading variations observed during the study were extensively studied to determine deposition, accumulation, washoff, and fugitive dust loss rates of the street surface particulates. Priority pollutant analyses were included as part of many of the NURP projects. However, the Castro Valley project was selected as the only NURP project to evaluate asbestos in urban areas. This paper is a summary of these asbestos observations.

Field and Laboratory Procedures

A special analytical program was designed that involved collecting and analyzing samples of source area particulates and urban runoff for asbestos fibers. The runoff samples were analyzed to evaluate asbestos fiber characteristics representing typical urban runoff, while the source area particulate samples were analyzed to identify locations having unusual asbestos characteristics (especially high fiber concentrations).

Particulate sampling procedures. Paved area particulates were sampled using vacuuming procedures developed during previous EPA-sponsored research projects.[8,9] The basic vacuum sampling equipment consisted of two 1.5-kW stainless steel industrial canister vacuum units connected by a wye connector to a hose 10 m long and 40 mm in diameter. The hose was connected to a triangular aluminum attachment that cleaned strips 200 mm wide (about 10 m in length) across the pavement. The strips were vacuumed at a velocity of about 0.15 to 0.3 m/s for rough pavement and up to 1 m/s for smooth pavement. Each sample was composed of 20 to 35 sub-sampling strips, depending on the previously measured pavement particulate loading variabilities. After each sample was obtained, the particulates were carefully transported from the canisters to sample bottles and transferred to the laboratory for processing. During the 2-year sampling program (1979 through 1980), about 1 000 paved area particulate samples (and more than 20 000 sub-samples) were obtained from the study area.

Particulate samples from unpaved areas were collected from the soil surface using soft bristled paint brushes. This restricted the samples to particulates that would be most likely eroded during typical rains. Core soil samples would not be as indicative of the characteristics of runoff particulates from the unpaved source areas. Many different types of unpaved areas were sampled. Each sample was composed of at least five composite sub-samples from each of three to five representative areas for each area type. Six creek sediment samples were also obtained, two in the rural and four in the urban Castro Valley Creek reaches. Each sample was composed of at least five very shallow (5 cm in depth) cores in a 10-m stretch of creek.

Water sampling procedures. Two automatic water sampling stations were installed on Castro Valley Creek for this urban runoff monitoring project. The upper sampling station was located at the approximate boundary between the urban and rural areas (Seaview) and the lower sampling station was located below the urban study area (Knox). The lower station therefore captured runoff from both the urban and rural areas, while the upper station captured runoff from the rural area alone. Each sampling station was housed in a semi-permanent enclosure adjacent to the creek and contained automatic wastewater samplers and connected flow meters for automatic flow-weighted sampling. The samplers were modified to collect the samples in 200-L stainless steel drums, allowing a great variety of storms to be sampled, each with large numbers of sub-samples. The U.S. Geological Survey (USGS), in a cooperative effort, installed concrete control sections in the creek, developed stage-discharge rating curves, installed and maintained continuous flow measuring equipment (manometer surface water level sensors and digital tape recorders), and performed the conventional water quality analyses. Three recording tipping bucket rain gauges were also available close to the study area, two installed and maintained by the USGS under a long-term agreement with the Corps of Engineer's HEC unit, and the third maintained by the Alameda County Flood Control and Water Conservation District.

The water sampling equipment started sampling automatically when the creek stage exceeded a set value. The samplers then collected sub-samples at pre-determined flow increments. The samplers were set to collect about 10 sub-samples during the smallest events sampled (corresponding to about a 0.3 mm of rain) and several hundred sub-samples during large events. This monitoring scheme allowed 47 events to be sampled at each sampling location during the 2-year program. These events accounted for about 90% of the total runoff that occurred in Castro Valley Creek during the study period.

Laboratory procedures for asbestos analyses. A two-phased approach was employed for asbestos sample analyses. Eighty-eight selected composite samples from the complete sampling effort were initially analyzed using a screening procedure which used both optical and qualitative transmission electron microscopic procedures. Twenty-two samples that were found to contain asbestos were then subjected to more detailed quantitative transmission electron microscopic and selected-area electron diffraction (TEM/SAED) procedures to better characterize the asbestos. One of the main reasons for using this two-phased approach for asbestos analyses was the high cost of the quantitative TEM/SAED analyses (about $300 to $500 per sample in 1980). The screening qualitative procedure was substantially less expensive (about $50 per sample in 1980) but still included both the important transmission electron microscopic analyses and polarized light microscopy (PLM) with dispersion staining. The asbestos analysis procedures used were based on several methodologies published by EPA and other researchers.[10–14]

Study Area Description

Castro Valley is an unincorporated community within Alameda County, Calif., about 40 km east of San Francisco (on the eastern side of South San Francisco Bay). The project was conducted in a 614-ha unincorporated area characterized primarily by residential and rural land uses. The uppermost portion of the watershed (above the Seaview Gaging Station) consisted of about 250 ha of rural area that was slowly being replaced with suburban residential housing. The 364-ha urban study area consisted mostly of residential land uses (70%) with lot sizes varying from 0.05 to 0.1 ha, in addition to some light commercial areas (7%), six schools, and a short portion of Interstate Highway 580. The remaining land was made up of a mixture of open space and institutional land uses. Development along the stream banks in Castro Valley was intense and houses were frequently constructed very close to the creek bed.

The climate of the area is characterized by dry summers followed by wet winters, with irregularly spaced, frontal rainstorms. Over 90% of the annual rain usually occurs between October and April. In a normal rain year, there are about 63 days of measurable rainfall, and annual rainfall is about 53 cm. During the project field activities, there were about 60 days/y having measurable rainfall, with 46 cm of rain the first year and 65 cm of rain the second year.

Typical base flows at the Seaview (rural) monitoring station were about 1 to 2 L/s, but increased to about 3 to 7 L/s at the Knox (rural plus urban) monitoring station. Common peak storm flow rates at Seaview were about 30 to 300 L/s and increased to about 150 to 3000 L/s at Knox.

There are no known asbestos-containing serpentine outcrops of bedrock in the test watershed, but the alluvial deposits in the downslope areas of the watershed may contain some greatly-diluted serpentine erosion products mixed with other local erosion products.[15–19]

Asbestos fiber concentrations from the different municipal water systems near Castro Valley vary[6] with average chrysotile asbestos concentrations approximately 1×10^6 fibers/L, and amphibole asbestos fiber concentrations averaged approximately 1×10^5 fibers/L. Although some asbestos pipe may be involved, the primary source of asbestos in San Francisco Bay Area drinking water is the erosion of serpentine rock formations, including reservoir linings.

Study Results

Asbestos was found in 69% of the screening samples analyzed by electron optics, while polarized light optical methods only detected asbestos fibers in about 3% of the samples. Most of the particulate samples were mainly composed of rock forming minerals and general debris. Glass and grass fragments were found more commonly in the street surface particulate samples than in the other samples.

Table 1 shows the quantitative asbestos analyses results for the 22 samples analyzed by TEM/SAED. The screening procedure met its objectives in that all samples submitted for quantitative TEM/SAED had significant asbestos fiber concentrations (there were no false positives). However, no samples having "no" qualitative asbestos fibers observed by the screening procedure were analyzed quantitively. Some of these "no" samples may have had

Table 1—Results of TEM/SAED quantitative asbestos analyses on selected samples.

Sample description	Total asbestos fiber concentration, 10^6 fiber/g or 10^6 fiber/L	Chrysotile fiber concentration, 10^6 fiber/g or 10^6 fiber/L	Amphibole fiber concentration, 10^6 fiber/g or 10^6 fiber/L	Total asbestos fiber mass, μg asbestos/g of sample or μg/L	Median particle length, μm	Median particle width, μm	Median aspect ratio, length: width	Number of fibers counted for sample	Detection limit for sample, 10^6 fibers/g or 10^6 fibers/L
Creek water samples									
Runoff—Seaview, 3/7/80	152	152	<15	3.2	1.28	0.09	17.0	9	15.2
Runoff—Knox, 11/3/79	22.1	22.1	<0.3	0.6	1.16	0.09	14.2	40	0.3
Runoff—Knox, 3/4/80	114	111	2.7	3.1	1.39	0.08	16.1	41	2.7
Runoff—Knox, 3/7/80	319	289	30.4	11.2	1.30	0.08	16.7	38	7.6
Runoff—Knox, 4/23/80	7.6	7.6	<0.3	5.9	1.74	0.08	21.6	25	0.3
Creek sediment samples									
Rural creek sediment—Seaview confluence	230	230	<12	2.2	0.99	0.07	15.5	20	12
Urban creek sediment—Heyer	39	39	<4.8	0.27	0.99	0.07	17.8	8	4.8
Unpaved areas									
Rural vacant lot—1	77	77	<1.8	1.1	1.33	0.07	18.9	44	1.8
Urban vacant lot—2	110	110	<7.9	1.2	1.17	0.07	19.9	14	7.9
School turf	730	730	<16	10	0.96	0.07	18.3	45	16
Unpaved parking lot	54	54	<1.9	1.8	1.49	0.08	21.3	24	1.9
Paved playground, parking lot, and rooftops									
Paved school playground	830	830	<6.8	16	1.26	0.07	21.0	121	6.8
Paved parking lot	55	54	1.2	1.8	1.24	0.07	20.5	46	1.2
Rooftop asphalt shingles, less than 1 year old	1200	1200	<21	17.9	0.93	0.07	15.9	55	21
Rooftop asphalt shingles, greater than 1 year old	1900	1900	<20	48	0.86	0.07	15.9	98	20
Rooftop wooden shingles/shakes, 20 years old	303	303	<4	2.9	0.86	0.07	16.0	69	4
Rooftop—commercial composite of gravel, tar, wood, and asphalt roofs	670	670	<14	8.8	0.95	0.07	16.0	48	14
Street surface particulates[a]									
Lower area, 250–600 μm	831	825	6	13.6	0.98	0.07	18.3	143	5.8
Middle area, 600–850 μm	431	413	18	26	0.90	0.07	16.6	95	4.5
Middle area, 106–250 μm	1300	1270	23	16	0.73	0.07	12.9	112	12
Upper area, 850–2000 μm	385	363	22	31	0.89	0.07	16.5	102	3.6
Fall, 9/6–10/30/79, 2000–6370 μm	73	73	<1.1	1.2	1.70	0.07	29.9	66	1.1

[a] Size ranges refer to street dirt particle sizes, and not to asbestos fiber sizes.

important detectable asbestos concentrations (false negatives). Because the purpose of the screening tests was to identify samples having high probabilities of detectable asbestos concentrations for analyses on a limited analytical budget, the screening technique was successful.

The detailed quantitative descriptions contained in Table 1 indicated highly variable concentrations of asbestos fibers in the water and soil media, but quite consistent fiber characteristics for all of the samples analyzed. Almost all of the asbestos fibers observed by the TEM/SAED quantitative procedure were individual chrysotile fibrils or bundles of a few fibrils. Very few large fiber bundles were observed. The observed fibers had median lengths from 0.7 to 1.7 μm for all of the samples analyzed, with median widths of 0.07 to 0.09 μm. The median aspects (length:width ratio) ranged from 12.9 to 29.9. The asbestos concentrations ranged widely, from 7.6×10^6 to 319×10^6 fibers/L for the five creek water samples analyzed, and from 39×10^6 to almost 2×10^9 fibers/g for the 17 particulate samples. Less than 10% of all asbestos fibers observed were amphibole.

Chrysotile asbestos is associated with the serpentine minerals that are fairly common in the San Francisco Bay area. Good quality chrysotile asbestos fibers are silky, flexible, and have a high tensile strength. Chrysotile asbestos is the most common form of asbestos used in commercial applications.[20,21] The amphibole group of asbestos includes anthophyllite, cummingtonite-grunerite, tremolite-actinolite, and crocidolite asbestos. It is usually found with much shorter fiber lengths.[22] The relative ingestion hazards of the different forms of asbestos are probably different. Several researchers[2,23,3] feel that physical properties of asbestos (especially length and width) are much more important than the chemical composition of different asbestos types in determining their relative toxicities.

The summarized particle size information presented in

Table 2—Chrysotile size distribution.

Sample description	Fiber lengths, μm						Number of chrysotile fibers counted
	<0.50	0.50–0.99	1.00–1.49	1.50–1.99	2.00–2.49	>2.49	
	Percent in each category						
Creek water samples							
Runoff—Seaview, 3/7/80	0	13	63	13	13	0	9
Runoff—Knox, 11/3/79	0	38	35	15	8	4	40
Runoff—Knox, 3/4/80	0	34	20	24	12	10	41
Runoff—Knox, 3/7/80	3	29	29	16	8	16	38
Runoff—Knox, 4/23/80	4	20	12	28	8	28	25
Creek sediment samples							
Rural creek sediment—Seaview confluence	0	50	40	5	5	0	20
Urban creek sediment—Hayer	0	50	38	13	0	0	8
Unpaved areas							
Rural vacant lot—1	0	30	34	27	2	7	44
Urban vacant lot—2	0	29	57	7	0	7	14
School turf	0	53	18	11	9	9	45
Unpaved parking lot	4	21	25	33	4	13	24
Paved playground, parking lot, and rooftops							
Paved school playground	1	35	26	16	10	13	121
Paved parking lot	0	35	30	13	13	9	46
Rooftop asphalt shingles, less than 1 year old	5	51	18	11	7	7	55
Rooftop asphalt shingles, greater than 1 year old	10	54	23	6	3	3	98
Rooftop wooden shingles/shakes, 20 years old	6	59	13	12	7	3	69
Rooftop—commercial composite of gravel, tar, wood, and asphalt roofs	8	46	27	6	8	4	48
Street surface particulates							
Lower area, 250–600 μm	11	40	20	13	6	10	143
Middle area, 600–850 μm	7	53	19	12	5	4	95
Middle area, 105–250 μm	27	47	17	8	1	0	112
Upper area, 850–2000 μm	1	61	20	8	8	3	102
Fall, 9/6–10/30/79, 2000–6370 μm	0	18	27	12	12	30	66

Table 1 implies a great deal of similarity between the chrysotile asbestos fibers observed, irrespective of the sampling location. Tables 2 through 4, however, indicate some interesting differences in the particle size distributions associated with the various sampling locations. The fibers obtained from the creek water and sediment, and from the unpaved areas, were somewhat larger than the fibers obtained from the paved areas. Because the paved areas (especially the streets and parking areas) experience much mechanical disturbance, fibers from those areas may undergo abrasive mechanical effects that are sufficient to divide any remaining small fiber bundles into individual fibrils, or to even break the fibrils into shorter lengths. Very small fibers were not generally found in the runoff water, possibly because of their preferential loss to the atmosphere, or because of the difficulty in finding them beneath other sample debris during analyses.

The detection limits varied according to the amount of sample on the filter, but the observed total asbestos fiber concentrations were at least ten, and often more than 100 times the detection limits. The number of asbestos fibers counted for each sample was typically between 40 and 100, but was less than 10 for two of the samples. Again, the screening tests enabled the quantitative analyses to be optimized, especially when selecting the samples for further analyses and in determining the sample quantities needed for the quantitative TEM/SAED analyses.

Conclusions

The values of the limited asbestos data obtained during this study was significantly increased because of the related extensive stormwater, rainfall, and urban soils monitoring that was simultaneously collected as part of the other tasks associated with the Castro Valley NURP project.[24] The

Table 3—Chrysotile size distribution.

Sample description	Fiber widths, µm						Number of chrysotile fibers counted
	<0.05	0.05–0.09	0.10–0.14	0.15–0.19	0.20–0.24	>0.24	
	Percent in each category						
Creek water samples							
Runoff—Seaview, 3/7/80	0	50	50	0	0	0	9
Runoff—Knox, 11/3/79	0	50	45	3	2	0	40
Runoff—Knox, 3/4/80	0	56	41	2	0	0	41
Runoff—Knox, 3/7/80	0	71	16	8	5	0	38
Runoff—Knox, 4/23/80	0	60	36	0	0	4	25
Creek sediment samples							
Rural creek sediment—Seaview confluence	0	90	10	0	0	0	20
Urban creek sediment—Hayer	0	88	13	0	0	0	8
Unpaved areas							
Rural vacant lot—1	0	89	11	0	0	0	44
Urban vacant lot—2	0	86	14	0	0	0	14
School turf	4	80	13	2	0	0	45
Unpaved parking lot	13	63	17	8	0	0	24
Paved playground, parking lot, and rooftops							
Paved school playground	2	83	14	1	0	0	121
Paved parking lot	7	76	11	2	2	2	46
Rooftop asphalt shingles, less than 1 year old	2	75	20	2	2	0	55
Rooftop asphalt shingles, greater than 1 year old	1	86	8	2	2	1	98
Rooftop wooden shingles/shakes, 20 years old	0	84	10	4	1	0	69
Rooftop—commercial composite of gravel, tar, wood, and asphalt roofs	2	73	21	2	2	0	48
Street surface particulates							
Lower area, 250–600 µm	2	90	3	1	1	2	143
Middle area, 600–850 µm	0	84	4	5	1	5	95
Middle area, 105–250 µm	3	80	12	3	1	2	112
Upper area, 850–2000 µm	2	95	3	0	0	0	102
Fall, 9/6–10/30/79, 2000–6370 µm	2	91	8	0	0	0	66

Table 4—Chrysotile size distribution—fiber aspect ratios.

	Fiber aspect ratios, length:width						Number of chrysotile fibers counted
	<10	10–19.9	20–29.9	30–39.9	40–49.9	>49.9	
Sample description	Percent in each category						
Creek water samples							
Runoff—Seaview, 3/7/80	0	70	20	10	0	0	9
Runoff—Knox, 11/3/79	25	58	8	5	4	0	40
Runoff—Knox, 3/4/80	15	56	17	7	2	2	41
Runoff—Knox, 3/7/80	18	47	13	11	5	5	38
Runoff—Knox, 4/23/80	12	36	12	20	12	8	25
Creek sediment samples							
Rural creek sediment—Seaview confluence	5	80	15	0	0	0	20
Urban creek sediment—Hayer	0	63	25	13	0	0	8
Unpaved areas							
Rural vacant lot—1	5	50	32	7	2	2	44
Urban vacant lot—2	0	50	43	0	7	0	14
School turf	7	51	22	11	4	4	45
Unpaved parking lot	8	38	29	8	4	13	24
Paved playground, parking lot, and rooftops							
Paved school playground	6	41	28	9	6	10	121
Paved parking lot	2	46	33	11	4	4	46
Rooftop asphalt shingles, less than 1 year old	18	53	16	7	4	2	55
Rooftop asphalt shingles, greater than 1 year old	21	48	22	4	3	1	98
Rooftop wooden shingles/shakes, 20 years old	20	49	14	7	6	3	69
Rooftop—commercial composite of gravel, tar, wood, and asphalt roofs	23	44	21	6	4	2	48
Street surface particulates							
Lower area, 250-600 μm	18	38	20	10	8	6	143
Middle area, 600-850 μm	19	56	17	3	5	0	95
Middle area, 105-250 μm	34	54	8	4	1	0	112
Upper area, 850-2000 μm	10	61	17	4	6	2	102
Fall, 9/6-10/30/79, 2000-6370 μm	0	18	32	12	11	27	66

following conclusions are significantly affected by these other monitoring and data analyses activities.

Analytical procedures. An important aspect of the study was to investigate the use of screening procedures (polarized light microscopy and qualitative electron microscopy) to identify samples for further quantitative TEM/SAED analyses. The light microscopic procedure alone resulted in many false negatives, while all samples found to have asbestos fibers by qualitative electron microscopic procedure had asbestos fibers identified during the more detailed quantitative TEM/SAED analyses (no false positives). This finding confirmed that optical techniques alone may be inadequate for the study of small asbestos fibers commonly found in environmental samples. Optical analysis techniques for asbestos were developed mainly for assessing occupational exposures where the enumeration of large fibers (typically greater than 5 μm in length) is most important. However, asbestos fibers found in natural water are generally smaller than the resolving power of light microscopes and are often hidden under other heavy debris. Others[25] also recently reported difficulties in using optical microscopy when investigating small fibers (less than 0.2 μm in width).

Asbestos fibers observed in Castro Valley Creek. Table 5 summarizes the asbestos fiber concentrations observed in Castro Valley Creek during 11 runoff periods. Asbestos concentrations for samples having no detectable asbestos fibers during the screening electron microscopic procedure are listed as less than 5×10^6 fibers/L, the approximate electron microscopic detection limit during these screening tests. Table 5 also shows the monitored creek flows of Castro Valley Creek at both the Seaview and Knox stations during these monitoring periods.

Only about 10% of the monitored runoff flows had de-

Table 5—Castro Valley Creek asbestos concentrations and observed flows.

Runoff period starting date	Asbestos concentration,[a] 10^6 fibers/L	Total period flow, 10^6 L
Knox		
11/3/79	22.1	47.3
11/17	<5	16.3
11/30	<5	29.5
12/21	<5	9.2
12/26	<5	189.5
12/31	<5	29.5
2/25/80	<5	536.2
2/28	<5	36.4
3/4	114	21.2
3/7	319	47.7
4/23	7.6	4.3

Minimum flow-weighted concentration = 19 × 10^6 fibers/L
Maximum flow-weighted concentration = 24 × 10^6 fibers/L
Range of observed concentration = <5 × 10^6 to 319 × 10^6 fibers/L

Runoff period starting date	Asbestos concentration,[a] 10^6 fibers/L	Total period flow, 10^6 L
Seaview		
11/30/79	<5	0.1
12/26	<5	16.3
2/25/80	<5	113.2
2/28	<5	8.6
3/4	<5	5.1
3/7	152	11.5

Minimum flow-weighted concentration = 11 × 10^6 fibers/L
Maximum flow-weighted concentration = 16 × 10^6 fibers/L
Range of observed concentration = <5 × 10^6 to 152 × 10^6 fibers/L

[a] The <5 × 10^6 fiber/L concentrations are the approximate detection limits for the qualitative TEM screening procedures. These samples were not analyzed using the quantitative TEM/SAED procedures, so these more conservative values were used for these calculations.

tectable asbestos fibers. Using this limited data, the flow-weighted asbestos fiber concentration in the creek water was estimated to about 25 × 10^6 fibers/L. The overall range, however, varied from less than 5 × 10^6 fibers/L (the detection limit) to more than 300 × 10^6 fibers/L. The calculated asbestos weight concentrations varied from about 3 to 5 μg/L. The unit fiber weights ranged from about 1.3 × 10^6 to about 50 × 10^6 fibers/μg, averaging about 25 × 10^6 fibers/μg for the creek samples. Almost all of the asbestos fibers observed were of the chrysotile type, with less than 10% of the observed asbestos fibers being amphibole asbestos.

As was shown in Table 5, the calculated flow-weighted asbestos concentrations observed are estimated to be about 19 × 10^6 to 24 × 10^6 fibers/L at the Knox station and 11 × 10^6 to 16 × 10^6 fibers/L at the Seaview station. The corresponding estimated urban runoff asbestos concentrations were calculated using the mass balance (Knox mass equals Seaview mass plus urban runoff mass):

$$C_kF_k = C_sF_s + C_uF_u, \text{ therefore}$$

$$C_u = (C_kF_k - C_sF_s)/F_u$$

Where

C_u = urban runoff asbestos fiber concentration;
C_k = asbestos fiber concentration at Knox, 19 × 10^6 to 24 × 10^6 fibers/L;
C_s = asbestos fiber concentration at Seaview, 11 × 10^6 to 16 × 10^6 fibers/L;
F_u = urban runoff flow, 967 × 10^6 L − 155 × 10^6 L = 812 × 10^6 L;
F_k = flow at Knox, 967 × 10^6 L; and
F_s = flow at Seaview, 155 × 10^6 L.

The estimated flow-weighted urban runoff asbestos concentration was therefore between 20 × 10^6 and 26 × 10^6 fibers/L, based on these observations. Individual creek asbestos concentrations, as shown on Table 5, vary widely, however. Only a few medium sized runoff events (5 of the 17 events analyzed using electron optics) contributed most of the asbestos. These concentration estimates can therefore be expected to vary appreciably for other periods and locations of monitoring.

Street surface particulate asbestos observations. About 65% of all street surface particulate samples collected during both years were represented in samples analyzed for asbestos using the screening procedure. About 80% of these samples had detectable asbestos fiber concentrations, with an average weighted concentration (from the quantitative TEM/SAED analyses) of approximately 300 × 10^6 asbestos fibers/g total solids. Almost all of the asbestos fibers observed were chrysotile, with only about 3% being amphibole asbestos. The fiber sizes and unit fiber weights were quite similar to those observed in the creek water.

Most of the asbestos on the street surface particulates was associated with street surface particles in the middle size ranges (100 to 600 μm), with fewer fibers observed associated with the very small or the very large particle sizes. There was no appreciable differences in asbestos fiber sizes associated with the different street surface particulate sizes.

Street surface asbestos loading values, deposition and accumulation rates, and fugitive dust losses were estimated based upon the observed average concentration of 300 × 10^6 asbestos fibers/g street surface particulates and the associated street surface particulate loading and fugitive dust loss information presented elsewhere.[8,24] The asbestos fiber street surface deposition rate is estimated to be about 8 × 10^{12} to 16 × 10^{12} asbestos fibers/curb km·d. The accumulation rate is initially high (close to the deposition rate) immediately after a major rainfall or street cleaning. However, the accumulation rate then decreases (to minimum values after 2 or 3 weeks) because of fugitive dust losses from the street surface to the air (caused by automobile and wind turbulence). The difference between the deposition rate and the accumulation rate equals the amount which is lost to the air (as fugitive asbestos losses). This fugitive loss is very small for the first few days after a major storm or a thorough street cleaning. However, it could be very large if several months passed with no street cleaning or major rains.

Previous efforts[26–28] have examined vehicle asbestos sources in detail. Generally, at least 70% of the asbestos lost during braking operations falls directly to the road surface.

Other source area asbestos observations. Particulate samples were collected from several additional source areas, besides streets, in the Castro Valley basin, and were analyzed for asbestos content. Asbestos fibers were observed in about 70% of all source area samples analyzed using the screening qualitative electron microscopy procedure. The average asbestos fiber concentrations were found to range from 50 × 10^6 to 1 × 10^9 asbestos fibers/g total solids during the quantitative TEM/SAED analyses. The driveway and parking lot samples had the lowest observed asbestos fiber concentrations, while rooftop particulates had the highest fiber concentrations. Almost all of the asbestos fibers observed were chrysotile asbestos with only a few amphibole asbestos fibers observed. The unit fiber weights ranged from about 30 × 10^6 to 140 × 10^6 fibers/μg asbestos. The fiber sizes were quite similar to those found in the creek water and street surface particulate samples previously described.

The highest concentrations of asbestos fibers for any source area were found on old asphalt shingled roofs, with asbestos concentrations of about 2 × 10^9 fibers/g total solids. Particulate material collected from wooden shingled and shaked roofs in the Castro Valley area had smaller concentrations of asbestos fibers (about 300 × 10^6 fibers/g total solids). The commercial composite sample included a mixture of roof types such as gravel, tar, wood, and ashphalt, and had concentrations of asbestos fibers of about 7 × 10^6 fibers/g total solids. The relative contributions of asbestos fibers from atmospheric dry fallout, precipitation, and weathering of the roof material is not well known. Some of the roofs sampled were covered with asphalt shingles which commonly use imbedded asbestos fibers for reinforcement. In addition, many roofing compounds also contain asbestos fibers. Because the asphalt roofs had much greater concentrations, it can be expected that the erosion of the asphalt roofing materials and patching compounds is responsible for much of the observed asbestos fibers on these roofs. The observed asbestos fibers were very small (about 1 μm in length and less than 0.1 μm in diameter), implying that they were individual fibrils and not bundles of asbestos fibers embedded in larger particulates.

Surprisingly high concentrations of asbestos fibers were also observed on the school playground pavement and turf; however, extensive use of asbestos in the schools was not known. Rural soil, vacant lots, and creek sediments had much lower observed asbestos concentration. This indicates that the natural soils may have relatively small asbestos concentrations and that most of the urban runoff asbestos fibers remain in suspension in the water and do not settle out or become trapped in sediments. The street surface particulate sample asbestos concentrations were at the approximate mid-point of the range of the asbestos fiber concentrations reported for these other source area particulate samples.

Urban area asbestos mobility and fate. This Castro Valley study found that most of the asbestos fibers identified in the creek water, creek sediment, and soils were individual fibrils, or small bundles of fibrils, about 1μm in length and about 0.1 μm in width. These sized fibers are very mobile in water and air, but relatively immobile in soils.[30] However, asbestos fibers mixed with surface soils can be easily moved to the more active atmospheric and water environments. Natural asbestos sources are not likely present in the test watershed, but airborne transport could be responsible for moving natural fibers from regional natural sources into the test watershed. The limited asbestos data collected during this study cannot be used to directly determine the significance of regional redistribution of asbestos fibers. However, the highly variable asbestos abundances observed for adjacent source areas indicated important local urban sources. The urban runoff yield of asbestos was also estimated to be several times greater than the rural unit area yield, further implying significant urban area asbestos sources.

Thermal degradation and chemical stability of asbestos fibers is not likely to be important under normal environmental conditions. Others[31] described surface charge changes on asbestos fibers and asbestos dissolution and resultant adsorption of organic matter on asbestos fibers after discharge to receiving waters. This indicated some chemical changes of asbestos in natural waters. The stability of the materials used to bind asbestos fibers in products (especially asbestos cement) is extremely important, however. Waters containing high levels of dissolved carbon dioxide (carbonic acid), alkalinity, calcium, or hydrogen sulfide can degrade the cement binder and release large quantities of asbestos fiber into the water.[32]

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