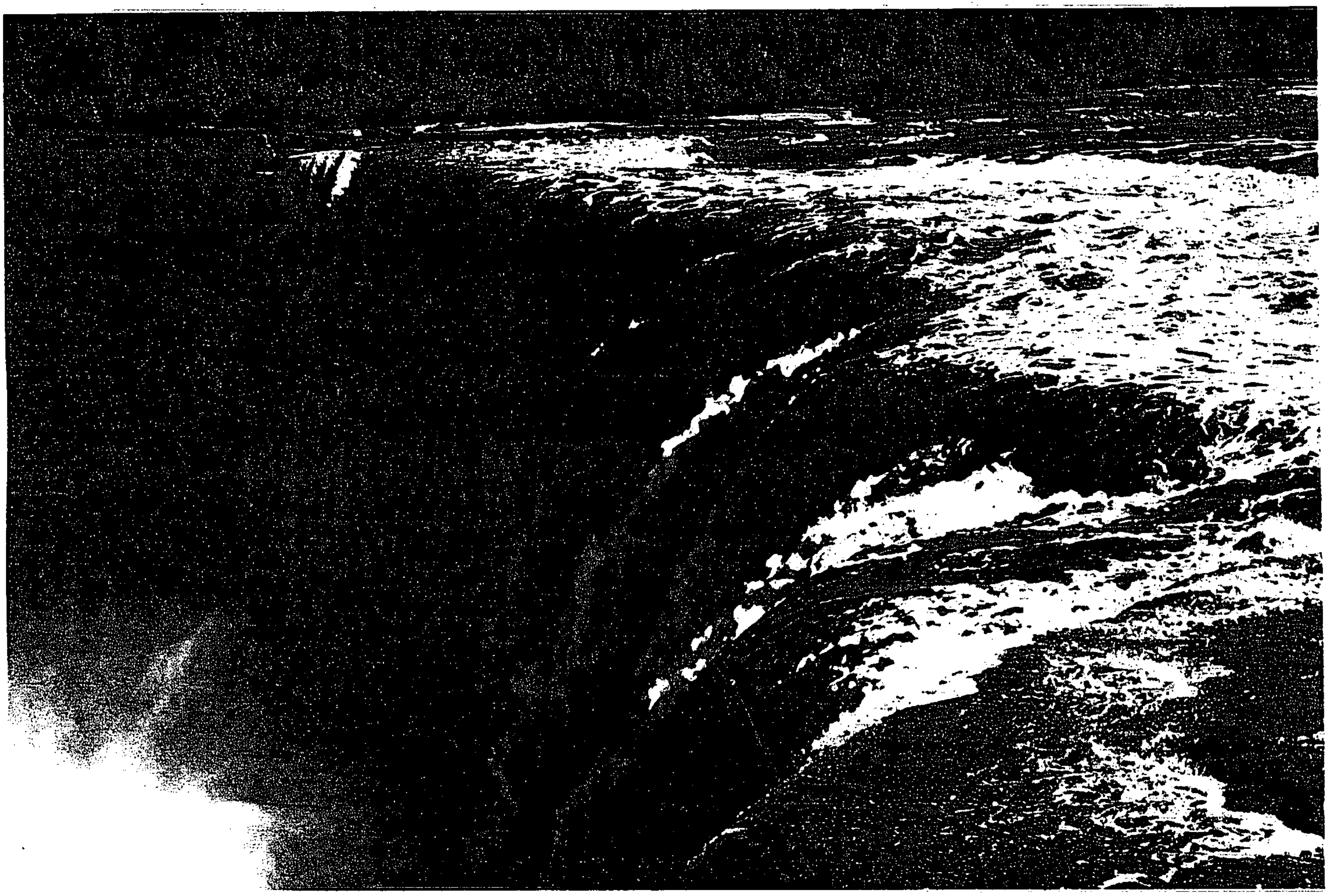
[illegible]

Asbestos Fibres in Receiving Waters

H. Schreier and J. Taylor



TECHNICAL BULLETIN NO. 117

INLAND WATERS DIRECTORATE
PACIFIC AND YUKON REGION
WATER QUALITY BRANCH
VANCOUVER, BRITISH COLUMBIA, [illegible]

Environment Canada Environnement Canada

Asbestos Fibres in Receiving Waters

H. Schreier and J. Taylor

TECHNICAL BULLETIN NO. 117

INLAND WATERS DIRECTORATE
PACIFIC AND YUKON REGION
WATER QUALITY BRANCH
VANCOUVER, BRITISH COLUMBIA, 1980

Cat. No. En 36-503/117

ISBN 0-662-11066-8

Contents

Page

Contents (Cont.)

Tables

Illustrations

Abstract

Little is known about asbestos fibre concentration in water supplies and drainage systems and the possible health hazard which it could create. A comprehensive review of the subject is provided in this report, which includes results of exploratory studies in British Columbia and the Yukon, and a comparison with concentrations elsewhere in North America. Asbestos fibres, which can be introduced into the hydrologic system by natural and man-made processes, were reported in all phases of the hydrologic cycle. The greatest source appears to be natural exposures of asbestos-bearing bed rock where the fibres are introduced by surface runoff as well as by groundwater drainage. Levels of up to 10^{11} fibres/L were measured in natural river systems in British Columbia; these results were significantly higher than those reported for drinking water supplies in eastern Canada and the eastern United States. The concentrations are comparable with those reported from mine effluents in Quebec and groundwater levels in New Mexico. Weathering processes and the abundance of asbestos-bearing metamorphic rocks in British Columbia are thought to be the main causes of these high concentrations. It is suggested that bedrock geology be used as a means of predicting high asbestos concentrations in drainage systems. Finally, for a better understanding of the processes responsible for the asbestos fibre distribution in water systems, it is suggested that an investigation of the transport mechanisms be initiated and that the spatial and seasonal variation in a number of drainage systems be determined.

Résumé

On connaît très peu de chose sur les concentrations de fibres d'amiante dans les approvisionnements en eau et les réseaux de drainage ou sur les dangers qu'elles peuvent occasionner pour la santé. Le présent rapport renferme un compte rendu assez complet de la question et, entre autres, les résultats d'études exploratoires en Colombie-Britannique et au Yukon, ainsi qu'une comparaison avec des concentrations semblables ailleurs en Amérique du Nord. On a noté la présence de fibres d'amiante dans toutes les phases du cycle hydrologique; celles-ci peuvent être introduites dans ce système par des processus naturels et artificiels. La plus grande partie des fibres semble venir de l'exposition naturelle de la roche de fond contenant de l'amiante, les fibres y étant introduites par le ruissellement superficiel et le drainage souterrain. Des teneurs atteignant jusqu'à 10^{11} fibres/L ont été mesurées dans des réseaux naturels de cours d'eau de la Colombie-Britannique et ces résultats étaient beaucoup plus importants que ceux observés dans les approvisionnements en eau potable de l'est du Canada et de l'est des É.-U. Ces concentrations sont comparables à celles des effluents miniers du Québec et des eaux souterraines du Nouveau-Mexique. On croit que les principales causes de ces fortes concentrations sont les processus d'érosion dus à l'exposition aux éléments et l'abondance des roches métamorphiques contenant du minerai d'amiante en Colombie-Britannique. On a suggéré l'utilisation de la géologie de la roche de fond pour prévoir les fortes concentrations d'amiante dans les réseaux de drainage. Enfin, pour mieux comprendre les processus responsables de la distribution de la fibre d'amiante dans les réseaux des cours d'eau, on a proposé d'étudier les mécanismes de transport et les variations spatiales et saisonnières dans un certain nombre de réseaux de drainage.

Asbestos Fibres in Receiving Waters

H. Schreier and J. Taylor

INTRODUCTION

In the summer of 1976, the Water Quality Branch of the Inland Waters Directorate (I.W.D.), Pacific and Yukon Region, was advised by External Affairs in Ottawa of what were thought to be abnormally high levels of asbestos fibres reported by the United States Environmental Protection Agency (U.S.E.P.A.) for the Sumas River system in the state of Washington. Since this water course commences on the western slope of the Cascade Mountains of Washington and then flows north, crossing the international border at Sumas, British Columbia, before emptying into the Fraser River, Canadian federal interest deemed it prudent that the level of asbestos fibre concentrations in the British Columbia portion of the Sumas River be determined. Fortunately, analytical capability was available at the National Water Research Institute (N.W.R.I.), Burlington, where Dr. Ray Durham very kindly provided advice and expertise.

Very little is known about asbestos fibres in the aquatic system. This report provides a brief introduction to the subject, identifies some of the problems of analysis and distribution, and provides general guidelines for exploratory water sampling for asbestos fibre content. It is hoped that these findings will benefit future related activities within the region.

PURPOSE AND SCOPE

The aims of this report are:

(1) to review the literature on asbestos in receiving waters,
(2) to summarize exploratory findings in the Pacific and Yukon Region and to compare the asbestos levels with those reported elsewhere, and
(3) to illustrate possible ways of predicting natural asbestos levels in the water systems of the Pacific and Yukon Region.

Under the Environmental Contaminants Act, asbestos has been identified as one of the category II toxic substances, which are defined as "those substances which the government has reason to believe pose a significant danger to the environment or human health and which are being investigated in depth to determine the nature and extent of the danger and the appropriate means to alleviate that danger" (*The Canada Gazette*, May 1978).[1] To date, investigative work has been in the area of airborne asbestos, and medical evidence has substantiated the health hazard from that source; in contrast, very little is known about waterborne asbestos hazards and medical evidence so far has been inconclusive.

The topic of asbestos fibres in surface waters has not been addressed in any comprehensive manner, which may, in part, be due to (a) the complexity of asbestos minerals, (b) the problems in analytical procedures, and (c) the dynamic manner in which asbestos is transported. In this report background information has been compiled on types and concentrations of asbestos fibres in water systems, and areas of high levels of occurrence have been identified. A general background on the subject is provided in the next section, followed by a brief review of the most recent medical evidence of water-ingested asbestos. Then the few independent studies that have been done in the United States and Canada on asbestos levels in water systems are reviewed, and the results are compared with asbestos levels found in exploratory studies in British Columbia and the Yukon Territory.

Finally, taking into account the high cost of asbestos analysis, a method is outlined which involves the prediction and identification of water systems in the Pacific and Yukon Region that have the potential for high asbestos levels.

ASBESTOS FIBRES – GENERAL BACKGROUND

Asbestos is the name used for a group of naturally occurring fibrous materials which have cotton-like aspects, are heat resistant to 550°C, and are partially resistant to acid decomposition. Because of these attributes asbestos

---

[1] As of December 1, 1979, asbestos was deleted from category II of the 1979 List of Priority Chemicals and is now in the list of Important Environmental Contaminants Being Investigated or Controlled under Other Legislative Mandates.

is of great commercial value. Canada is a leading producer, being ranked second in the world behind the U.S.S.R. (Vogt, 1976), with enough reserves to sustain production for some 50 years (Charlebois, 1978). Asbestos and related topics are therefore of special interest to Canada.

Asbestos Types and Properties

Of the great variety of asbestos fibres, the more common types have been classified as follows:

Serpentine group	Amphibole group
Chrysotile (hydrated Mg_3-silicate)	Actinolite (hydrated $Ca_2 Fe_5 Mg_5$ silicate)
	Tremolite (hydrated $Ca_2 Mg_5$ silicate)
	Crocidolite (hydrated $Na_2 Fe_3 Mg$ silicate)
	Anthophylite (hydrated $Fe_7 Mg_7$ silicate)
	Amosite (hydrated $MgFe_6$)

Commercially, only chrysotile, crocidolite and amosite are important. All asbestos minerals are considered to be various forms of hydrated magnesium silicates in which the basic SiO_4^{-4} tetrahydra are arranged in a band structure (amphibole) or sheet structure (serpentine). Unfortunately, a simple chemical analysis does not suffice to identify different types of asbestos, since (a) isomorphic substitutions of metals in the structure are common, (b) elements in more than one valence state are often present, (c) impurities or contamination by trace metals is frequent, and (d) anomalies and areas of structural disorder in the chain sequence that make up the band structure are common. The latter case is characteristic of amphibole minerals and has recently been documented by Veblen *et al.* (1977) and Franco *et al.* (1977). The former authors have postulated that breaks and anomalies in the structure of amphiboles might be responsible for fibre production, since massive amphiboles do not exhibit such anomalies. Amphiboles are known to be the most complicated of the rock-forming silicates and have often been referred to as "mineral wastebaskets." This is substantiated by the presence of several cation sites in the structure that have contrasting size and can therefore accommodate cations of ionic radii between 0.4 Å and 1.8 Å, which includes all of the important cations in the environment. Because of these structural disorders and cation substitution a number of amphibole asbestos fibres may elude simple classification.

The physical properties, which are determined by the crystal structure and chemical composition of the asbestos mineral, are the most important for commercial applications of asbestos. Given the difficulties of chemical analysis, emphasis has been placed on the analysis of fibre structure. Under an electron microscope chrysotile fibres exhibit a hollow tubular structure with a pale green translucent tinge. The fibres are imprecise capillaries and tend to curve and coil. In contrast, amphibole fibres are solid glass fibres with amosite showing colours of grey to yellow and crocidolite, blue. Other physical properties are summarized in Table 1.

Table 1. Physical Properties of Asbestos Fibres

Type of asbestos	Density	Hardness (Mohs' scale)	Crystal system	Fibre structure
Chrysotile	2.2–2.8	2.5–4.0	Monoclinic	Hollow
Crocidolite	3.0–3.4	5	Monoclinic	Solid
Amosite	3.1–3.6	5–6	Monoclinic	Solid
Anthophylite	2.8–3.6	5–6	Orthorhombic	Solid
Actinolite and tremolite	3.0–3.4	5–6	Monoclinic	Solid

Since many fibres are imperfect and have extremely small dimensions, quantification is difficult. The question of whether to measure asbestos fibres by weight, fibre size or fibre frequency has been raised by Cooper and Cooper (1978), but no consensus has been reached on this subject. The same authors noted that if the fibre geometry is responsible for carcinogenesis, then fibre counts and the determination of the length to diameter ratio of the fibres are important. It has also been suggested that the fibre ends are important in health studies. Amphibole fibres frequently have blunt ends, while chrysotile fibres are often spear-like.

Sources and Origin

Canada has extensive asbestos deposits in Quebec, Ontario, British Columbia and the Yukon Territory. Amphibole and chrysotile varieties can occur in quite contrasting geological formations. Chrysotile probably forms in a two-stage metamorphic process. First, ultrabasic volcanic rock is transformed to serpentine by hydrothermal alterations. In the final stages of metamorphism, chrysotile fibres crystallize in rock cracks and fracture patterns as a result of a sweating process at high temperature and pressure, during which the union of amorphous silica, iron oxides, sodium, magnesium and water takes place. The mineral constituents are usually derived from travelling solutions or from *in situ* molecular reorganization of the serpentine rock.

The genesis of amphibole fibres is more complex. The mineral derives its name from the Greek word *amphibolos* which means ambiguous (Speil and Leineweber, 1969), and given its complexity and variability, the name is appropriate. Most amphibole minerals are thought to be associated with metamorphic rocks of sedimentary origin.

Crocidolite and amosite occur in banded ironstone, while tremolite and actinolite result from metamorphism of carbonate rocks.

Pathways

Because of their small size and low density, asbestos fibres can readily be transported by wind and water and thus enter a variety of environmental pathways. The subject of airborne transport has recently been reviewed by Charlebois (1978) and will not be repeated here except to note that asbestos fibres are not only introduced into the atmosphere from asbestos mining and manufacturing processes but also from specific construction projects (Rohl *et al.*, 1977) and off-road vehicle movement (Kruse *et al.*, 1974).

A distinction is made between point and non-point sources for asbestos fibre studies in water systems. Point sources have initially received the most attention and include input from mining, mine tailings, asbestos milling and manufacturing, and asbestos pipes used for water transport.

The effect of dumping taconite mine tailings into Lake Superior has resulted in a drastic increase in asbestos levels in the water supply of the Duluth area of Minnesota, and the resulting problems and processes have been widely documented (see "Asbestos Fibres in Water Supplies and Drainage Systems — A Literature Review"). Evidence of direct asbestos input into the water system by asbestos milling and manufacturing operations has been produced by Lawrence and Zimmermann (1977), and the input of asbestos from asbestos pipes used to transport water has proven to be insignificant (Olson, 1974; Oliver and Murr, 1977; Hallenbeck *et al.*, 1978).

It appears that non-point sources contribute far more asbestos to the overall water system. Only a few investigations, however, have been carried out on this topic. From exploratory studies it appears that rain and snow can contain significant asbestos concentrations and it is possible that water can act as a collector of airborne asbestos fibres. Hallenbeck *et al.* (1977a) found concentrations of 10^5-10^6 fibres/L in rainwater in Chicago, while Cunningham and Pontefract (1971) found 10^7 fibres/L in melted snow in Ottawa. The former authors claim that wet deposition may be the principal pathway for the asbestos levels in Lake Michigan. Ottawa river water was found to contain 9×10^6 fibres/L (Cunningham and Pontefract, 1971), and it is assumed that natural accumulation processes, where surface and groundwater flow over or through asbestos-bearing geological formations, are responsible for the levels. If similar asbestos values in rain and snow samples are found elsewhere, it will probably be difficult to determine the proportional contribution from the atmospheric and surface input.

Unfiltered tap water from a small lake source in the heart of the asbestos mining industry in Quebec was found to have levels of 10^8 fibres/L (Cunningham and Pontefract, 1971), and since the airborne levels are presumed to be higher in that area, the input by rain cannot be disregarded.

It seems likely that the amount of surface exposure of asbestos-bearing rocks is important in determining natural asbestos levels in the river system. There is some limited evidence that surface erosion processes can contribute to an increase in asbestos concentrations in streams (see "Exploratory Studies in British Columbia and the Yukon Territory"). Asbestos-bearing rocks have been transported during the continental glaciations and have been scattered in places far from the original source. Although no documentation could be found on the subject, it is possible that asbestos fibres from these relocated sources can in some instances add to the general fibre concentration. It is suggested that asbestos from glacially transported sources together with airborne input may be responsible for background levels in water systems where geological and commercial asbestos sources are absent.

Current national investigations of community water supplies in Canada (Chatfield, in preparation)[2] and in the United States (Stewart *et al.*, 1976) will likely provide a better basis for an overall evaluation, but from the work by Oliver and Murr (1977) in New Mexico, Cooper and Murchio (1974) in California, Cunningham and Pontefract (1971) and Kay (1973) in Ontario, it is evident that natural levels are somewhat higher in areas where the hydrologic regime comes in contact with asbestos-bearing geological formations.

Finally, and as a point of interest, asbestos concentrations of 10^6-10^7 fibres/L have been reported in beverages such as beer and soft drinks (Cunningham and Pontefract, 1971; Biles and Emerson, 1968) and concentrations of up to 10^6 fibres/L, in wine (*Canadian Consumer*, July 1977). At this stage it is not clear whether asbestos has been introduced into these drinks via the water supply, from aerial sources or during the preparation and bottling process.

---

[2] Published as "A National Survey for Asbestos Fibres in Canadian Drinking Water Supplies" by Health and Welfare Canada, Rep. 79-EHD-34.

Analytical Procedure and Sampling

Of such common analytical techniques as X-ray diffraction, neutron activation, electron microscopy, chemical and infrared analysis, only electron microscopy studies have produced asbestos values which are consistent in the required sensitivity range. Mineral interference and resolution problems have more or less eliminated all other procedures (Bagioni, 1975).

Transmission and scanning electron microscopes were found to be useful in differentiating between chrysotile and amphibole asbestos fibres (Gerber and Rossi, 1977), but even with those instruments it was found by Cook *et al.* (1976) that not all amphibole fibres could be identified because of their extremely small diameter. The identification, measurement and fibre-counting procedures with these instruments are tedious, and widely divergent results have been obtained by different laboratories from the analysis of identical water samples. Because of this problem the Ontario Ministry of Environment established a committee to examine and describe a reliable analytical procedure so that more precise results could be obtained. The Committee on Asbestos Analysis (1977) produced a report entitled "An Interim Method for the Determination of Asbestos Fibre Concentrations in Water by Transmission Electron Microscopy," which outlines a procedure that improves reliability. The same procedure was used to analyze all of the water samples examined in the Pacific and Yukon Region. Some of the essential points of the method are summarized in Table 2.

The International Union against Cancer [Union internationale contre le cancer (U.I.C.C.)] has initiated the preparation and distribution of standard reference samples of the most common types of asbestiforms (Timbrell *et al.*, 1968), and these standards are recommended to be used as keys in the identification of asbestos fibres in electron microscope studies (Skikne *et al.*, 1971).

The method described in Table 2 is also similar to the one used in the U.S.E.P.A. Laboratory in Duluth, Minnesota (correspondence, P.E. Cook) and seems to conform with that described by Hallenbeck *et al.* (1977b) at the University of Illinois. The latter authors also emphasized that care should be taken in frequency measurements of counts of fibres, since large errors seem to be inherent in the counting procedure.

The general considerations used for water quality sampling also apply to the sampling of water for asbestos analysis. Sites are selected according to purpose of examination. If samples cannot be analyzed within 48 h of collection, $HgCl_2$ should be added to prevent algal and bacterial growth (concentrations of 20 ppm of Hg or 1 mL of 2.71% $HgCl_2$ per litre of water). The use of 1-L polyethylene sample bottles is recommended.

Table 2. Summary of Analytical Procedure for Asbestos Analysis

Procedure	Detail
Instrumentation	Electron microscope with 0.5- to 1.0-nm resolution and magnification range of 300 to 100 000 times.
Sample treatment	Water sample is filtered through a Nuclepore filter with 0.1-μm pore size and then carbon-coated. Sections of the filter are mounted on EM grids and the filter material dissolved by contact with chloroform. Insoluble organic material can be removed by prefiltration on a 0.1-μm Millipore filter, which is then ashed at low temperature in an oxygen plasma system. The ash is then resuspended in distilled water before Nuclepore filtration.
Viewing and analytical procedure	U.I.C.C. reference samples should be used in the identification of fibres. Measure length and width of fibres; examine morphology (tubular vs. solid structure); count number of fibres in grid sectors (a minimum of 100, preferably about 200 fibres should be counted for statistical reliability).
Range	0.1×10^6 to 1×10^9 fibres/L can be determined without dilution of sample (5-50 mL of the original sample is used).
Precision	34% to 60% relative standard deviation is expected for mean fibre concentrations in the range of 9 to 310 million fibres/L.

HEALTH AND MEDICAL ASPECTS OF ASBESTOS TOXICITY IN WATER

General Health Hazards

From the evidence reviewed by Charlebois (1978), it appears that inhaled airborne asbestos causes lung and bronchial cancer and mesothelioma (tumour) of the pleura (lung cavity) and peritoneum (abdominal cavity). Conclusive evidence has been extremely difficult to produce, especially since there is a lag time of 15 to 40 years between the start of asbestos exposure and the development of the cancer (Hill, 1976; Charlebois, 1978). The exact causes of asbestos-induced cancer have yet to be established; some of the contradictory suggestions found in the literature are listed in Table 3.

Table 3. **Some Suggested Causes of Asbestos Carcinogenicity from the Literature**

Suggested causes of carcinogenicity	Source
Contamination of asbestos by other compounds such as polycyclic aromatic hydrocarbons.	Pylev and Shabad (1972)
The presence of trace metals such as Cr, Ni and Be could inhibit metabolism of benzo (a) pyrene, which increases residence time of carcinogens.	Morgan and Cralley (1972)
Trace metals such as Cu, Zn, Pb, Ni, Cr, Fe and other factors inhibit enzyme activity.	Thomson *et al.* (1974)
Chemical factors including trace metals are suggested to be of importance.	Harington (1972)
Physical structure, such as fibre size and fibre shape, is important.	Timbrell (1972)
Fibre length and property rather than chemical composition and presence of trace metals determine its carcinogenicity.	Wagner *et al.* (1973) Stanton (1974)
It is not known which type of asbestos is more hazardous or which fibre property is more important in inducing toxicity, but surface charges may be important.	Light and Wei (1977)

It should be noted that almost all medical evidence is based on the causal relationship between exposure and response, and all forms of asbestos seem to show health effects. Different risk factors, however, seem to be associated with various types and exposure concentrations (Bogovski *et al.*, 1972; Redfearn, 1977).

Hazards through Water-Ingested Asbestos

As noted by Hallenbeck and Hess (1977), it is expected that a considerable proportion of inhaled asbestos is also swallowed and thus becomes ingested. Experiments performed on rats by Evans *et al.* (1973) showed that up to 48% of inhaled asbestos is swallowed. Medically, it therefore becomes extraordinarily difficult to examine separately that portion which is swallowed directly and that which is ingested in association with food and water. Ingested asbestos fibres were thought to be the cause of an increase in digestive system cancer in studies by Selikoff *et al.* (1964), Merliss (1971), Wagner *et al.* (1973), Evans *et al.* (1973) and Selikoff (1974). The latter authors found the rate of digestive system cancer in asbestos workers two to three times higher than that of the general population. Merliss (1971) noted that the consumption of talc-treated rice and gastrointestinal cancer were highly correlated in Japan. Commercial talc is most commonly contaminated with the amphibole asbestos tremolite (Speil and Leineweber, 1969). The only known case of long-term exposure of water-ingested asbestos has come from the studies of the water supply contamination problems of Duluth, Minnesota (Hill, 1976). No scientific evidence that could stand up in court could be produced to demonstrate health hazards from asbestos ingested through the drinking water supply. It should, however, be noted that the exposure lasted from 1956 to 1974 and, given the lag time of 15 to 40 years for the development of medical evidence, it cannot definitely be stated that no risk is involved. Kay (1973), Olson (1974), Hallenbeck *et al.* (1977b) and Wigle (1977) noted that up to the time of their studies asbestos fibre ingestion with water had caused no significant health effects.

Recent medical evidence presented by Pontefract and Cunningham (1973), Cunningham and Pontefract (1974), Piper (1976) and Storeygard and Brown (1977) revealed that asbestos fibres can indeed penetrate the digestive tract and internal membranes and enter tissues and the bloodstream. Piper (1976) suggests that fibres which have been detected that produce cancerous lung tissues may be able to infiltrate the gastrointestinal tract. How the fibres penetrate, where they accumulate and what health hazards are associated with such actions have yet to be determined. No definite conclusions can be drawn from human autopsy studies and animal feeding experiments. As noted by Hallenbeck and Hesse (1977), such problems as insufficient sample size, absence of sufficient control specimens, and insufficient observation time of animals are the most serious shortcomings faced in research conducted on the subject thus far.

Summary of Medical Evidence

It appears that no conclusive health hazards have yet been identified as a result of asbestos ingestion through the water supply. The subject does, however, merit continuous attention, since in-depth investigative work has been minimal and latency periods for the development of diseases are considerable. Some medical evidence for health hazards exists but scientific proof has yet to be developed (Hill, 1976).

ASBESTOS FIBRES IN WATER SUPPLIES AND DRAINAGE SYSTEMS – A LITERATURE REVIEW

A number of studies of asbestos concentration in water have been undertaken in North America. These include:

(1) the Lake Superior study,
(2) programs in Ontario and Quebec,
(3) the Rio Grande Valley investigations in New Mexico,
(4) U.S. regional analysis of asbestos in water supplies,
(5) U.S. investigations of asbestos fibre concentrations in natural runoff and in discharge of asbestos manufacturing industries, and
(6) Canadian national asbestos analysis of water supplies.

Since these studies had slightly different aims, they will be discussed separately. All of the data are then summarized to compare concentrations.

The Lake Superior Study

Since 1956 taconite tailings from mining operations at Silver Bay, Minnesota, have been dumped into Lake Superior. The tailing material has a high content of amphibole asbestos, and the dumping process has produced high asbestos fibre levels in the water supplies of Duluth and neighbouring communities, all of which draw their water supply from the lake.

Evidence identifying the asbestos fibre source was obtained from an analysis of drill cores of bottom sediments. Those sediments deposited prior to 1950 were found to have only traces of amphibole asbestos, while sediments from 1964 to 1965 and more recent periods were found to contain large amounts of cummingtonite-grunerite (amosite) asbestos. This type of asbestos is absent in the older sediments, and its origin was traced to the Silver Bay mining operation (Great Lakes Research Advisory Board, 1975).

Much attention has been given to asbestos concentrations in lake water. Cook *et al.* (1974), for example, found that asbestos concentrations in Lake Superior ranged from 1 × 10^7 to 1 × 10^9 fibres/L in the Duluth water supply, while Durham and Pang (1976) found concentrations ranging from less than 0.1 × 10^6 to 8.7 × 10^7 fibres/L in the open waters of Lake Superior. Fibre distribution was found to be extremely variable, and the cause of variability was attributed to seasonal and meteorological variations, and circulation patterns in the lake (Cook *et al.*, 1976). Durham and Pang (1975, 1976) observed little transboundary movement of asbestos in the open waters of the lake but noted a decrease in concentrations between June and November. Fairless (1977) reported decreasing concentrations in a counterclockwise direction from the source and across the lake.

Because of the fear of a potential health hazard from ingested fibres, filtering operations were introduced into the water supply systems (Franz, 1976) and, according to Schmitt *et al.* (1977), were found to be effective and reasonably simple. Because of its legal implications the Duluth case has been given considerable attention and, as noted by Hill (1976), has shown that despite medical evidence no scientific proof of health hazards could be produced. The company was given time to develop a new site and techniques for the disposal of the mine tailings in the future.

Programs in Ontario and Quebec

As a result of an early study by Cunningham and Pontefract (1971), the Ontario Ministry of the Environment initiated a study to determine asbestos levels in water supplies across the Province. The results produced by Kay (1973) revealed that asbestos fibres were present in all 22 water samples analyzed, and concentrations varied from 1 × 10^5 to 4 × 10^6 fibres/L (for a more detailed comparison, see Table 4).

Table 4. Asbestos Concentrations in City Water Supplies

City water supply	Low-fibre concentration	High-fibre concentration (fibres/L)	Dominant type of fibre
Boston	BDL*	1 × 10^7	Chrysotile and amphibole
Philadelphia	BDL	2.3 × 10^8	Chrysotile
Atlanta	BDL	1.2 × 10^7	Chrysotile
San Francisco	BDL	2.4 × 10^8	Chrysotile
Seattle	BDL	1.9 × 10^6	Chrysotile

* BDL = Below detection limit.

From data published by Cunningham and Pontefract (1971), a comparison between filtered and non-filtered river water was made. It revealed that in a number of Ontario rivers, the asbestos levels in filtered water ranged from 2 × 10^6 to 6 × 10^6 fibres/L and in non-filtered water, from 8 × 10^6 to 1 × 10^7 fibres/L.

A lake near the Thetford Mines area in Quebec showed fibre levels of 1.7 × 10^8 fibres/L as compared with 4 × 10^6 fibres/L for Lake Ontario. This suggested that inputs associated with asbestos mining operations were probably responsible for the higher lake concentrations in the former. It is assumed that this discovery eventually prompted the studies by Lawrence and Zimmermann (1977), who examined filtering procedures for treating effluents from asbestos mining and processing plants in Ontario, Quebec and Newfoundland. Levels in the untreated effluents were in the range from 1×10^9 to 1×10^{11} fibres/L, and sedimentation followed by mixed media filtration was found to be very effective in removing most of the asbestos from the mine and processing plant effluents.

The Rio Grande Valley Investigation in New Mexico

Oliver and Murr (1977) produced data on asbestos fibre concentrations for a number of water sources in New Mexico. The purpose of their study was to determine whether asbestos pipes, used extensively in water transport in the semi-arid area, cause an increase in asbestos concentrations in the water. A large number of water samples examined in their study originated from groundwater wells and many showed considerable asbestos fibre levels. They concluded that no asbestos pickup was observed by water that had passed through asbestos pipes and that well water levels in many cases exceeded levels found in the asbestos pipe distribution system. The absence of asbestos release from asbestos water pipes was also confirmed from a study made elsewhere (Hallenbeck *et al.*, 1978).

Fibre levels were found to range from below detection limit to 2.1×10^9 fibres/L and are considered high in comparison with those reported in the Ontario and Duluth studies. The more frequent occurrence of serpentine and amphibole-rich geological formations in the New Mexico area is thought to be the cause of the high concentrations.

■ Counties with reported occurrence of amphibole and chrysotile asbestos

Figure 1. Asbestos occurrences in the United States.

This can be confirmed from Figure 1, which represents a greatly generalized diagram of asbestos occurrences reported in counties across the United States (Olson, 1974; Kuryvial *et al.*, 1974).

U.S. Regional Analysis of Asbestos in Water Supplies

Between 1973 and 1975, two surveys were conducted in which asbestos fibre concentrations were determined in regional water supplies. Cooper and Murchio (1974) reported asbestos concentrations in water supplies in northern California, while Stewart (1976) compiled information on ten regional cities: Boston, New York, Kansas City, Philadelphia, Denver, Seattle, Atlanta, Dallas, Chicago and San Francisco. Cooper and Murchio (1974) reported that asbestos fibres were present in a number of water supplies and that concentrations were generally below the level of 1×10^6 fibres/L. The exception was one sample from a Marin County water supply reservoir that had an asbestos concentration of 2×10^8 fibres/L. Samples from water supply systems in the Lake Superior area were also examined and the results were compared with those of Stewart (1976), who had examined the same water supplies. Concentrations in these waters ranged from 1×10^6 to 1×10^7 fibres/L.

The results of the ten-city investigation by Stewart (1976) revealed that water supplies in New York, Chicago, Dallas, Kansas City and Denver were essentially free from asbestos but fibres were detected in the water supplies of Boston, Philadelphia, Atlanta, Seattle and San Francisco. Stewart noted that fibres were generally small (from 1.5 µm to 2 µm) and that concentrations were subject to seasonal variation in Atlanta and Philadelphia. Increases in asbestos counts were associated with higher river flow rates. The high and low concentrations in water supplies of the five cities are given in Table 4.

U.S. Investigations of Asbestos Fibre Concentrations in Natural Runoff and in Discharge of Asbestos Manufacturing Industries

Stewart *et al.* (1976) published results of asbestos fibre concentrations in natural waters. They found that concentrations varied according to seasonal fluctuations in flow and are therefore subject to great variation. Concentrations of up to 5×10^7 fibres/L were found in some streams and lakes in Montana, California and Vermont. No detectable concentrations were found in three streams examined in Georgia, North Carolina and Tennessee.

Effluent discharge from major asbestos manufacturing industries was examined in all parts of the United States by Stewart *et al.* (1976). The production of asbestos paper was found to produce the highest asbestos fibre concentrations in effluents. Results of studies on various industries and asbestos concentrations found in their effluents, as published by Stewart *et al.* (1976), are provided in Table 5.

Table 5. Effluent Concentrations from Different Asbestos Manufacturing Industries

Product	Concentrations of asbestos in effluents (fibres/L)
Asbestos cement pipes	10^6-10^7
Asbestos tiles	10^6-10^7
Asbestos cement sheets	10^7-10^{10}
Asbestos paper	10^8-10^{12}
Friction material	10^9-10^{10}
Asbestos textile	10^6-10^7

Table 6. Summary of Asbestos Concentrations in Natural Water Sources

		Asbestos concentrations		
Type of water source	Area	Presumed natural levels with no point sources	Presumed to be influenced by asbestos mining and related industries	Source
Lakes	Lake Superior (west), Duluth area		4×10^7 to 1×10^9	Cook *et al.* (1976)
	Lake Ontario	2×10^6		Kay (1973)
	Lake Michigan		1×10^6 to 1×10^8	Cunningham and Pontefract (1971) Hallenbeck *et al.* (1977a)
	Lake Oroville, California	Up to 1.7×10^6		Stewart *et al.* (1976)
	Lake-A, Marin County, California	Up to 2×10^8		Cooper and Murchio (1974)
Rivers	Ottawa River at Ottawa	9.5×10^6		Cunningham and Pontefract (1971)
	Trinity River, California	Up to 4.8×10^7		Stewart *et al.* (1976)
	Beaverhead River, Montana	Up to 2.7×10^7		Stewart *et al.* (1976)
Groundwater	Rio Grande Valley, New Mexico	Up to 2×10^9		Oliver and Murr (1977)
	Illinois	Up to 3×10^5		Hallenbeck *et al.* (1978)
	Houston, Texas	BDL*		Cooper and Murchio (1974)
Rainwater	Chicago, Illinois	1×10^5 to 1×10^6		Hallenbeck *et al.* (1977a)
Melted snow	Ottawa	3.4×10^7		Cunningham and Pontefract (1971)

*BDL = Below detection limit.

Canadian National Asbestos Analysis of Water Supplies

In 1977, the Ontario Research Foundation (ORF) was awarded a federal contract to initiate a national drinking water survey program for asbestos. The aims of the study were to determine asbestos levels in drinking water sources for the majority of the Canadian population. Emphasis was to be placed on sampling some 75 water sources for large urban areas and to cover the most significant water sources in areas of known asbestos-related industries. A total of 230 samples were to be collected and concentrations analyzed by electron microscopy. The data are currently being compiled and the report is to be completed by Chatfield *et al.* (in preparation)[3] at ORF in Mississauga by the end of September 1978.

Summary of Results

To compare asbestos fibre concentrations, a distinction was made between waters affected by point sources (asbestos mining, milling and manufacturing industry) and those affected by natural sources. A comparison of the variability of asbestos concentrations in the natural water system given in Table 6 reveals that considerable concentrations can be present in precipitation and melted snow. Because the data are insufficient, it is impossible to determine whether these levels are representative and how much they are affected by industrial and transportation emissions. Groundwater concentrations as well as river concentrations seem to be related to the presence of asbestos-bearing geological formations. Given this very limited data base, it is impossible at this time to predict levels and variability of asbestos in the natural system, and it is suggested that some research emphasis be directed toward better understanding of the asbestos-water cycle and asbestos variability in nature.

Asbestos levels in municipal distribution systems, drinking water supplies, and effluents associated with the asbestos industry are summarized in Table 7. It appears that asbestos levels vary considerably between different areas and sources of influence. Receiving waters affected by asbestos-related industries have reached asbestos concentrations of up to 1×10^{12} fibres/L. Water supplies in areas of known asbestos-bearing bed rock and presumed absence of asbestos input through industrial effluents have reached concentrations of up to 2×10^{7} fibres/L. Finally, it should be stressed that most observations have so far been based on minimal information or an insufficient data base and are therefore tentative.

EXPLORATORY STUDIES IN BRITISH COLUMBIA AND THE YUKON TERRITORY

Asbestos in the Sumas and Fraser River System

In 1976, the Seattle office of the U.S.E.P.A. informed Canadian authorities of the presence of potentially high asbestos fibre concentrations in the Sumas River system. The Sumas River, which has its headwaters in the northern Cascade Mountains in the state of Washington, crosses the border between the United States and Canada at Huntingdon and eventually becomes part of the lower Fraser River drainage system in British Columbia (Fig. 2).

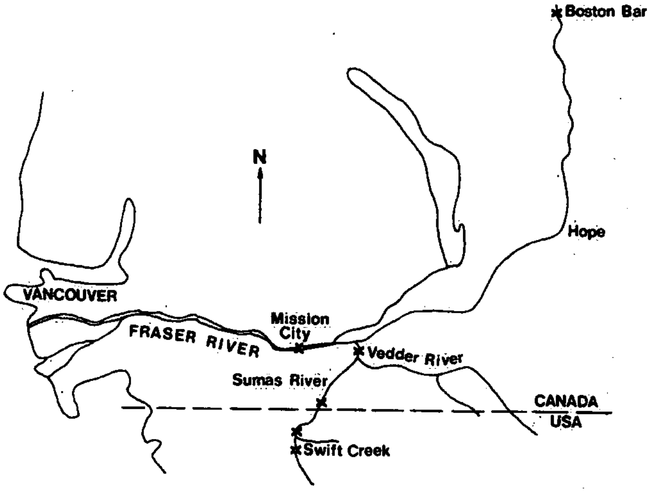


Figure 2. Location of Fraser and Sumas drainage system (*x* indicates sampling stations).

Between January 1976 and December 1977, a number of water samples were collected by Provincial Pollution Control Branch, Ministry of Health, and federal Water Quality Branch personnel to:

(a) determine asbestos fibre concentrations in a few locations within the Fraser River system,
(b) examine potential asbestos fibre sources in the area, and
(c) evaluate accuracy of analysis and sources of variability.

No coordinated program was set up; instead, an exploratory project was initiated where samples were collected in combination with other on-going field programs in the area.

(a) Asbestos Fibre Concentrations in the Fraser River System

Water samples were collected, preserved and analyzed in the manner described in the "General Background." The

---

[3] See footnote 2.

Table 7. Summary of Asbestos in Municipal Water Supplies and Effluents

		Asbestos concentrations		
Type of water source	Area	Presumed natural levels with no point sources	Presumed to be influenced by asbestos mining and related industries	Source
Municipal distribution system	Ontario (rivers and lakes)	$\leqslant 3.9 \times 10^6$		Kay (1973)
	Lake Superior (west)		10^6–10^8	Kay (1973)
	Lake Superior (general)		$\leqslant 10^7$	Charlebois (1978)
	Detroit River (raw)	2.5×10^7		Kay (1973)
	Toronto municipality	$\leqslant 4 \times 10^6$		Kay (1973)
	Lake Michigan	$\leqslant 6.7 \times 10^5$		Hallenbeck *et al.* (1978)
	Ontario drinking water (raw)	1.7×10^7		Brown (1977)
	Rio Grande Valley	$\leqslant 2 \times 10^9$		Oliver and Murr (1977)
	Illinois groundwater	$\leqslant 3 \times 10^5$		Hallenbeck *et al.* (1978)
	Philadelphia	$\leqslant 2.3 \times 10^8$		Stewart *et al.* (1976)
	San Francisco	$\leqslant 2.4 \times 10^8$		Stewart *et al.* (1976)
Tap water	Ontario river source	9.5×10^6		Cunningham and Pontefract (1971)
	Thetford Mines, Quebec		1.7×10^9	Cunningham and Pontefract (1971)
Effluents related to asbestos industrial operations	Asbestos, Quebec		1×10^9	Lawrence and Zimmermann (1977)
	Baie Verte, Newfoundland		1×10^{11}	Lawrence and Zimmermann (1977)
	Asbestos cement plant*		5×10^9	Lawrence and Zimmermann (1977)
	Asbestos cement pipes and sheets*		10^6 –10^{10}	Stewart *et al.* (1976)
	Asbestos paper*		10^8 –10^{12}	Stewart *et al.* (1976)

*Industrial sources from various areas.

first set of samples were analyzed at N.W.R.I. in Burlington by Dr. R. Durham. The analytical work on the remaining samples was performed in Vancouver by Levelton & Associates Ltd. and analytical verifications were made by sending duplicate samples to other laboratories [see section (c)]. Asbestos fibre concentrations were found to vary between 5 x 10^8 and 1 x 10^{11} fibres/L in the Sumas system (Fig. 3) and from 8.5 x 10^6 to 1.2 x 10^9 fibres/L in the Fraser system (Fig. 4). The data in Figure 3 do not suffice for an analysis of seasonal trends; an examination of upstream-downstream changes in both the Fraser and Sumas systems should be made with caution, since none of the samples in either case were collected during the same time period. The data are presented merely to emphasize that asbestos levels in the Sumas and Fraser systems were consistently high.

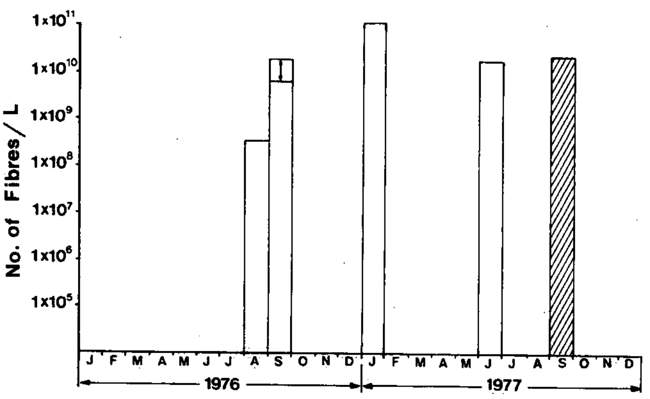


Figure 3. Asbestos fibre concentrations in Sumas River at United States–Canada border. Two-way arrow indicates range of two or more samples; cross-hatching represents fibres per litre below Swift Creek confluence.

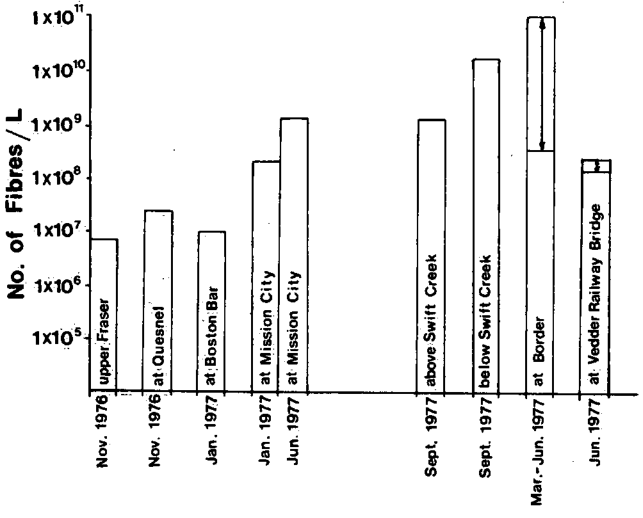


Figure 4. Asbestos fibre concentrations in downstream direction of Fraser and Sumas rivers. Two-way arrows indicate range of two or more samples.

(b) Asbestos Fibre Sources in the Two Drainage Areas

In the absence of any known asbestos-related industry in the area, emphasis was placed on examining the bedrock geology for sources of asbestos fibres in both watersheds.

Sumas River — The asbestos source in the Sumas River was thought to be an active landslide in the headwaters of Swift Creek (a small tributary of the Sumas near Nooksack, Washington). The landslide is considered a major point source of suspended sediment load, which according to Converse, Davis, Dixon and Associates Inc. (1976), originated in the early post-glacial period (±10 000 years). It is assumed that the slide had stabilized itself until about 35 years ago when it was reactivated. Sequential aerial photography has provided evidence of continuous mass movement since that time; a major slope failure was recorded in 1971 after which Swift Creek had to re-establish its channel. Since that time Converse, Davis, Dixon and Associates Inc. (1976) have estimated a rate of movement of about 9 m/yr, the dominant process being soil creep.

The bedrock geology is highly fractured by thrust faulting and consists of chert and shale, overlain by major intrusions of dunites and peridotites. The latter two have been highly altered to form serpentine and clay and are in turn covered by conglomerate rocks of the Huntingdon and Chuckanut formation.

All formations have been uplifted and exhibit steep dipping beds. The serpentine and clay layers are impermeable, and water which readily penetrates the more permeable conglomerate formation accumulates in the contact zone. It is postulated that during periods of above average rainfall, this saturated zone becomes the sliding plane of mass failure. Evidence of this is provided in Figure 5, which shows where a section of the conglomerate formation has slipped off, exposing green serpentine bed rock. Asbestos fibres are common in the serpentine formation, and surface water now has more effective access to the asbestos source.

To determine whether the serpentine exposed in the landslide is the cause of the high asbestos fibre levels in the Sumas River, a one-day field trip was organized in September 1977, during which quadruplicate water samples were collected from the Sumas River at a point immediately above and at a point 500 m downstream from the Swift Creek confluence. The results from this experiment revealed that Swift Creek was responsible for an asbestos fibre concentration increase of approximately one order of magnitude (2 x 10^9 fibres/L above the Swift Creek confluence compared with 3 x 10^{10} fibres/L below the

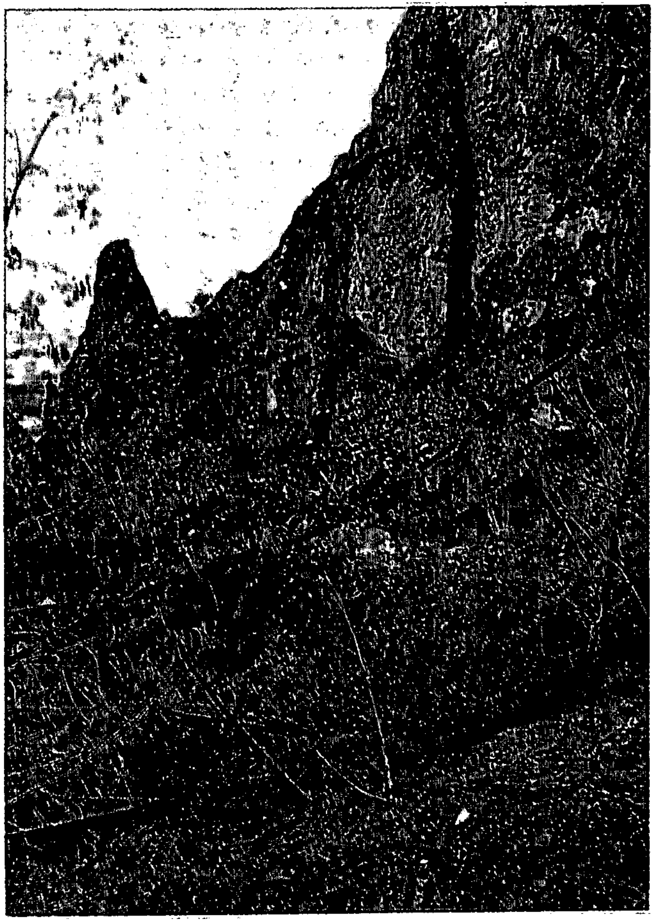


Figure 5. Exposure of serpentine bed rock after mass failure of overlying conglomerate.

Swift Creek confluence). Although a significant increase in asbestos levels was attributed to the landslide processes, it was concluded that the size and flow rate of Swift Creek were insufficent to account for the overall asbestos levels measured on the Sumas River at the Fraser confluence. In addition, asbestos concentrations above the Swift Creek confluence were considered approximately equal to the levels measured at the border. It is thus concluded that the abundance of asbestos-bearing serpentine rock and its proximity to the surface of the drainage basin are responsible for the overall asbestos concentrations.

Fraser River system — A considerable difference in asbestos concentration was observed in different locations in the Fraser River. Because sample time varied, it is highly speculative to make a spatial assessment of asbestos levels in the drainage basin. It appears that asbestos concentrations in the Fraser above Boston Bar vary between 8 x 10^6 and 4 x 10^7 fibres/L. Higher values were obtained on the Fraser at Mission City.

Besides the Sumas asbestos source, a major serpentine belt occurs on the east side of the Fraser Canyon between Boston Bar and Hope. It is referred to as the Serpentine Belt of the Coquihalla region (Cairnes, 1929). No detailed analysis was made for the watershed as a whole but it is likely that drainage from that source could account for the observed asbestos level, especially since the area exhibits a sparse vegetation cover and is subject to erosion processes.

(c) Evaluation of Analytical Accuracy and Sources of Variability

As noted above, quadruplicate samples were collected on the Sumas River, above and below Swift Creek. The purpose of this sampling was to determine the reliability of the analytical procedure. Each set of samples was sent to a different laboratory for an independent verification of fibre concentration. The results are provided in Table 8.

One set of samples remains to be analyzed, but from Table 8 it is clear that a reasonable agreement was obtained by the different laboratories.

As previoulsy noted, the Fraser and Sumas data are not suitable for an assessment of spatial, downstream and seasonal trends of asbestos variability. Separate studies should be initiated to determine whether such trends exist. The latter subject is of particular interest, since contradictory evidence can be found in the literature. Nicholson

Table 8. Verification of Analytical Results

	Sumas River above Swift Creek		Sumas River below Swift Creek	
Analytical results	Concentration (fibres/L)	Mean fibre size units (μm)	Concentration (fibres/L)	Mean fibre size units (μm)
Levelton & Associates Ltd., Vancouver	0.5 X 10^9	1.30	3.1 X 10^{10}	Clusters
N.W.R.I., Burlington	2.2 X 10^9	1.26	2.9 X 10^{10}	2
U.S.E.P.A., Seattle	1.6 X 10^9		Too numerous to count	

and Pundsack (1972) found no statistical seasonal variability, whereas Hallenbeck *et al.* (1977a) stated that seasonal differences are pronounced. It is assumed that seasonal hydrologic conditions influence asbestos fibre transport but conclusive evidence has yet to be produced.

Cross-sectional variability of asbestos concentrations was examined for three different streams (Table 9). The stream cross-sectional variability is relatively small and well within analytical reliability, suggesting that single grab samples can be used as an accurate indicator of conditions. Additional observations during different hydrologic conditions, however, are needed for verification.

Table 9. Variability of Asbestos Concentrations of River Cross Sections

	Fibre concentrations and position in river cross section		
Location	Left bank*	Midstream	Right bank*
Fraser River at Mission City (June 10, 1977)	9.4×10^8	1.0×10^9	1.2×10^9
Vedder River at rwy bridge (June 10, 1977)	1.0×10^8	1.4×10^8 2.3×10^8	2.6×10^8
Sumas at border (September 3, 1976)	1.5×10^{10}	0.8×10^{10}	1.3×10^{10}

*Facing downstream.

Asbestos in the Yukon River

Two Yukon River water samples collected in August 1977, were analyzed for asbestos concentrations. The purpose of the exploratory study was to provide background information on transport of pollutants across the Alaska-Yukon boundary. One sample was collected on the Yukon River at the border and the other, on the Yukon above the Fortymile River confluence. The levels at the border were found to be 2×10^8 fibres/L and above the Fortymile River confluence, 3.3×10^7 fibres/L. Given the relatively small size of Fortymile River, it was concluded that only a small portion of the asbestos at the boundary could be attributed to drainage from the Fortymile River basin, which contains a defunct asbestos mine. The rest was contributed by the presence of asbestos-bearing bed rocks, which are common in most of the lower Canadian sections of the Yukon River. A more detailed study of the mining area is currently being pursued by the Department of Indian and Northern Affairs; no data are yet available.

Comparison of West Coast, East Coast and U.S. Levels of Asbestos Concentration

A direct comparison of asbestos fibre concentrations between different water sources in various parts of North America is somewhat difficult, since each system is subject to an independent contributory source and is influenced by processes which are not clearly understood and determined. A barometric type of indicator has been produced (Fig. 6), which lists the range of fibre concentration in different studies.

Effluent waters from asbestos-related industries exhibited the highest asbestos fibre concentrations but water from natural systems such as the Sumas River in British Columbia did in fact show asbestos levels which came very close to those found in industrial effluents. The Sumas River showed higher values than any other natural water source examined in the recent literature.

One of two inferences can be made from these observations. Either the geological conditions in the lower

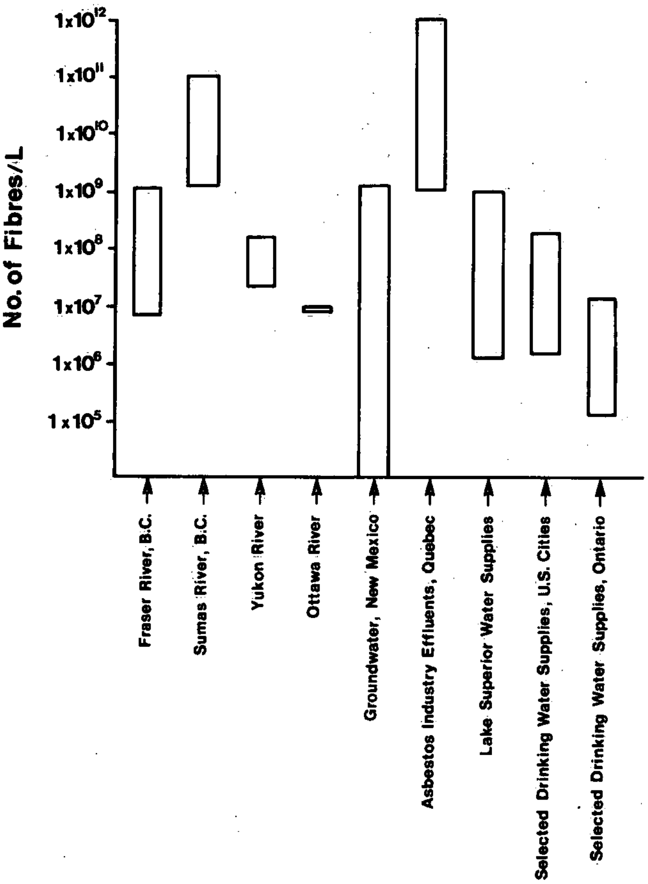


Figure 6. Comparison of asbestos fibre concentrations in various water sources.

Fraser Basin are exceptional or not enough in-depth investigations have been made of asbestos concentrations in natural water systems elsewhere. The latter explanation is probably more likely.

For reference purposes, a summary list of all Yukon and B.C. asbestos water samples analyzed to date is given in the Appendix.

POSSIBLE WAYS OF PREDICTING ASBESTOS LEVELS IN RECEIVING WATERS

From the relatively scarce evidence provided in the literature it appears that asbestos fibres are dynamic and enter all stages of the hydrologic cycle. At present, neither the mechanism of movement nor the causes of variability are well understood. To develop a method of predicting asbestos levels in receiving waters it is essential to examine source areas first and then to trace the asbestos through the pathways of the hydrologic cycle.

Source Area Identification

Asbestos fibres are formed during metamorphism and are thought to be the altered product of ultrabasic rocks. Fibres occur in association with volcanic intrusions between sedimentary rocks or in zones of metamorphism of igneous rocks. An analysis of the bedrock geology both regionally and within each watershed is therefore of primary importance.

Figure 7 is a map indicating the likelihood of the presence of asbestos-bearing formations in British Columbia and the Yukon Territory, which is based on the Metamorphic Map of the Canadian Cordillera (Monger and Hutchison, 1971). A great portion of the region has been influenced by metamorphism and the identified bedrock areas correspond to assemblages of metamorphic minerals and degree of intensity of metamorphism. Those areas of high-pressure high-intensity metamorphism were considered to have the highest probability of asbestos fibre occurrence. Superimposed on this are the known asbestos fibre occurrences (published by the B.C. Department of Mines and Petroleum Resources, 1974), many of which were used as references or aerial indicators for classification of the different formations of metamorphic facies.

The regional map (Fig. 7) is useful in the selection and identification of drainage basins in asbestos-related studies, but once the basin is identified, a more detailed analysis of asbestos sources is necessary. This includes bedrock location; surface exposure, both natural and through mining activities; extent and thickness of bed rock; amount of surficial material cover; and amount, direction, and type of material introduced as a result of glaciation.

Pathways and the Asbestos Cycle

Once source areas have been identified it is essential not only to examine the general asbestos concentrations in the stream but also to determine ways in which the fibres are introduced into the system. This has to include tropospheric input by rain and snow, groundwater contribution and surface runoff. It is presumed that the degree of exposure of asbestos-bearing bed rock, both by natural and artificial causes, is important in determining the input of asbestos via airborne media. In addition, the variability of asbestos concentrations should be studied both spatially and over time to gain a better understanding of the transportation mechanisms in nature.

Outline of Study Approach

First, a pilot project should be initiated to examine the cause and variability of asbestos fibre concentrations in natural water systems. In this context three small watersheds could be selected, as follows:

(a) a watershed in an area having no known contact with asbestos-bearing rocks,
(b) a watershed in an area of intermediate metamorphism, and
(c) a watershed draining an area of extensive metamorphic rocks with known evidence of asbestos fibres in the structure.

For each of the three systems the following minimal setup would be required:

(a) Three sampling stations in the upstream to downstream direction. Water samples should be analyzed at least four times over a one-year period, and sampling should coincide with major hydrologic events such as high water flow, late summer flow and minimal flow.
(b) Two precipitation collectors should be analyzed four times over a one-year period, covering spring, summer, fall and winter.
(c) Bed sediments should be analyzed four times over a one-year period.

This pilot study would provide essential basic information such as seasonal trends both in the runoff and precipitation input, spatial variability, possible effects of

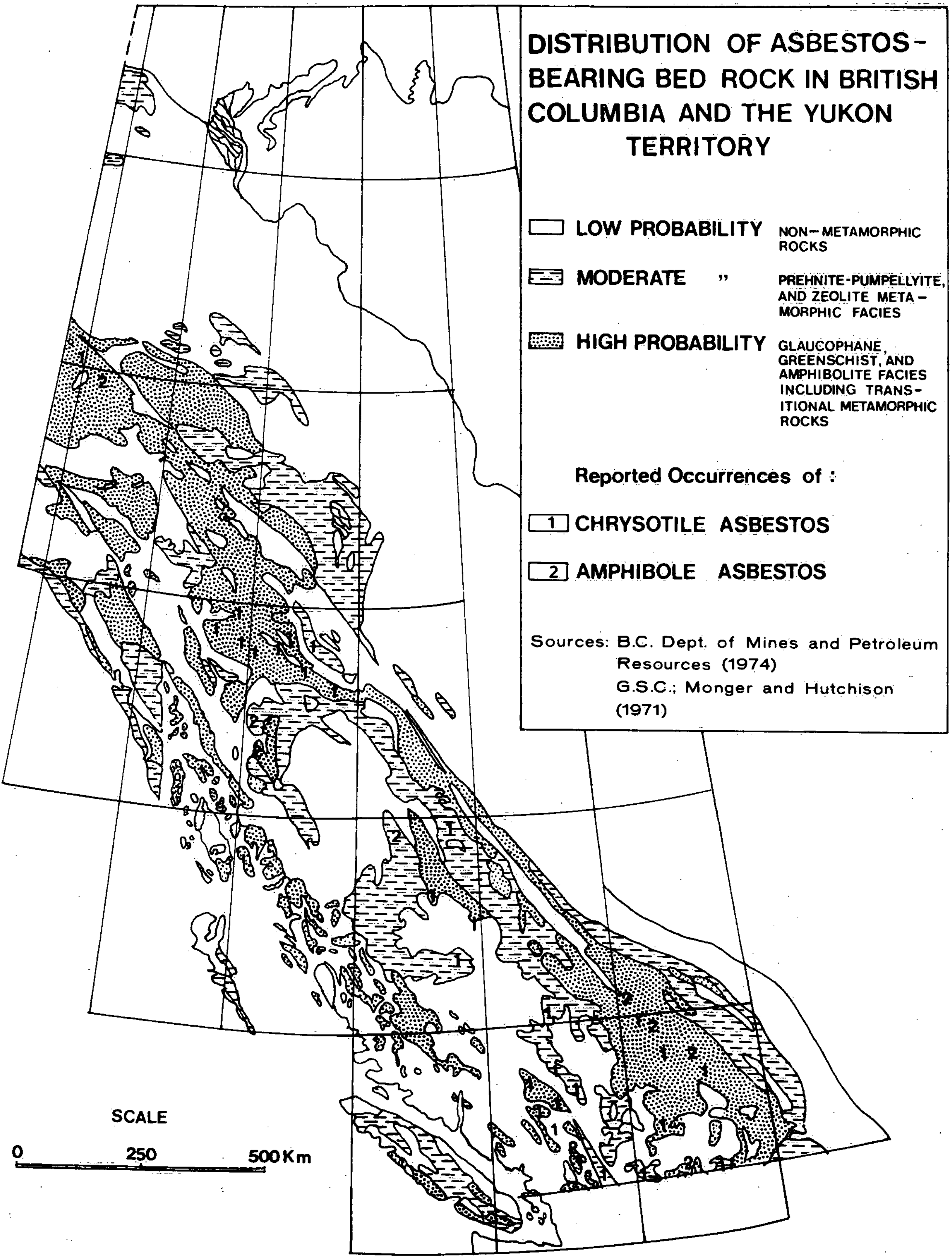


Figure 7. Distribution of asbestos-bearing bed rock in British Columbia and the Yukon Territory.

the flow regime on concentrations, type of watershed surface and its effect on asbestos concentrations, and the influence of distance and amount of asbestos bed rock on concentrations in water. The most effective sampling procedure could then be chosen and a reconnaissance survey initiated to produce reliable background concentrations for suspected high asbestos drainage systems in the region.

CONCLUSIONS

Only a few attempts have been made to examine asbestos fibre distributions in receiving water. The limited scientific literature concerns mostly waters affected by asbestos mining and manufacturing industry, and the occurrence of asbestos fibres in natural systems has not been studied to any great extent. Because of the limited knowledge on the topic some of the conclusions reached below are only tentative.

Asbestos in the Hydrologic Cycle

Significant asbestos fibre concentrations have been found in rainwater, melted snow, lakes, rivers and groundwater in different parts of North America, suggesting that asbestos fibres are very mobile and enter all pathways of the hydrologic cycle.

Sources of Asbestos

Asbestos fibres are formed during metamorphism of ultrabasic volcanic rocks (chrysotile) and metamorphism of sedimentary rocks (amphibole). Both types are widely distributed in North America. The fibres are usually introduced into the water system by point sources (usually asbestos-related industry) or non-point sources (natural bedrock formations). It is expected that not all natural sources are *in situ* and that a complex situation may exist in areas where glaciation has been responsible for the redistribution of asbestos-bearing bed rock.

Factors Affecting Asbestos Distribution in Water Systems

Because of their small size fibres can readily be transported by wind and water. There is some evidence that asbestos fibres, which become airborne as a result of mining and industrial activities and emissions from construction and off-road transport, are readily collected and introduced into the water system by rain and snow. The contribution from this source, however, is not well documented. The exposure of asbestos-bearing bed rock and related processes were found to influence asbestos concentrations in water. Asbestos fibres are also introduced by surface wash water and groundwater draining asbestos-rich bed rock.

It is assumed that hydrologic conditions influence asbestos variability, and limited evidence on this subject has been produced from the Lake Superior investigation where the lake circulation pattern was found to be responsible for the asbestos distribution. Seasonal patterns of asbestos concentrations are expected to exist in rivers but scientific evidence so far has been contradictory.

Asbestos Concentrations in Receiving Waters

Levels of up to 1 x 10^{12} fibres/L were found in asbestos mine effluents but exploratory results from the Fraser and Sumas rivers in British Columbia and groundwater sample analysis in New Mexico have shown that natural asbestos concentrations can reach levels of up to 1 x 10^{11} fibres/L. The latter concentrations are significantly higher than those reported from analysis of drinking water supplies in Lake Superior and from much of Ontario. It is possible that the greater abundance of asbestos-bearing metamorphic rocks in British Columbia and New Mexico as well as the proximity to the source may be responsible for these higher levels. At this time it is not possible to determine whether these concentrations are unusually high, since only a small number of natural systems have been examined in North America.

Health Hazards from Water-Ingested Asbestos

Asbestos fibres are known to be carcinogenic when inhaled, but no such evidence exists to date to show that this applies to water-ingested asbestos. Health hazards from water-ingested asbestos are difficult to determine not only because a 15- to 40-year time lag exists between exposure and health effects but also because no residual population with long-term high-level asbestos exposure has yet been investigated. More in-depth medical evidence is needed before a satisfactory decision can be made on the subject.

Asbestos Fibre Distribution in the Pacific and Yukon Region

Based on a geological analysis it is evident that a large portion of British Columbia and south central Yukon is underlain by asbestos-bearing metamorphic rocks. The bedrock evidence can be used as an indicator for locating drainage basins with potentially high asbestos fibre concentrations. In the final analysis, however, other factors and processes should be included to obtain reliable predictions.

Need for Research

Little is known about asbestos fibres in the aquatic system. Some basic investigations on asbestos variability and mechanisms of transport will be necessary to attain better understanding of the key processes and distribution pattern of asbestos fibres in receiving waters.

ACKNOWLEDGMENTS

The help of all those who contributed to this project is gratefully acknowledged. Dr. R. Durham of the National Water Research Institute in Burlington was helpful in the early sample analysis and provided guidance for the analytical work performed in Vancouver. Mr. R. Jones of the U.S.E.P.A in Seattle arranged for the joint field analysis program on the Sumas River. Analysis of asbestos was performed by Mr. A.J. Shaw of Levelton & Associates Ltd. in Vancouver. Cooperation of the Provincial Pollution Control Branch and the Ministry of Health, in particular Mr. W. Bailey and Dr. L.L. Kulak, is gratefully acknowledged. Finally, thanks go to members of the Water Quality Branch of the Inland Waters Directorate in Vancouver for their participation in the sampling program and review of this report.

REFERENCES

Bagioni, R. 1975. Separation of chrysotile asbestos from minerals that interfere wth its IR-analysis. Environ. Sci. Technol. 9: 262-263.

Biles, B. and T.R. Emerson. 1968. Examination of fibres in beer. Nature, 219.

Bogovski, P., V. Timbrell, J. Gibson and J. Wagner. 1972. Biological effects of asbestos. International Agency for Research on Cancer, IARC Sci. Pub. No. 8, pp. 1-346.

British Columbia Department of Mines and Petroleum Resources. April 1974. Asbestos Occurrences in British Columbia.

Brown, W.F.M. 1977. Environmental protection and control: asbestos studies. Environment, 7: 11.

Cairnes, C.E. 1929. The Serpentine Belt of Coquihalla Region, Yale District. Geol. Surv. Can. Summary Rep. 1929A, pp. 144-147.

Canadian Consumer. June 1977. Test: asbestos in wine, pp. 44-47.

Charlebois, C.T. March 1978. An Overview of the Canadian Asbestos Problem. Sponsored by Science Council of Canada. Chem. Can., pp. 19-38.

Chatfield, E.J. *et al.* Sampling of Canadian Drinking Water Supplies for Asbestos. Ontario Research Foundation, Mississauga, Ontario. In preparation.

Committee on Asbestos Analysis. 1977. An Interim Method for the Determination of Asbestos Fibre Concentrations in Water by Transmission Electron Microscopy. Laboratory Services Branch, Ontario Ministry of the Environment.

Converse, Davis, Dixon and Associates Inc. 1976. Swift Creek Tributaries and Sumas River Watershed. Final Geotechnical Report, Soil Conservation Service Contract A653-00041, Converse, Davis, Dixon and Associates Inc., Seattle, Washington.

Cook, P., G. Glass and J. Tucker. 1974. Asbestiform amphibole minerals: detection and measurement of high concentrations in municipal water supplies. Science, 185: 853-855.

Cook, P., I. Rubin, C. Maggiore and W. Nicholson. 1976. X-Ray diffraction and electron beam analysis of asbestiform minerals in Lake Superior. Inst. Electr. Electron. Eng. J. 75-34-1.

Cooper, R.C. and C. Cooper. June 1978. Public health aspects of asbestos fibres in drinking water. J. Am. Water Works Assoc., pp. 338-340.

Cooper, R.C. and J.C. Murchio. 1974. Preliminary studies of asbestiform fibres in domestic water supplies. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, Pap. No. 5, pp. 61-73.

Cunningham, H. and R. Pontefract. 1971. Asbestos fibres in beverages and drinking water. Nature, 232:332-333.

Cunningham, H. and R. Pontefract. 1974. Placental transfer of asbestos. Nature, 249: 177-178.

Durham, R.W. and T. Pang. 1975. Asbestos fibres in Lake Superior. Am. Soc. Test. Mater. Spec. Tech. Pub. 573, pp. 5-13.

Durham, R.W. and T. Pang. 1976. Asbestiform fibre levels in Lakes Superior and Huron. Sci. Ser. No. 67, Inland Waters Directorate, Environment Canada, Canada Centre for Inland Waters, Burlington, pp. 1-12.

Evans, J.C., R.J. Evans, A. Holmes, R.F. Houssam, D. Jones, A. Morgan and M. Walsh. 1973. Studies on the deposition of inhaled fibrous materials in the respiratory tract of rats and its subsequent clearance using radioactive tracer techniques. Environ. Res. 6: 180-201.

Fairless, B. 1977. Asbestos Fibre Concentrations in Drinking Water of Communities Using the Western Arm of Lake Superior as a Potable Water Source. Environ. Prot. Agency U.S., EPA-905/4-77-003.

Franco, M., J. Hurchison, D. Jefferson and J. Thomas. 1977. Structural imperfection and morphology of crocidolite. Nature, 266: 520-521.

Franz, R. 1976. Public Behavior and Attitude in Response to Reported Hazardous Drinking Water. EPA-600/1-76/026.

Gerber, R. and R. Rossi. 1977. Evaluation of Electron Microscopy for Process Control in the Asbestos Industry. Aerospace Corp. Ltd. for Industrial Environmental Research Lab., Research Triangle Park, N.C., Rep. No. ATR-77 (7552)-1, NTIS.

Great Lakes Research Advisory Board. 1975. Asbestos in the Great Lakes Basin with Emphasis on Lake Superior. International Joint Commission, United States and Canada, Rep. No. STIJC-7503, p. 51.

Hallenbeck, W.H. and C.S. Hesse. 1977. A review of the health effects of ingested asbestos. Rev. Environ. Health, II(3).

Hallenbeck, W.H., C. Hesse, E. Chen, K. Patel-Mandlik and A. Wolff. 1977a. Asbestos in Potable Water. University of Illinois at Urbana-Champaign Water Resources Center, UILU-WRC-77-0118, pp. 1-77.

Hallenbeck, W.H., E.H. Chen, K. Patel-Mandlik and A.H. Wolff. 1977b. Precision of analysis for waterborne chrysotile asbestos by transmission electron microscopy. Bull. Environ. Contam. Toxicol. 17: 551-558.

Hallenbeck, W.H., E.H. Chen, C.S. Hesse, K. Patel-Mandlik and A. Wolff. February 1978. Is chrysotile asbestos released from asbestos-cement pipe into drinking water? J. Am. Water Works Assoc., pp. 97-102.

Harington, J. 1972. Chemical factors (incl. trace metals) as etiological mechanisms. *In* Biological Effects of Asbestos, Bogovski *et al.* (eds.), IARC Sci. Pub. No. 8, pp. 304-311.

Hill, J.P. 1976. Legal decisions and opinions in pollution cases: asbestos in water. Environ. Sci. Technol. 10: 235-236.

Kay, G. 1973. Ontario intensifies search for asbestos in drinking water. Water Pollut. Control, 33: 33–35.

Kruse, C.A., P.H. Carey and D.J. Howe. 1974. Silica content of dust from tank ranges. Army Medical Research Lab., Fort Knox, Kentucky, Rep. No. USAMRL-1.

Kuryvial, R.J., R.A. Wood and R.E. Barrett. 1974. Identification and assessment of asbestos emissions from incidental sources of asbestos. Battelle Columbus Laboratories, EPA-650/2-74-087.

Lawrence, J. and W. Zimmermann. 1977. Asbestos in water: mining and processing effluent treatment. J. Water Pollut. Control Fed. 49: 156–160.

Light, W.G. and E.T. Wei. 1977. Surface charge and asbestos toxicity. Nature, 265: 537–539.

Merliss, R. 1971. Talc treated rice and Japanese stomach cancer. Science, 173: 1141-1142.

Monger, J.W.H. and W.W. Hutchison. 1971. Metamorphic Map of the Canadian Cordillera. Geol. Surv. Can. Pap. 70-33, p. 71.

Morgan, A. and L. Cralley. 1972. Chemical characteristics of asbestos and associate trace elements. *In* Biological Effects of Asbestos, Bogovski *et al.* (eds.), World Health Organization and International Agency for Research on Cancer, IARC Sci. Pub. No. 8, pp. 113–118.

Nicholson, W. and F. Pundsack. 1972. Asbestos in the environment. *In* Biological Effects of Asbestos, Bogovski *et al.* (eds.), IARC Sci. Pub. No. 8, pp. 126–130.

Oliver, T. and L.E. Murr. August 1977. An electron microscope study of asbestiform fibre concentrations in Rio Grande Valley water supplies. J. Am. Water Works Assoc., pp. 428–431.

Olson, H.L. September 1974. Asbestos levels in potable water supplies. J. Am. Water Works Assoc., pp. 515–518.

Piper, A. 1976. Tiny straws in the wind. Nature, 261: 271–272.

Pontefract, R.D. and H.M. Cunningham. 1973. Penetration of asbestos through the digestive tract of rats. Nature, 243: 352–353.

Pylev, L.N. and L.M. Shabad. 1972. Some results of experimental studies in asbestos carcinogenesis. *In* Biological Effects of Asbestos, Bogovski *et al.* (eds.), IARC Sci. Pub. No. 8, pp. 99–105.

Redfearn, J. 1977. Asbestos: amplified evidence. Nature, 268: 7–8.

Rohl, A., A.M. Langer and I. Selikoff. 1977. Environmental asbestos pollution related to use of quarried serpentine rock. Science, 196: 1319–1322.

Schmitt, R., D.C. Lindsten and T. Shannon. 1977. Decontaminating Lake Superior of asbestos fibres. Environ. Sci. Technol. 11: 462–465.

Selikoff, I.J. 1974. Epidemiology of gastrointestinal cancer. Environ. Health Perspect. 9: 299–305.

Selikoff, I.J., J. Churg and E.C. Hammond. 1964. Asbestos exposure and neoplasia. J. Am. Med. Assoc. 188: 22–26.

Skikne, M.I., J.H. Talbot and R. Rendall. 1971. Electron diffraction patterns of U.I.C.C. asbestos samples. Environ. Res. 4: 141–145.

Speil, S. and J.P. Leineweber. 1969. Asbestos minerals in modern technology. Environ. Res. 2: 166–201.

Stanton, M.F. 1974. Fibre carcinogenesis: Is asbestos the only hazard? J. Nat. Cancer Inst. 52: 633–634.

Stewart, I. 1976. Asbestos in the Water Supply of the Ten Regional Cities. Part I, W.C. McCrone Associates Inc., for EPA-560/6-76-017, pp. 1–58.

Stewart, I., R.E. Putscher, H.J. Humecki and R.J. Shimps. 1976. Asbestos Fibres in Natural Runoff and Discharges from Sources Manufacturing Asbestos Products. Part II, Non-Point Sources and Point Sources Manufacturing Asbestos Products. W.C. McCrone Associates Inc., for EPA-560/6-76-020.

Storeygard, A.P. and A.L. Brown. 1977. Penetration of the small intestinal mucosa by asbestos fibres. Mayo Clin. Proc. 52: 809–812.

The Canada Gazette. May 20, 1978. Part I: 3012.

Thomson, R., I. Webster and T. Kilroe-Smith. 1974. The metabolism of benzo (a) pyrene in rat liver microsomes: the effect of asbestos-associated metal ions and pH. Environ. Res. 7: 149–157.

Timbrell, V. 1972. Physical factors in etiological mechanisms. *In* Biological Effects of Asbestos, Bogovski *et al.* (eds.), IARC Sci. Pub. No. 8, pp. 295–303.

Timbrell, V., J.C. Gibson and I. Webster. 1968. U.I.C.C. standard reference samples of asbestos. Int. J. Cancer, 3: 406–408.

Veblen, R.D., P.R. Buseck and C.W. Burnham. 1977. Asbestiform chain silicates: new minerals and structural groups. Science, 198(4315): 359–365.

Vogt, G.O. 1976. Asbestos. *Canadian Minerals Yearbook*. Department of Energy, Mines and Resources, Ottawa.

Wagner, J.C., G. Berry and V. Timbrell. 1973. Mesotheliomata in rats after inoculation with asbestos and other materials. Br. J. Cancer, 28: 173–185.

Wigle, D.T. July/August 1977. Cancer mortality in relation to asbestos in municipal water supplies. Arch. Environ. Health, pp. 185–190.

APPENDIX

LIST OF STREAM WATER SAMPLES ANALYZED FOR ASBESTOS IN BRITISH COLUMBIA AND THE YUKON TERRITORY

Table A-1

Sample location	Data	Fibre concentration (fibres/L)	Mean fibre size (μm)	Organization involved in collection of samples
Vedder River at rwy bridge				
Right bank*	June 10, 1977	2.56×10^8	2.6	W.Q.B.
Right bank	June 10, 1977	2.28×10^8	2.4	W.Q.B.
Left bank*	June 10, 1977	1.41×10^8	3.4	W.Q.B.
Left bank	June 10, 1977	1.05×10^8	3.1	W.Q.B.
Sumas River at border				
Left bank	September 3, 1976	1.5×10^{10}	0.7	W.Q.B.
Centre	September 3, 1976	0.8×10^{10}		W.Q.B.
Right bank	September 3, 1976	1.3×10^{10}		W.Q.B.
Sumas River at border	January 26, 1977	1.0×10^{11}	–	W.Q.B.
Sumas River at border	June 10, 1977	2.4×10^{10}	–	W.Q.B.
Sumas River at border	August 20, 1976	6.2×10^8	–	P.C.B.
Sumas River above Swift Creek	September 20, 1977	4.9×10^8	1.26	W.Q.B.
Sumas River below Swift Creek	September 20, 1977	3.1×10^{10}	(0.5–2.0)	W.Q.B.
Fraser River at Mission City				
Left bank	June 10, 1977	9.4×10^8	–	W.Q.B.
Centre	June 10, 1977	1.0×10^9	–	W.Q.B.
Right bank	June 10, 1977	1.2×10^9	–	W.Q.B.
Upper Fraser River	November 25, 1977	8.5×10^6	4.0	P.C.B.
Fraser River at Quesnel Bridge	November 25, 1977	3.3×10^7	2.3	P.C.B.
Fraser River at Boston Bar	January 17, 1978	9.9×10^6	2.5	P.C.B.
Fraser River at Mission City	January 17, 1978	2.3×10^8	3.1	P.C.B.
Yukon River at Forty Mile	August 1977	3.3×10^7	2.2	W.Q.B.
Yukon River at U.S. boundary	August 1977	2.0×10^8	1.8	W.Q.B.

*Right and left banks facing downstream.
W.Q.B. = Water Quality Branch (I.W.D.).
P.C.B. = Pollution Control Branch (B.C.).