BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT

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Air quality and climatic effects of the proposed Hat Creek project

Appendix F

The influence of the project on trace elements in the ecosystem

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F1.0 INTRODUCTION

Environmental Research & Technology, Inc. (ERT) has completed this report under the Terms of Reference for Appendix E3 of the Detailed Environmental Studies for the British Columbia Hydro and Power Authority's Hat Creek Project. The primary objective of the project has been to identify those trace elements in Hat Creek coals and source materials that present a potential hazard to Hat Creek and vicinity ecosystems. Pursuant to achieving this important objective project activities have focused on:

1. identifying which of the major trace elements in source materials were apt to be transmitted to biological systems and the potential for trace element enrichment in Hat Creek receptors;

2. ascertaining major sites and modes of uptake and accumulation of important trace elements in Hat Creek flora and fauna and the role of trace elements in the normal functioning of ecosystem components;

3. determining to the extent permitted by the available information, toxic (i.e., poisonous) concentrations, tolerance levels and bioaccumulation factors of selected trace elements in extant biological systems; and

4. developing a literature-derived trace element norm for comparison with existing environmental concentrations.

This information provides a basis for trace element impact assessment, recommendations for mitigation measures, and development of a long-term monitoring program. For impact assessment, all aspects of the Hat Creek Project, including site preparation, coal mining and transport, thermal power plant stack and cooling tower emissions, coal, overburden, and waste rock storage and solid waste disposal have been evaluated with reference to trace elements.

The scope of the study has been limited to "trace elements," defined as any elements in concentrations ranging from the lowest analytical detection limit to 0.1% [1000 mg/kg or parts per million (ppm)]. Throughout the study, the number of elements considered has been progressively reduced from most of the elements in the periodic table to only those of importance in an environmental assessment. This has been done in a series of steps based on analysis of trace elements in existing ecosystem components in the vicinity of the proposed site, analysis of Hat Creek coal, coal ash and stack emissions sampled during test burns, and a literature review of environmental pathways and potential trace element toxicity. In this manner, the report focuses on those elements that are considered significant because of their relatively high concentrations in source materials or waste products, their presence in existing Hat Creek receptors in greater than "normal" concentrations, and/or their identification in the literature as potentially toxic, subject to bioaccumulation, or of other environmental concern.

ERT has evaluated sources of trace elements by using information provided by B.C. Hydro, Ebasco Services of Canada Limited, and other B.C. Hydro consultants. Solid, particulate sources including coal, overburden, ashes, and stack effluents have been directly sampled, especially by means of test burns conducted using Hat Creek coal. Liquids, including leachates and cooling water, have also been sampled and analyzed.

Baseline ecosystem trace element concentrations have been established in a three phase sampling program covering fall 1976, and winter and spring 1977. The 1976 sampling was the most extensive and on these samples a broad element scan was conducted. Analyses of winter and spring samples were for selected elements of concern. At selected sites, samples of surface water, stream sediment, soil, airborne particulates, and various species of vegetation and animal life were taken.

Seventy three elements were analyzed in the first phase of the study. Based on element concentration in source and ecosystem materials, potential element toxicity to biological systems, and potential element mobility through the environment, elements of most environmental concern were selected for additional study. Trace element impact was assessed from a superposition of projected Hat Creek contributions of trace elements to natural or existing concentrations. Use was made of ERT's predictions of trace element atmospheric dispersion of tall stack emissions. The diffusion modeling results are discussed in Appendix B, Modeling Methodology. Also included in this report are discussions of possible mitigation and recommendations of programs to monitor the long term effects of trace elements emanating from project activity. Conclusions derived from project efforts are provided in Section F2.0.

The lack of standard and universally accepted techniques for conducting complex trace element studies must be recognized when evaluating methods and results presented in this report. Wherever possible, most commonly recommended sampling[228] and analytical[229,230,231] methods were used. Methods utilized in this study are documented so that any future investigations in this area can duplicate study techniques and arrive at results that can be compared to data presented in this report.

toxic to vegetation; generally non-toxic to animals; concentrations in sampled receptors compare favorably with literature values.

9. Zinc - concentrated on fly ash particles; high levels in coal, overburden, waste rock, and ash leachates; high potential for bioaccumulation; moderately toxic to vegetation; relatively non-toxic to birds and mammals; concentrations in sampled receptors are similar to levels reported in the literature.

Information summarized above for the elements of concern together with project technical design data and information supplied by other project activities (e.g., air quality modeling) provided the basis for assessing the potential impact of the project on natural trace element concentrations in Hat Creek ecosystems. Projections of ground level concentrations of trace elements emanating from the power plant stack as provided by ERT's air quality model indicate that no appreciable increases in trace element concentrations in biota will result.

Fugitive dust emissions and cooling tower drift will be highly localized and will not be important sources of trace elements to receptors in the Hat Creek area. Overburden, waste rock, and coal ash piles will contain large amounts of some trace elements, such as arsenic, copper and zinc, in water soluble forms. However, current technical design information indicate that elements will be mostly retained either within, or near, storage piles or in seepage treated to remove trace elements.[241]

Radioactive elements (uranium, thorium, and their daughter products) will be emitted along with other trace elements from the power plant. Levels of uranium and thorium in coal from Hat Creek are comparable to amounts in typical coal burned in the United States.[233] Based on predictive model studies recently made in the United States, radiation levels near a 2000 megawatt coal-fired power plant with 99.7% flyash removal are below U.S. guidelines.[234]

Provided that technical design information and data provided by the air quality model are representative and barring any accidents or natural catastrophes, no significant impact on local or regional ecosystems is expected from release of trace elements by the Hat Creek project.

F2.0 SUMMARY

Trace elements existing in coals, overburden, and waste rock will be released to the environment during coal mining and power generating operations of the Hat Creek Project. The primary objective of this study has been to identify those trace elements whose concentrations and distributions in ecosystem components may be potentially affected by project activities. Analysis of source materials (coal, overburden, waste rock and ash disposal pile leachates, fugitive dust emissions, stack emissions from test burns, and projected cooling tower drift), determination of existing trace element concentrations in selected ecosystem receptors, and an extensive literature review of trace element ecology provided the information base for evaluating and selecting elements of major concern. Primary criteria for eliminating all but 21 trace elements as being of concern to the Hat Creek Project were toxicity potential to plants and animals and potential for release and relatively wide distribution from project activities. Of these 21 trace elements, nine were ascertained to be of greatest environmental concern in local ecosystems because of their relatively high concentration in source materials and their potential to be highly mobile or readily accumulated in receptors. These trace elements are arsenic, cadmium, chromium, copper, fluorine, lead, mercury, vanadium, and zinc. Detailed and quantified discussions of these elements in source and ecosystem materials are given in Sections F4.0, F5.0, F6.0, and F7.0. Qualitative summary information for each element is presented below:

1. Arsenic - concentrated on fly ash particles*; relatively high levels in Hat Creek coal, waste rock, overburden, and bottom ash leachates; high mobility in alkaline media (i.e., Hat Creek soils, water, and stream sediment); high potential for bioaccumulation; potentially very toxic to plants and animals; exhibits relatively high natural levels, as compared to values reported in the literature, in receptors sampled, especially soil, stream sediment and small mammals.

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* Unless qualified otherwise, fly ash includes both ash collected by precipitators and ash emitted from the gas stack.

2. Cadmium - slightly concentrated on fly ash particles; high bioaccumulation potential; moderate to high toxicity to plants and animals; natural concentrations are higher than those reported in the literature for soil and stream sediment.

3. Chromium - concentrated on fly ash particles; moderate potential for bioaccumulation; relatively toxic to plants and animals; high concentration in fish and small mammal samples.

4. Copper - concentrated on fly ash particles; relatively high levels in coal, overburden, waste rock, and ash leachates; moderate potential for bioaccumulation; relatively toxic at high concentrations in biota; high concentrations in small mammal samples.

5. Fluorine - relatively high levels in stack emissions; potential for bioaccumulation of airborne fluoride; gaseous fluorine compounds potentially very toxic to plants and animals; concentrations in Hat Creek receptors are higher than values reported in the literature for some soil, stream sediment, and grass samples.

6. Lead - concentrated on fly ash particles; potential for bioaccumulation of airborne lead compounds; moderately toxic to plants and animals; concentrations are higher than literature values for water and small mammal samples.

7. Mercury - emitted from stack primarily as a gas; high potential for bioaccumulation; certain mercuric compounds are very toxic to biota; concentrations are consistent with values in the literature for sampled receptors.

8. Vanadium - concentrated on fly ash particles; mobile in alkaline media; potential for bioaccumulation; moderately

F3.0 METHODOLOGY

F3.1 Sample Collection

Air TSP (total suspended particulates) samples were collected by B.C. Hydro using high volume samplers. Samples were obtained from four sites during spring 1977 in the Hat Creek area and submitted to ERT for trace element analyses (see Figure F3-1).

Samples of coal and coal ash from pilot test burns were provided by Canadian Combustion Research Laboratories.[245] A complete description of these samples is given in Section F4.3. Coal, overburden, waste rock, and coal ash leachate samples were collected and leachate testing performed by Acres Consultants.

Biotic and abiotic samples for trace element analysis were collected from five terrestrial and four aquatic sites during October 1976, and January and May, 1977. Four of the five terrestrial sites were located within a 25 kilometer radius (range of local air quality model) of the plant site and the fifth site (Ashcroft) was located just outside this radius. Aquatic sites were located in Hat Creek and the Bonaparte River. Aquatic Site 1 was located on upper Hat Creek just above the proposed plant site and the No. 1 coal deposit, but near overburden and waste rock storage areas. Aquatic Site 2 was located on lower Hat Creek downstream from the proposed project. Both of these locations may be affected by the project. Sampling locations on the Bonaparte River included Site 3 above Hat Creek and Site 4 below Hat Creek. Except for any deposition of pollutants from the gas stack, Site 3 should not be affected by project activities. Other considerations in sample site location for both aquatic and terrestrial stations were accessability, presence and ease of sampling of desired receptor materials, and availability of supportive information at the site (e.g., air quality data). Terrestrial and aquatic sample site locations are shown in Figure F3-1. Terrestrial site characteristics are provided in Table F3-1.

Criteria considered in selecting receptor materials included: (1) representation of general classes of receptors in the Hat Creek vicinity,

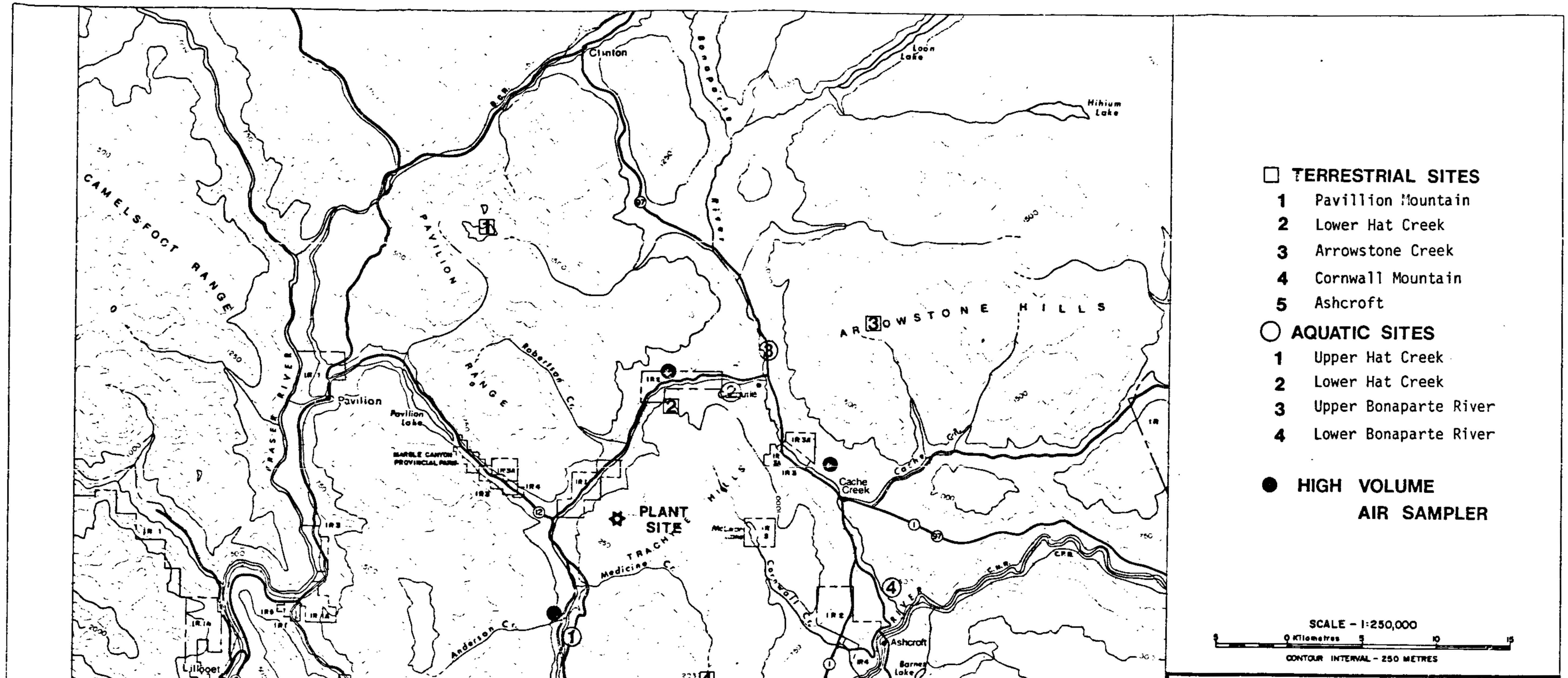

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Figure F3-1. Trace Element Sampling Locations

Table F3-1

Site characteristics of terrestrial trace element sampling locations

Site Number	Name	Elevation (m)	Slope (degrees)	Aspect
1	Pavillion Mountain	2089	20-25	SE
2	Lower Hat Creek	750	<10	SW
3	Arrowstone Creek	1500	20	WSW
4	Cornwall Mountain	2036	<10	NW
5	Ashcroft	1250	10-20	W

(2) importance to ecosystem structure and function (or indicator of the accumulation of selected trace elements), (3) availability, and (4) ease of sampling. Materials collected at each sampling location and primary considerations for these selections are provided in Table F3-2.

Although large mammals and birds are important receptors of trace elements, habitats for these animals range over a wide area. Thus, impacts from the Hat Creek project on these highly mobile animals is difficult to monitor. Additionally, collection of a sufficient number of samples to define trace element levels in these animals is difficult and potentially harmful to existing populations.

At each aquatic and terrestrial site, three samples of each receptor were collected. Samples were collected during fall, winter, and spring. Shrubs, grasses, small mammals, and fish were not collected in winter when plants and animals were generally less available and more difficult to sample. Sampling methodologies are discussed below for each receptor.

1. Water - Three samples were collected from midstream by submerging a 1-liter polypropylene bottle just beneath the surface with the mouth pointed upstream. Bottles had been acid-washed with 10% nitric acid. Samples were fixed with 5 ml of 50% nitric acid at the time of collection and appropriately labeled. Information provided on labels for water and all other samples included type of sampled materials, sample site number and location, date of collection, and collector(s).

2. Soil and Stream Sediment - Samples of soil and stream sediment were collected from the top 5 cm of surface material with an acid-washed stainless steel trowel. Three soil samples were randomly collected from an area of approximately 100 square meters at each site. Stream sediment samples were collected along a 10 meter stretch of the stream. Each sampled contained about 500 cc of material. Samples were double-bagged in clean polyethylene containers and the label placed in the outer bag to avoid contact with sample.

Table F3-2

Receptor materials collected at each sampling location for trace element analysis

Habitat Type	Receptors Sampled	Primary Factor(s) for Selection
Aquatic	Water	Important transmission media
	Stream sediment	Important sink and transmission media
	Rainbow trout *(Salmo gairdneri)*	Economically important game species and aquatic carnivore
Terrestrial	Soil	Important sink and transmission media
	Shrub Willow *(Salix)*	Food source for browsers, abundant throughout study area, easily sampled
	Grass Bunchgrass *(Agropyron spicatum)*	Important food source to grazers (i.e., cattle)
	Sedge *(Carex* sp.)*	Only grass species available for collection at Site 4 (Cornwall Mountain)
	Lichen *(Letharia vulpina)*	Known indicator of trace element pollution
	Small mammals - deer mouse *(Peromyscus maniculatus)* - yellow pine chipmunk *(Eutamias amoenus)* - montane vole *(Microtus montanus)*	Important omnivores, food base for predators

* Only collected at Site 4 (Cornwall Mountain)

3. Vegetation - Above ground (within 3 to 5 cm from the soil) portions of grasses and ends (approximately 30 cm or less) of willow branches, including new stem and leaf growth, were collected by cutting with an acid-washed stainless steel knife. Lichens were hand picked from trees. Plastic disposable gloves were worn to prevent contamination. All samples were randomly collected from an area of approximately 100 square meters. Each sample contained 100 to 200 grams of material. Samples were double-bagged, labeled and cooled to prevent decomposition.

4. Small Mammals - Small mammals were collected by randomly placing Sherman live traps or snap traps baited with oats and peanut butter throughout a 20 to 30 hectare area at each site. Traps were checked daily and each animal collected was placed in a separate Whirl-Pak, double-bagged, labeled and frozen.

5. Fish - Fish were collected by electro-shocking with a "back-pack" shocker. All specimens were small (15 cm or less) rainbow trout and 3 to 5 specimens comprised a single replicate at each site. Approximately 500 to 700 meters of stream were sampled at each location. All fish collected were double-bagged, labeled, and frozen. Fish and small mammals were shipped by air to the laboratory in Fort Collins, Colorado stored in coolers packed with dry ice to prevent decomposition of tissue.

F3.2 Sample Preparation

Although each receptor material required specific kinds of preparation, there were certain procedures that were common to all samples. Field identifications were confirmed upon receipt of samples and all samples, except water, were frozen until preparation. To minimize contamination, only stainless steel, glass or plastic utensils were used during preparation. Additional precautions included washing utensils with 10% nitric acid, rinsing with demineralized water between samples, and using polyethylene gloves. Sample pulverization was done in a Vir Tis "23" homogenizer run at approximately 31,000 rpm and sieving performed with appropriately sized stainless steel sieves. The wet samples were dried at 40°C to avoid loss of volatile elements. After drying and sieving, a subsample was obtained for analysis while the remainder of the prepared material was placed in the laboratory freezer for future reference. All prepared samples were stored in Whirl-Paks. Each subsample was labelled with a different code and these codes were recorded on the work order accompanying the sample to the analytical lab. A cover letter identifying the sample code, project name and number, sample location, type of sample and taxon (where appropriate), was submitted with the sample as well.

In October, three replicates of each parameter from each location were submitted for trace element analysis. For January and May samples, only one replicate was submitted for analysis. Because sampling success dictated type and numbers of fish and small mammals available for analysis, replicates for these parameters were not always homogeneous (Table F3-3). Specific preparation methods for each receptor material are discussed below. Water required no special preparations.

1. Soil and Stream Sediment - Each sample was placed in a plastic petri plate and oven-dried (wet samples only) and lyophilized (vacuum-dried) to total dryness. Dried samples were ground with an agate mortar and pestle and sieved to less than 200 mesh which insured uniformity of the sample. A subsample of approximately 2.0 g was placed in a Whirl-Pak and labelled for submission to the analytical lab.

2. Vegetation - Frozen samples were carefully sorted and all extraneous materials removed to insure composition uniformity. Approximately 12 g of wet tissue were cut into 3 cm segments and placed in plastic petri plates, oven-dried, and lyophilized. Dried tissues were then pulverized and sieved through 100 mesh screens. The resulting material was then subsampled (about 1 to g) into Whirl-Paks and coded for submission to the analytical lab.

Table F3-3

Composition of fish and small mammal samples submitted for trace element analysis

	Aquatic sites			
	1	2	3	4
October 1976	rep 1 = 3 rainbow trout	rep 1 = 2 rainbow trout	- *	rep 1 = 1 rainbow trout
	rep 2 = 3 rainbow trout	rep 2 = 2 rainbow trout	-	rep 2 = 1 rainbow trout
	rep 3 = 3 rainbow trout	rep 3 = 2 rainbow trout	-	rep 3 = 1 rainbow trout
May 1977	rep 1 = 1 rainbow trout	rep 1 = 1 rainbow trout	-	

	Terrestrial sites				
	1	2	3	4	5
October 1976	rep 1 = 1 deer mouse	rep 1 = 3 deer mice	rep 1 = 1 deer mouse	rep 1 = 2 deer mice	rep 1 = 2 deer mice
	rep 2 = 1 deer mouse	rep 2 = 3 deer mice	rep 2 = 1 vole	rep 2 = 1 deer mouse	rep 2 = 2 deer mice
	rep 3 = 1 vole	rep 3 = 3 deer mice	rep 3 = 1 least chipmunk	rep 3 = 1 deer mouse	rep 3 = 1 least chipmunk
May 1977	rep 1 = 2 deer mice	rep 1 = 3 deer mice	rep 1 = 2 deer mice	rep 1 = 3 deer mice	rep 1 = 2 deer mice

* - indicates no sample could be collected due to high water levels

3. Small Mammals - Thawed animals were skinned (leaving nails and tail), gutted to remove any unassimilated trace element material, and then quartered to increase surface area. Each animal was placed in a plastic petri plate and lyophilized to a constant dry weight. In most instances, composite samples of at least 3 specimens were made before pulverization. After pulverizing, the composite sample was sieved through a 100 mesh screen and subsampled (about 1 to g) for submission to the analytical lab.

4. Fish - At least 30 g wet-weight was required for each sample. Due to small size of fish collected in October 1976, entire gutted fish had to be used for trace element analysis. Longer fish were collected in May 1977 and a square area of axial musculature was removed posterior to the pelvic fins on both sides of each fish. The skin from this area was carefully removed and chunks of muscle cut into smaller pieces to facilitate drying. Samples were oven-dried and lyophilized to complete dryness. Sieving was done through a 100 mesh screen and a subsample obtained for submission to the analytical lab.

F3.3 Sample Analysis

Spark source mass spectrometry, atomic absorption spectrophotometry, plasma atomic emission spectroscopy, and specific ion electrode techniques were employed to analyze the various samples involved in the B.C. Hydro trace element program. These methodologies were selected in order to provide the most comprehensive coverage possible, accuracy, and detection limits compatable with the elements of concern. A description of each methodology is presented below.

All samples collected in October 1976 were analyzed by spark source mass spectrometry except water, which was analyzed using plasma emission spectroscopy. Since plasma emission spectroscopy is a relatively new and not widely used analytical technique, it was decided that January water samples should be analyzed using mass spectrometry. Mass spectrometry gave very satisfactory results (see Section F4.3) when used to analyze pilot test burn coal and ash samples. Other January samples and all May samples were analyzed for selected trace elements by atomic absorption spectroscopy.

(a) Spark Source Mass Spectrometry

Analysis preparation began by subsampling materials and transferring the subsample to a porcelain dish. The sample was inserted into a cold muffle furnace and heated gradually, with occasional stirring, until the temperature reached 300°C (about an hour) and then 500°C (2 hours). Heating was continued until all carbonaceous material had disappeared. The resulting ash was removed, cooled and thoroughly ground in a clean agate, mullite, or tungsten carbide mortar. The ash was reignited at 750°C for 1 hour, cooled rapidly, and immediately weighed. Approximately 3 g of material was needed for analysis.

Seventy elements were analyzed using spark source mass spectrometry. Because of its high volatility, mercury was measured by flameless atomic absorption spectrophotometry. Lead was also measured by atomic absorption because lead measurements by mass spectrometry are often inaccurate (Jacobs, personal communication). Fluorine, another volatile element, was measured by specific ion electrode methods. Standards for quality control were prepared from certified reagent grade chemicals or high purity metals.

For analysis, sample materials with particle size of 200 mesh or less were mixed with ultrapure graphite powder. A known amount of indium, also mixed into this powder, provided an internal reference standard. This powdered mixture was compacted in a press to form a solid pellet that was introduced into the mass spectrometer. After a vacuum was applied, a 20 to 30 thousand kilovolt radio frequency was used to strip electrons from trace elements on the pellet. Elements were accelerated by an electromagnetic field in a manner depending upon their mass to charge ratio. Sensitive photoplates were used to record tracks of the elements as they passed through the electromagnetic field. Photoplates were then developed and a "just disappearing line" technique (visual estimation of length of element lines) was used to calculate concentrations of various trace elements by comparison to the indium reference lines. Detection limits for solid phase materials, such as coal and ash, ranged from approximately 0.05 to 0.1 mg/kg up to 1000 mg/kg. Uncertainties of results in the <1 to 1 mg/kg concentration range were estimated to be ± 100% whereas uncertainties at the 100 mg/kg level were estimated to be ±50% of the reported concentration.

(b) Atomic Absorption Spectrophotometry

Very often it is advantageous to measure and monitor selected trace elements by the method of atomic absorption spectrophotometry. In general, this method is used to provide more accurate data on only specific elements which are of importance.

The principles of atomic absorption spectroscopy are similar to other flame emission photometry techniques in that a sample is aspirated into a flame and atomized. Atomic absorption spectroscopy is generally much more sensitive because it depends on the measurement of free unexcited atoms by absorption of light through the flame rather than the measurement of amount of light emitted which can be affected by overlapping and interferences by other atoms. In atomic absorption, because each metallic element has its own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free of spectral or radiation interferences. The amount of light absorbed in the flame is therefore proportional to the concentration of the element in the sample. Sample preparations vary depending upon the form in which it is collected (i.e., animal tissue, plant tissue, water, air particles, etc.). In general all preparations ultimately produce an acid solution containing dissolved elements. This solution is then aspirated in the atomic absorption instrument. The exact methodology for solution preparation utilized in this study is presented below.

Analytical preparations were initiated with the transfer of 1.0 g of sample to a 150 ml beaker. Ten ml of water and 10 mg HNO_3 were then added. The beaker was covered with a watch glass, placed on a shaking hot plate, and boiled until the volume of the solution was reduced to about 5 ml. The beaker was removed from the hot plate and the sides of the beaker and lid washed down with about 20 ml water. The beaker was then placed on a steam bath and the contents digested for 1 hour. The contents of the beaker were transferred to a 50-ml volumetric flask, cooled, and diluted to volume with water. The solids were allowed to settle overnight. A portion of the clear sample solution was aspirated into the air-acetylene flame of the atomic absorption instrument using deuterium background correction. Analytical techniques specific to each receptor material are described below:

1. Soil and Stream Sediments - Materials were crushed by mortar and pestle and a 1 g subsample was transferred to a Pyrex beaker. This sample was then dissolved with a mixture of nitric, perchloric and hydrofluoric acids and the solution diluted to 50 ml with deionized water. These samples and standard solutions, prepared by diluting the pure metal salt in an equivalent concentration of the same mineral acids, were then aspirated into the atomic absorption unit.

2. Vegetation - From each ground sample, a subsample of 1 g was weighed into a Pyrex beaker. The organic matter was digested by a mixture of nitric and perchloric acid at low heat. When all the organic matter was removed, the acid solution was diluted to 50 ml with deionized water. Vegetation samples and standard solutions were then measured in the atomic absorption unit.

3. Small Mammals and Fish - Sample preparation for these materials was conducted in the same manner as vegetation samples.

(c) Plasma Atomic Emission Spectroscopy (PES)

Plasma atomic emission spectroscopy (PES) provides multi-element determinations in concentration ranges of greater than 100,000 mg/kg without adjustment, operator intervention or sample manipulation. Several widely diverse types of samples can be analyzed for multi-elements with sensitivity at the ppb (parts per billion) level. This technique is also an improvement over other techniques in that PES is virtually free of chemical interferences. PES is an inductively coupled argon plasma excitation for multi-element determinations of trace metals in solution. The basis of the method is atomic emission promoted by coupling the sample, nebulized to form an aerosol, with high temperature inert argon gas produced by passage of argon through a powerful radio-frequency field. Radiation from the plasma, defined by an entrance grating slit (60,000 grooves/in) to the spectrometer, is dispersed by the grating and selected wavelengths. Photomultipliers (a separate one for each element) transduce and fingerprint elements of interest. Results are reported directly as concentration of each element. Analyses of several elements in the same aqueous solution are at μg/kg (ppb) levels for most with precisions of better than ±1% at the 1 mg/kg (ppm) level on a short-term basis and greater than ±2% over a three hour period.

The advantages of this system include low detection limits, large linear dynamic range and relative freedom from matrix effects. The detection limits for the 20 elements generally analyzed are presented in Table F3-4. Detection limits are reported in μg/l (ppm) and represent the concentration of that element necessary to produce a signal twice the standard deviation of the background noise. Another useful approach, which is similar to the lower optimum concentration range reported for atomic absorption use, is the lowest quantitative determinable concentration (LQD). The LQD is defined as the amount of material necessary to produce a signal that is 10 times the standard deviation of the noise in the system (i.e., 5 times the detection limit). The LQD for the 20 elements are also shown in Table F3-4.

Sample preparation prior to PES analysis is identical to that reported for atomic absorption. Subsamples of at least 1 g or more from vegetation and animal tissue preparations and at least 100 ml of aqueous solutions were digested by the addition of 3 ml of concentrated nitric acid in a Griffin beaker. The beaker was covered with a ribbed watch glass and carefully heated to dryness on a hot plate. After cooling, an additional 3 ml of concentrated nitric acid were added and the beaker was heated to a gentle boil.

Table F3-4

Mean detection limits (DL) and lowest quantitatively determinable concentrations (LQD) for 20 trace elements by plasma atomic emission spectroscopy

Element	DL* ug/1 (ppm)	LQD** µg/1 (ppm)
Ag	4	20
Al	7	35
B	3	15
Ba	1	5
Ca	<0.5	1
Cd	2	10
Co	4	20
Cr	1	5
Cu	1	5
Fe	2	10
Mg	<0.5	1
Mn	1	5
Mo	5	25
Ni	15	75
Pb	12	60
Sn	12	60
Ti	1	5
V	1	5
Y	~1	5
Zn	1	5

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* Detection limit; the amount of material that will produce a signal that is twice as large as the standard deviation of the noise.

** Lowest quantitatively determinable concentration; five times greater than the DL and the lowest concentration that can be reported.

To the warm nitric acid mixture, 5 ml of 1:1 hydrochloric acid was added while stirring and the volume was increased with 100 ml of deionized water. The sample was then introduced into the PES instrument for analysis. Prepared standard solutions were processed through the same procedures and analyzed along with the other samples.

(d) Specific Ion Electrode Method

Fluorine was determined by a fluorine specific-ion electrode method. In this procedure 0.25 g of sample were mixed in a zirconium crucible with a slurry of MgO and $MgNO_3$. The mixture was dried at 110°C and then ashed in a muffle furnace which was gradually raised to 525°C. The ashed mixture was fused with 1.0 g NaOH over an open burner with the zirconium crucible covered. The crucible and lid were placed in a plastic beaker, water was added to dissolve the fused mass, and the solution was then filtered into a 100 ml volumetric flask. The residue was washed with about 5 ml of a 1% v/v solution of NaOH, diluted to volume with water and mixed. A 50 ml portion of the sample solution was transferred to a 100 ml volumetric flask, diluted to volume with 1 M ammonium citrate solution and mixed. Fifty milliliters of this solution were poured into a plastic beaker and the potential was measured using the specific ion electrode and meter. In some cases, about 10 minutes were required before a constant reading was obtained. The limit of determination of the method is about 20 mg/kg.

F3.4 Data Analysis

Results of the analysis of trace element concentrations in selected Hat Creek receptors were entered on magnetic cassette tapes under control of a special data base management program developed for a Hewlett-Packard 9830A calculator. All inputs were double-checked and verified before storing them on tape. Analysis programs were generated that provided means and estimates of the variation (i.e., standard error) for specific trace elements in each receptor at a site and over all sites. As sample size was low (i.e., 3) the calculated mean concentration and associated variance may not be truly indicative of real population trace element levels and ranges.

Nevertheless the sampling intensity is sufficient to identify trace elements which, because of higher than normal levels, warrant subsequent consideration. Furthermore, estimated variances provide a reasonable basis for projecting sample sizes required to detect desired levels of response of trace element concentration in sampled material; information essential to a sound monitoring program design (Section F9.0).

F4.0 SOURCES OF TRACE ELEMENTS

Principal source materials of trace elements associated with the coal mine are coal, overburden, and waste rock. Coal burned in the power plant results in various forms of ash and gaseous emissions that are major sources of trace elements. Distribution of water-soluble trace elements in various source materials was determined by leachate tests on coal, overburden, waste rock, and ashes. Analysis of test burn samples provided means for determining trace element distributions from the input coal, output ash from the boilers, and emissions from the stack. Trace element content of cooling tower drift was also estimated.

F4.1 Leachable Source Materials

Overburden and waste rock from the mine and ash from the power plant will be placed in various above ground storage piles or basins where weathering and chemical reactions can dissolve various trace elements. To estimate amounts of water-soluble trace elements contained in coal, overburden, waste rock, and ash, salt extraction tests were performed on crushed test materials (Table F4-1).[247] For those trace elements analyzed, arsenic (As), boron (B), chromium (Cr), copper (Cu), fluorine (F), and zinc (Zn) had the highest concentration in the water extract. To estimate potential water-soluble weights of various trace elements that would exist in overburden and waste rock storage piles, total weights of materials to be stored in these piles[196] were multiplied by water soluble concentrations as listed in Table F4-1. Results of these calculations (converted from mg to metric tons) indicated that several thousand metric tons of water-soluble trace elements will exist in these storage piles (Table F4-2). Since the relative amount of coal with a particular heating value that will exist in the storage pile is not known and will likely vary with time, the average value of extractable salts from samples of coals A, B, and C (low, medium and high heating value, respectively) was calculated and is assumed to be representative of leachate from a storage pile containing all three types of coal. Since fine and coarse tailings will be stored in the same basin, average values for extractable salts from these

Table F4-1

Total extractable salts from various source materials

(concentrations in mg/kg)

					Ash††	
Element	Coal*	Waste Rock**	Overburden***	Wash Plant Tailings†	Fly	Bottom
Aluminum (Al)	14	24	20	18	10	7
Arsenic (As)	0.6	1.0	0.9	0.2	4.3	3.1
Boron (B)	1.0	2.0	1.0	1.1	6.3	0.7
Cadmium (Cd)	<0.08	<0.08	<0.08	0.03	0.02	0.06
Chromium (Cr)	<1	<1	1.3	<1.2	<1	<1
Copper (Cu)	6.2	4	2.8	2.1	0.2	0.2
Fluorine (F)	<1	2.4	<0.4	9.1	55	7
Iron (Fe)	34	76	23	46	1	1
Lead (Pb)	<3	<3	<3	<3	<3	<3
Mercury (Hg)	0.006	0.006	0.01	<0.003	<0.002	<0.001
Selenium (Se)	0.6	0.2	0.2	0.2	<0.02	<0.01
Strontium (Sr)	<4	<4	<4	<4	<4	<4
Vanadium (V)	0.2	0.2	<0.2	0.5	1.4	3.8
Zinc (Zn)	10	8.8	8.8	1.4	40	80
pH	7.2	7.9	7.6	5.4	9.4	8.8
Alkalinity (as $CaCO_3$)	1560	1320	1020	650	2600	1110

(Footnotes on following page)

Table F4-1

(CONTINUED)

NOTE: Amount of extractable salt in source materials was determined by agitating 50 g of crushed sample with 250 ml of deionized water. The sample was then centrifuged and filtered and the extract retained. An equivalent volume of deionized water was added to the sample and the procedure repeated. The sample was washed a total of eight times and analyses performed on the combined extract. Results are milligrams extracted per kilogram of solid. Tests were conducted by Acres Consultants, Vancouver, B.C.[247]

* Average for tests on coal A (low heat value), coal B (medium heat value) and coal C (high heat value).

** Samples of waste rock from the 1976 diamond drilling program were selected by Dolmage, Campbell and Associates, Ltd. and composited for test purposes.[247] Samples were composed of boulders, clay shale, mixed detritals and some sandstones.

*** Average for tests on overburden from Bucket Auger Hole 76-1, "TR" samples TR-1 through TR-13, composite 0 to 41 feet and Bucket Auger Hole 76-13, "TR" samples TR-1 through TR-13, composite 0 to 58 feet.[247]

† Average for tests on coarse tailings from 5 gallon pail of "Sample A-Shale" from Birtley tests and fine tailings from 45 gallon drum of "Sample A-Thickener Solids" from Birtley tests.[247]

†† Fly ash from composited samples from test runs 2.1, 4.1, 6.1 (precipitator products) from burns on raw coal A, B and C at Canadian Combustion Research Laboratory.[245] Bottom ash from same test burns.

Table F4-2
Potential amounts (metric tons) of water soluble trace elements in various mine and power plant storage basins

Element	Coal*	Waste Rock**	Overburden***	Ash†
Aluminum (Al)	4,956	17,016	5,860	704
Arsenic (As)	212	709	264	305
Boron (B)	354	1,418	293	358
Cadmium (Cd)	<28	<57	<23	2
Chromium (Cr)	<354	<709	381	<77
Copper (Cu)	2,195	2,836	820	15
Fluorine (F)	<354	1,711	117	3,142
Iron (Fe)	12,036	53,884	6,739	77
Lead (Pb)	<1,062	<2,127	<879	<232
Mercury (Hg)	2	4	3	<0.2
Selenium (Se)	212	142	59	<2
Strontium (Sr)	1,416	<2,836	<1,172	<310
Vanadium (V)	71	142	<59	146
Zinc (Zn)	3,540	6,239	2,578	4,025

NOTE: Water soluble concentrations (mg/kg) from salt extract tests as listed in Table F4-1. Less than symbol (<) reflects detection limit of trace element measurement.

* Total coal required by a 2000 MW plant operating for 35 years at an overall capacity of 65% is about 354 x 10^6 metric tons.[243]

** No. 1 open pit will have 709 x 10^6 metric tons waste rock.[196]

*** No. 1 open pit will have 293 x 10^6 metric tons overburden.[196]

† Collected ash from power plant for 35 year operating period is estimated to be 77.4 x 10^6 metric tons.[243] To utilize salt extraction test data for fly and bottom ash (Table F4-1) in the calculation of water soluble trace elements in ash, percentages are needed for the fly ash and bottom ash in collected ash. Coal ash will likely be 55 to 85% fly ash and 15 to 45% bottom ash.[243] Therefore, assuming median values of 70 and 30% for fly and bottom ash, respectively, calculations of water soluble trace elements in ash can be made utilizing a total collected ash of 77.4 x 10^6 metric tons and salt extraction data in Table F4-1. Trace element weights listed for ash assume that leaching of trace elements from coal by rain or snowmelt will not alter amounts of leachable trace elements in ash. Since leaching of trace elements from coal piles will likely reduce amounts available for leaching from ash, trace element weights listed for ash represent upper limits calculated from available salt extraction tests.

materials were used and assumed to be representative of leachate from waste basins containing these materials. Bottom and precipitated fly ash will be placed in a storage basin where weathering and chemical reactions can dissolve various trace elements. Coal ash will likely be 55 to 85% fly ash and 15 to 45% bottom ash.[243] Median values of 70% fly ash and 30% bottom ash were used as typical ash distributions for calculating amounts of water soluble trace elements in ash collected during 35 years of plant operation (Table F4-2).

F4.2 Cooling Tower Source Materials

A secondary and localized source of trace elements will be cooling tower drift. As condenser cooling water is recycled, evaporation causes salt concentrations to increase in the circulating water. A small portion of this concentrated water is carried to areas near the cooling towers as winds disperse some of the water away from the towers. It is predicted that Thompson River water, the source of cooling water for the power plant, will be concentrated by a factor of about 14 as it is recycled through the cooling system.[242] Chemical characteristics of Thompson River water and cooling tower drift for a recirculation build-up factor of 14 are listed in Table F4-3. A value of 109 ppm was used for the concentration of dissolved solids in river water. This value was obtained from a water quality study of the Thompson River performed in 1975 by the Calgon Corporation. Studies performed by Environment Canada indicate that levels of total dissolved solids in the river are generally less than this value of 109 ppm. Thus, concentrations listed in Table F4-3 represent likely worst-case trace element concentrations in drift based solely on evaporative water losses in the cooling cycle. These estimates do not include any contribution from corrosion inhibitors (e.g., chromates) or corrosion products (e.g., oxides of Cu and Zn). Predicted amounts of various trace elements that would be contained in cooling drift are also listed in Table F4-3.

F4.3 Power Plant Source Materials

Coal is essentially a colloidal suspension of noncombustible matter in a complex of both volatile and nonvolatile organic compounds. Trace elements

TABLE F4-3

Chemical characteristics of cooling water and cooling tower drift

Element	Thompson River* (mg/l)	Cooling Tower Drift** (mg/l)	Predicted amount in drift (kg/yr)***
Total dissolved solids (TDS)	109	1526	155,652
Arsenic (As)	0.05	0.7	71
Cadmium (Cd)	0.005	0.007	7.1
Chromium (Cr)	0.002	0.028	2.9
Copper (Cu)	0.01	0.14	14
Fluoride (F)	0.1	1.4	142
Lead (Pb)	0.05	0.7	71
Mercury (Hg)	0.001	0.014	1.4
Vanadium (V)	0.006	0.084	9
Zinc (Zn)	0.031	0.43	44

* Thompson River will be source of cooling water; TDS value from a 1975 study; trace element values from samples collected in May 1977.

** Cooling water recirculation buildup factor assumed to be 14.[242]

*** Estimated drift is 194 liters/minute; see Appendix D - Assessment of Atmospheric Effects and Drift Deposition due to Alternate Cooling Tower Designs.

found in both the noncombustible portion, called ash, and the organic complex can be released to the environment during power generating operations. The emissions of trace elements from the power plant are expected to be specific to the Hat Creek coal and the power plant design. In order to estimate emissions to the atmosphere from the power plant a knowledge of coal, combustion and emission control, and operating characteristics is necessary. From this information a pathway or estimated material balance of trace elements can be traced from the mine to eventual stack emissions.

The trace element material balance cannot with today's knowledge be predicted from theory alone. Too many variables are present in the processes involved. Since empirical tests are also very necessary for engineering design of the power plant, B.C. Hydro expanded the already planned test burns of Hat Creek coal to include trace element measurements.

Two test burns have been conducted. The first, a pilot test burn, was performed in January 1977 by the Canadian Combustion Research Laboratory (CCRL).[245] A small amount of coal was obtained from the Hat Creek mine site and was burned to evaluate coal combustion characteristics and the solid trace element residues. A complete material balance, equating trace element measured inputs with measured outputs, was not possible. This test did provide a preliminary set of fly ash emission samples for trace element analysis.

The second trace burn, conducted at the Battle River power plant in Alberta, Canada in August 1977, was designed to be a full-scale test of Hat Creek coal.[241] State-of-the-art trace element analysis of emissions were included. Again because of engineering design of the test power plant, a complete material balance was not possible.

These two test burns provide empirical data on the results of burning Hat Creek coal. Given additional data to determine the representativeness of the coal tested in comparison to the expected mean coal for the Hat Creek power plant operations and to scale the tested emissions to the full-scale Hat Creek plant, reasonably reliable estimates of trace element emissions can be obtained. This section will present that data and the resulting emission estimates.

Because of the complexity of the calculations of projected emissions, the assumptions necessary to simplify the analysis, the natural variability of the parameters used and the small sample sizes, the presented calculated full-scale emissions are indeed estimates. It is not possible to mathematically calculate the uncertainty in the emissions given in this report, but their value for evaluating the Hat Creek Project can be determined (see ERT main report - Air Quality and Climatic Effects of the Proposed Hat Creek Project).

Throughout the analyses, conservatism in favor of overpredicting emissions has been maintained. Where doubt--due to analytical sensitivity or design incompleteness, for example--has been encountered, the element of concern has been assumed to be a part of the emission stream. Every effort has been taken to simulate the Hat Creek power plant at full continuous load as the worst case. The emissions are therefore expected to be maxima.

The next three subsections will further describe the test burns, review the Hat Creek coal analyses and present the emission estimates, respectively.

(a) Test Burns

(i) CCRL Test Burn

At the direction of B.C. Hydro, CCRL conducted pilot scale test burns of the Hat Creek coal in January 1977.[245] Samples of crushed coal, pulverized composite coal, furnace bottom ash, precipitator ash and filter samples of fly ash from the exit flue gas from this test were provided to ERT by B.C. Hydro for trace element analysis. Table F4-4 lists the characteristics of test operations for which trace element samples were included.

Samples from tests 2.2, 4.2, 5.2, and 6.2 were analyzed because 3% excess oxygen was a basic design feature of the planned boilers and type A, B, and C Hat Creek coal would be represented along with one sample of washed coal (B.C. Hydro, personal communication with M. Tennis). The samples have the following characteristics and significance to trace element studies:

Table F4-4

Characteristics of various coal samples and CCRL test burn conditions

Test Number	Coal type (heating value)*	Drying	Washing	Excess oxygen
2.2	A	double	raw	3
4.2	B	twice	raw	3
5.2	B	double	washed	3
6.2	C	double	raw	3

NOTE: Details of the test burn are provided in CCRL report.[245]

* Coal type A is classified as having low heat value, coal type B as medium heat value, and coal type C as high heat value.

1. Crushed Coal - Coal was collected by bucket-auger drilling at the Hat Creek mine and crushed. Samples collected represent raw feed coal, unprocessed, and without additives.

2. Pulverized Composite Coal - Withstanding the assumptions addressed later in this report, elemental concentrations in the Hat Creek coal can be determined from the composite coal samples, which represent pulverized input coal to the test burn.

3. Furnace Bottom Ash - The ash samples are of unburned coal components that fall to the bottom of the furnace. They have been collected from a sluice system and thus have been "washed" to some extent. No samples of the wash liquor were available for analysis.

4. Electrostatic Precipitator Ash - These ash samples were collected by the plates of the electrostatic precipitator. They represent the bulk of fine particulates to be captured by the control system.

5. Fly Ash - Filter papers mounted on a probe inserted in the exit flue of the precipitator were used to collect fly ash samples. Isokinetic conditions were maintained. The samples are thus composed of suspended particulate fly ash and are assumed to represent the particulate matter that would be emitted by a power plant burning Hat Creek coal.

Sample Description

Samples were contained in either standard Whirl-Pak containers or on Millipore filters with appropriate plastic holders specific to the 0.45 Millipore filter size. General physical descriptions of samples selected for analysis are given below.

1. Crushed Coal - Crushed coal samples consisted of a fine black mixture. A subsample from each bag was ground by mortar and pestle for about 3 minutes. Approximately 10 g of this evenly

fine-ground material was sealed in another Whirl-Pak and submitted for elemental analysis.

2. Composite Pulverized Coal - All samples appeared black in color and were very fine in particle size. Large sized particles were not found in pulverized coal samples, and as a consequence, no further crushing was deemed necessary. Subsamples consisting of approximately 30% of the total pulverized coal sample were sealed in Whirl-Pak containers and submitted for elemental analysis.

3. Furnace Bottom Ash - Solid unburned matter that settled to the bottom of the furnace was the most varied in composite particle sizes. The consistency of the sample ranged from lumps approximately 1 cm in diameter to very fine particles. Color of the material varied from a mostly light brown to reddish. A subsample of 30% of the original material was transferred to a mortar and ground by pestle for approximately 5 minutes until the sample was of fairly fine composition. A subsample of approximately 10 g was sealed in a Whirl-Pak container and submitted for elemental analysis.

4. Electrostatic Precipitator Ash - This material was a very fine brown or black colored particle mixture. No additional grinding was necessary and subsamples of approximately 30% of the ash were sealed in Whirl-Pak containers and submitted for elemental analysis.

5. Fly Ash - Particulates downstream from the electrostatic precipitator were collected on a Millipore filter which was placed in a Millipore plastic container after sampling. These samples contained very fine particles and if the plastic container top was removed, air currents easily dispersed particles from the filters. As a consequence, plastic containers were simply sealed as received and submitted for elemental analysis.

Element Concentrations in Coal and Ash

Results of elemental analyses for crushed coal, pulverized composite coal, furnace bottom ash, electrostatic precipitator ash and fly ash are presented in Table F4-5. To evaluate the accuracy of the mass spectrometry analysis, certified samples of coal and fly ash from the United States National Bureau of Standards (NBS) were submitted to the laboratory. Results of this quality assurance check for spark source mass spectrometry (SSMS) are listed in Table F4-6. NBS samples are not available for all of the elements likely to be analyzed in coal or fly ash. Instead, the standards check is utilized as a comparison of levels of accuracy among the different techniques which are used for specific elemental analyses. Since most scan techniques, such as mass spectrometry, are utilized in a generally semi-quantitative mode, the analysis of certified standards indicates the relative accuracy of individual element concentration measurements. As discussed in Section F3.3(1) mercury, lead, and fluorine were analyzed by other more quantitative analytical techniques. For other elements, Table F4-6 shows that the SSMS values are conservative, that is, higher than the standards.

Since coal samples were collected for three (3) different heat values (coal A, B, and C), variability in element concentrations among these samples was expected. This variability is summarized in Table F4-7 where mean values and coefficients of variation are listed for coal and ash analyses of coal samples A, B, and C. The washed coal B sample would bias the estimates and was not included in this statistical analysis. These averages and coefficients of variation are based on only one sample from each type, that is, there is no replication of the samples. Variability in elemental concentrations among samples was also observed in various ash types as well as coal. The increased variability of element concentrations in ash material may be a result of variable test burn operating conditions, difficulty in obtaining truly representative samples from large volumes of ash, and sampling and analytical errors. Coefficients of variation range from near zero to 1.18 (118%), but no pattern is discernible. Higher variability for a given element in the coal samples, for example, does not indicate a corresponding large coefficient of variation in the ash samples. With only one coal sample from each type per heat content, it is not possible to statistically distinguish the three

Table F4-5

Element concentrations (mg/kg or ppm) in Hat Creek coal and ash from CCRL test burns

Element	Crushed Coal*				Pulverized Coal				Furnace Bottom				Electrostatic Precipitator				Composite Fly Ash			
	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C
Aluminum	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Antimony	0.6	1	<0.6	<0.4	1	0.4	0.7	1	0.7	<0.3	0.8	1	4	6	2	2	9	16	20	9
Arsenic	12	25	12	11	12	12	8	8	16	4	3	17	110	160	120	62	140	820	380	250
Barium	520	320	700	310	310	350	310	220	MC	MC	700	MC	MC	MC	MC	MC	MC	MC	MC	MC
Beryllium	0.3	0.2	0.2	0.3	0.2	0.4	0.5	0.7	0.7	1	1	0.7	2	2	1	1	0.2	0.2	0.2	0.7
Bismuth	0.3	0.5	≤0.5	0.4	0.4	≤0.2	≤0.3	0.3	≤0.2	≤0.3	0.2	0.3	≤0.9	1	0.8	0.8	0.8	2	3	1
Boron	2	6	6	4	3	8	14	6	9	14	20	8	43	70	63	22	11	20	68	17
Bromine	1	2	2	1	3	1	2	3	0.8	1	0.4	3	6	8	19	5	5	5	36	5
Cadmium	≤0.1	0.7	0.7	0.6	≤0.2	0.3	0.6	0.4	≤0.2	≤0.1	0.3	0.4	1	0.1	0.4	0.5	0.9	4	3	2
Calcium	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Carbon	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Cerium	34	0.9	17	12	21	30	9	20	44	38	40	78	30	45	52	69	34	120	100	79
Cesium	2	2	0.9	1	1	2	0.4	2	11	3	5	6	3	3	4	4	10	7	4	8
Chlorine	9	10	33	34	16	33	82	35	12	8	22	23	63	50	50	42	37	65	800	76
Chromium	34	45	45	61	110	150	55	72	96	11	110	150	230	270	120	340	200	270	400	250
Cobalt	7	6	6	7	9	13	11	4	14	11	19	15	17	27	45	30	20	60	92	91
Copper	66	30	40	19	44	44	22	21	280	39	44	180	150	120	120	88	240	790	520	290
Dysprosium	1	1	2	1	1	2	1	1	4	2	3	3	3	5	2	4	3	8	<0.2	5
Erbium	0.5	0.7	0.5	0.7	0.5	0.8	<0.3	0.6	0.9	1	0.9	1	2	2	0.5	2	2	0.8	<0.2	2
Europium	0.3	0.6	0.6	0.4	0.4	0.5	0.7	0.4	2	0.9	1	1	2	1	0.7	1	1	2	.3	1
Fluorine	180	100	18	22	120	60	30	120	≤30	46	28	38	950	770	370	1030	800	780	502	680
Gadolinium	0.9	1	1	0.3	0.8	1	1	0.8	3	2	2	2	3	3	2	3	2	5	4	3
Gallium	24	10	22	14	12	17	12	13	42	21	26	29	56	45	89	43	87	440	400	180
Germanium	0.4	0.5	0.5	0.4	0.7	0.7	0.4	0.4	0.5	0.3	0.4	0.9	5	6	6	3	3	14	20	10
Gold	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.2	<0.5	<0.5

Table F4-5

(Continued)

Element	Crushed Coal*				Pulverized Coal				Furnace Bottom				Electrostatic Precipitator				Composite Fly Ash			
	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C
Hafnium	0.6	2	2	2	0.9	1	0.3	3	2	2	2	2	3	3	2	3	3	12	<0.2	6
Holmium	0.4	0.9	0.9	0.7	0.6	0.7	<0.3	0.6	2	1	1	2	3	2	0.8	2	1	3	<0.2	2
Hydrogen	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Indium	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD	STD
Iodine	0.3	0.2	0.6	0.4	0.7	1	0.4	0.7	0.2	<0.1	0.2	0.2	2	2	0.6	0.6	1	1	2	1
Iridium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Iron	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Lanthanum	19	12	8	10	15	13	9	13	33	38	40	52	23	36	56	61	36	120	84	120
Lead	3	4	4	4	7	6	3	3	14	7	4	8	21	50	33	24	48	110	110	66
Lithium	23	9	2	7	5	18	17	9	33	46	30	19	180	100	11	41	15	8	24	8
Lutetium	0.1	0.1	<0.1	0.2	0.2	0.2	<0.3	0.2	0.2	0.2	0.2	0.2	0.5	0.6	<0.3	0.5	0.3	0.7	<0.2	0.7
Magnesium	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Manganese	74	100	50	240	30	150	61	53	190	250	160	680	100	710	450	500	270	MC	360	MC
Mercury	0.16	0.11	0.13	0.13	0.14	0.10	0.08	0.09	0.03	0.02	0.2	0.03	1.15	1.88	2.39	1.41	0.61	0.97	1.52	1.36
Molybdenum	2	3	3	6	4	3	4	4	9	7	11	10	14	17	13	8	12	45	52	27
Neodymium	5	7	7	5	7	6	3	4	21	13	24	15	14	13	13	11	13	30	20	60
Nickel	13	27	24	18	27	22	33	16	15	27	40	83	84	140	250	120	110	550	330	220
Niobium	8	6	6	7	15	6	5	8	16	15	20	21	20	35	35	30	27	120	92	62
Nitrogen	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Osmium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Oxygen	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Palladium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Phosphorus	500	130	340	730	500	740	MC	670	650	840	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Platinum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	0.2	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Potassium	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC

Table F4-5

(Continued)

Element	Crushed Coal*				Pulverized Coal				Furnace Bottom				Electrostatic Precipitator				Composite Fly Ash			
	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	NB	C
Praseodymium	3	1	3	1	3	3	1	3	12	3	5	7	6	7	14	7	11	14	20	12
Rhenium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Rhodium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Rubidium	25	10	6	7	17	9	6	9	55	17	17	43	44	30	46	17	57	70	40	47
Ruthenium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Samarium	2	4	3	3	2	3	5	3	9	7	5	9	11	0.7	6	6	12	28	16	11
Scandium	6	8	4	10	7	17	8	3	14	9	11	16	29	20	39	34	15	75	84	31
Selenium	0.9	2	2	2	2	3	1	2	9	4	1	3	5	4	3	4	6	15	8	16
Silicon	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Silver	≤0.1	≤0.3	≤0.3	≤0.2	0.2	0.4	≤0.3	≤0.1	0.2	≤0.2	0.2	≤0.3	0.9	0.6	0.2	≤0.3	0.4	2	4	0.7
Sodium	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Strontium	120	110	210	69	94	170	120	25	340	240	350	320	360	560	960	380	420	940	MC	380
Sulfur	MC	MC	MC	MC	MC	MC	MC	MC	7	110	32	120	MC	MC	800	490	MC	MC	MC	530
Tantalum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.3	<0.1	<0.1	<0.1	<0.1	<0.2	<0.4	<0.3	<0.2	<0.1	<0.2	<0.5	<0.2	<0.5
Tellurium	≤0.1	<0.1	<0.1	≤0.4	≤0.2	<0.1	<0.3	≤0.3	≤0.2	<0.1	≤0.2	<0.2	<0.4	<0.3	<0.2	≤0.5	<0.2	<0.5	<0.2	<0.5
Terbium	0.2	0.3	0.3	0.2	0.2	0.4	0.3	0.3	1	0.5	0.4	0.6	0.9	0.7	0.4	0.9	0.5	1	2	1
Thallium	≤0.3	<0.7	≤0.8	≤0.6	0.4	≤0.6	<0.3	0.6	1	<0.4	0.5	0.5	1	<1	≤0.6	≤0.8	1	≤3	≤4	≤1
Thorium	3	4	5	4	3	2	4	3	14	17	10	11	9	30	5	8	8	17	24	10
Thulium	0.1	0.2	<0.1	0.2	0.1	0.2	<0.3	0.1	0.2	0.2	0.1	0.3	0.4	0.4	0.2	0.3	0.3	0.8	<0.2	0.6
Tin	1	0.9	0.9	0.8	1	1	0.7	1	0.9	0.4	0.4	2	5	3	1	3	5	25	16	11
Titanium	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Tungsten	<0.4	≤2	≤2	≤1	0.7	<1	0.3	0.9	0.9	≤0.8	1	≤1	<3	<2	<1	1	≤1	3	≤8	≤3
Uranium	2	3	3	2	2	2	3	2	7	5	8	7	4	13	4	5	4	9	16	5
Vanadium	120	56	49	81	73	220	110	79	180	150	240	340	380	MC	810	490	490	960	440	MC
Ytterbium	0.6	1	<0.1	1	0.9	1	<0.3	0.9	2	2	<1	2	3	4	<1	3	2	5	<0.2	3

Table F4-5

(Continued)

Element	Crushed Coal*				Pulverized Coal				Furnace Bottom				Electrostatic Precipitator				Composite Fly Ash			
	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C	A	B	WB	C
Yttrium	11	24	19	14	11	17	27	11	31	38	26	53	33	50	70	78	29	160	130	79
Zinc	64	20	16	14	32	34	19	100	83	13	21	88	150	230	180	160	430	970	MC	470
Zirconium	47	75	76	110	95	190	59	81	150	130	140	170	220	570	430	420	380	840	920	350

NOTE: MC indicates major component (> 1000 mg/kg).

NR indicates not reported (element cannot be reliably analyzed by mass spectrometry).

STD indicates that known amount of this element was added to sample for standardization.

* A, B and C are samples of coal designated as being of low, medium and high heating value, respectively.

WB is a washed sample of coal B.

Table F4-6

Results of quality control check using U.S. National Bureau of Standards coal and fly ash standards

	Coal		Fly Ash	
Element	NBS*	SSMS**	NBS*	SSMS**
Aluminum		MC		MC
Antimony		1.0		11
Arsenic	5.9±0.6	6.0	61±6	67
Barium		230		MC
Beryllium	1.5		(12)	10
Bismuth		0.4		0.7
Boron		50		900
Bromine		8.0		8.0
Cadmium	0.19±.03	0.7	1.45±0.06	0.8
Calcium		C		MC
Carbon		NR		NR
Cerium		28		170
Cesium		3.0		17
Chlorine		480		160
Chromium	20.2±.5	61	131±2	160
Cobalt	(6)	13	(38)	24
Copper	18±2	19	28±5	130
Dysprosium		2.0		6.0
Erbium		0.7		3.0
Europium		0.4		2.0
Fluorine		500		200
Cadolinium		1.0		4.0
Gallium		18		95
Germanium		1.0		14
Gold		<0.2		<0.2
Hafnium		2.0		3.0
Holmium		1.0		3.0
Hydrogen		NR		NR
Indium		STD		STD
Iodine		2.0		2.0
Iridium		<0.2		<0.2
Iron	MC	MC		MC
Lanthanum		18		120
Lead	30±9	5.0	70±4	58
Lithium		60		<400
Lutetium		<0.3		0.5
Magnesium		MC		MC
Manganese	40±3	36	493±7	490
Mercury	0.12±.02	0.1	0.14±.01	0.14
Molybdenum		11		36
Neodymium		6.0		32
Nickel	15±1	18	98±3	120
Niobium		11		33
Nitrogen		NR		NR
Osmium		<0.2		<0.2

Table F4-6

(Continued)

Element	Coal		Fly Ash	
	NBS**	CTE***	NBS**	CTE***
Oxygen		NR		NR
Palladium		<0.2		<0.2
Phosphorus		MC		MC
Platinum		<0.2		<0.2
Potassium		MC	(MC)	MC
Praseodymium		2.0		19
Rhenium		<0.2		0.2
Rhodium		<0.2		<0.2
Rubidium		19	(112)	310
Ruthenium		<0.2		<0.2
Samarium		2.0		7.0
Scandium		6.0		19
Selenium	2.9±.3	3.0	9.4±.5	12
Silicon	(MC)	MC		MC
Silver	(<0.1)	<0.2		0.3
Sodium		MC		MC
Strontium		140	(MC)	MC
Sulfur		MC		MC
Tantalum		<0.2		1.0
Tellurium	(<0.1)	<0.2		<0.2
Terbium		0.4		1.0
Thallium	0.59±.03	<0.8	(4)	6.0
Thorium	(3)	3.0	(24)	25
Thulium		0.2		0.4
Tin		2.0		3.0
Titanium	(800)	MC		MC
Tungsten		<1.0		2.0
Uranium	1.4±.1	<2.0	11.6±.2	7.0
Vanadium	38±8	64	214±8	430
Ytterbium		<1.0		2.0
Yttrium		<1.0		2.0
Zinc	37±4	19	210±20	310
Zirconium		55		370

NOTE: Numerical values are in mg/kg (ppm).

MC indicates major component (1000 mg/kg).

NR indicates not reported (element cannot be reliably analyzed by mass spectrometry).

STD indicates that known amount of this element was added to sample for standardization.

() Indicates that standard concentration is given, but not certified by NBS.

• Concentrations in sample as certified by NBS (U.S. National Bureau of Standards).

** Concentrations in NBS sample as analyzed with spark source mass spectrometry by CTE (Commercial Testing Laboratories, Inc.) laboratories.

Table F4-7

Mean concentrations (mg/kg or ppm) and coefficients of variation (CV) for element concentrations in coal and ash from the CCRL test burn

Element	Crushed Coal		Pulverized Coal		Furnace Bottom Ash		Electrostatic Precipitator Ash		Composite Fly Ash	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Aluminum	MC	--	MC	--	MC	--	MC	--	MC	--
Antimony	<0.7	0.46	0.8	0.43	0.7	0.53	4.0	0.50	11.3	0.36
Arsenic	16.0	0.49	10.7	0.22	12.3	0.59	110	0.44	403	0.90
Barium	384	0.31	293	0.23	MC	--	MC	--	MC	--
Beryllium	0.3	0.22	0.4	0.58	0.8	0.22	1.7	0.35	0.4	0.79
Bismuth	0.4	0.25	< 0.3	0.33	< 0.3	0.22	< 0.9	0.11	1.3	0.51
Boron	4.0	0.50	5.7	0.44	10.3	0.31	46.7	0.51	16.0	0.29
Bromine	1.3	0.43	2.3	0.49	1.6	0.76	6.3	0.24	5.0	--
Cadium	<0.5	0.69	<0.3	0.33	<0.2	0.65	0.5	0.85	2.3	0.68
Calcium	MC	--	MC	--	MC	--	MC	--	MC	--
Carbon	NR	--	NR	--	NR	--	NR	--	NR	--
Cerium	15.6	1.08	23.7	0.23	53.3	0.40	48.0	0.41	77.7	0.55
Cesium	1.7	0.35	1.7	0.35	6.7	0.61	3.3	0.17	8.3	0.18
Chlorine	24.3	1.06	28.0	0.37	14.3	0.54	51.7	0.21	59.3	0.34
Chromium	63.3	0.31	110	0.35	85.7	0.82	280	0.28	240	0.15
Cobalt	6.7	0.09	8.7	0.52	13.3	0.16	24.7	0.28	57.0	0.62
Copper	38.3	0.64	36.3	0.37	166	0.73	119	0.26	440	0.69
Dysprosium	1.0	--	1.3	0.43	3.0	0.33	4.0	0.25	5.3	0.47
Erbium	0.6	0.18	0.6	0.24	1.0	0.86	2.0	--	1.6	0.43
Europium	0.4	0.35	0.4	0.13	1.3	0,47	1.3	0.43	1.3	0.43
Fluorine	100	0.78	100	0.35	<38.0	0.21	916	0.15	753	0.09
Gadolinium	0.9	0.11	0.9	0.13	2.3	0.25	3.0	--	3.3	0.46
Gallium	16.0	0.45	14.0	0.19	30.7	0.35	48.0	0.15	235	0.78
Germanium	0.4	0.13	0.6	0.29	0.6	0.54	4.7	0.33	9.0	0.62
Gold	<0.1	--	<0.1	--	<0.1	0.43	<0.3	0.57	<0.4	0.43

Table F4-7

(Continued)

Element	Crushed Coal		Pulverized Coal		Furnace Bottom Ash		Electrostatic Precipitator Ash		Composite Fly Ash	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Hafnium	1.5	0.53	1.6	0.73	2.0	--	3.0	--	7.0	0.65
Holmium	0.7	0.38	0.6	0.09	1.7	0.35	2.3	0.25	2.0	0.50
Hydrogen	--	--	--	--	--	--	--	--	--	--
Indium	STD	--	STD	--	STD	--	STD	--	STD	--
Iodine	0.3	0.33	0.3	0.22	<0.2	0.35	1.5	0.53	1.0	--
Iridium	<0.1	--	<0.1	--	<0.1	0.43	<0.3	0.57	<0.4	0.43
Iron	MC	--	MC	--	MC	--	MC	--	MC	--
Lanthanum	13.7	0.35	13.7	--	41.0	0.24	40.0	0.48	52.1	1.18
Lead	3.7	0.16	5.3	0.39	9.7	0.39	31.7	0.50	74.7	0.43
Lithium	13.0	0.67	10.7	0.62	32.7	0.41	107	0.65	10.3	0.39
Lutetium	0.2	0.5	0.2	--	0.2	--	0.5	0.11	0.6	0.41
Magnesium	MC	--	MC	--	MC	--	MC	--	MC	--
Manganese	138	0.65	77.7	0.82	356	0.67	436	0.71	>756	0.56
Mercury	*0.1*	*0.19*	*0.1*	*0.24*	*0.0*	*0.22*	*1.5*	*0.25*	*1.0*	*0.38*
Molybdenum	3.7	0.57	3.7	0.16	8.7	0.18	13.0	0.35	28.0	0.59
Neodymium	5.7	0.20	5.7	0.27	16.3	0.25	12.7	0.12	34.3	0.69
Nickel	19.3	0.37	21.7	0.25	41.7	0.87	114	0.25	293	0.78
Niobium	7.0	0.14	9.7	0.49	17.3	0.19	28.3	0.27	69.7	0.67
Nitrogen	--	--	--	--	--	--	--	--	--	--
Osmium	< 0.1	--	< 0.1	--	< 0.1	0.43	< 0.3	0.57	< 0.4	0.43
Oxygen	--	--	--	--	--	--	--	--	--	--
Palladium	< 0.1	--	< 0.1	--	< 0.1	0.43	< 0.3	0.57	< 0.4	< 0.43
Phosphorus	453	0.67	636	0.19	> 830	0.21	MC	--	MC	--
Platinum	<0.1	--	<0.1	--	<0.2	0.35	<0.3	0.57	<0.4	0.43
Potassium	MC	--	MC	--	MC	--	MC	--	MC	--

Table F4-7

(Continued)

Element	Crushed Coal		Pulverized Coal		Furnace Bottom Ash		Electrostatic Precipitator Ash		Composite Fly Ash	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Praseodymium	1.7	0.69	3.0	--	7.3	0.61	6.7	0.09	12.3	0.12
Rhenium	0.1	--	< 0.1	--	< 0.1	0.43	< 0.3	0.57	< 0.4	0.43
Rhodium	< 0.1	--	< 0.1	--	< 0.1	0.43	< 0.3	0.57	< 0.4	0.43
Rubidium	14.0	0.69	11.7	0.40	38.3	0.51	30.3	0.45	58.0	0.20
Ruthernium	< 0.1	--	< 0.1	--	< 0.1	0.43	< 0.3	0.57	< 0.4	0.43
Samarium	3.0	0.33	2.7	0.22	8.3	0.14	5.9	0.87	17.0	0.56
Scandium	8.0	0.25	9.0	0.80	13.0	0.28	27.7	0.26	40.3	0.77
Selenium	1.6	0.39	2.3	0.25	5.3	0.60	4.3	0.13	12.3	0.45
Silicon	MC	--	MC	--	MC		MC	--	MC	--
Silver	< 0.2	0.50	<0.2	0.65	< 0.2	0.25	< 0.6	0.5	1.0	0.82
Sodium	MC	--	MC	--	MC	--	MC	--	MC	--
Strontium	99.7	0.27	96.3	0.75	300	0.18	416	0.30	580	0.54
Sulfur	MC	--	MC	--	79.0	0.79	>830	0.35	>843	0.32
Tantalum	< 0.1	--	< 0.1	--	< 0.1	0.43	< 0.3	0.57	< 0.4	0.43
Tellurium	< 0.2	0.87	< 0.2	0.50	< 0.2	0.35	< 0.4	0.25	< 0.4	0.43
Terbium	0.2	0.25	0.3	0.33	0.7	0.38	0.8	0.14	0.8	0.35
Thallium	< 0.5	0.39	< 0.5	0.22	< 0.6	0.51	< 0.9	0.12	< 1.7	0.69
Thorium	3.7	0.16	2.7	0.22	14.0	0.21	15.7	0.79	11.7	0.41
Thulium	0.2	0.35	0.1	0.43	0.2	0.25	0.4	0.16	0.6	0.44
Tin	0.9	0.11	1.0	--	1.1	0.74	3.7	0.31	13.7	0.75
Titanium	MC	--	MC	--	MC	--	MC	--	MC	--
Tungsten	< 1.1	0.71	0.9	0.18	< 0.9	0.11	< 2.0	0.50	< 2.3	0.49
Uranium	2.3	0.25	2.0	--	6.3	0.18	7.3	0.67	6.0	0.44
Vanadium	85.7	0.38	124	0.67	223	0.46	>623	0.53	>823	0.35
Ytterbium	0.9	0.27	0.9	0.86	2.0	--	3.3	0.17	3.3	0.46

Table F4-7

(Continued)

Element	Crushed Coal		Pulverized Coal		Furnace Bottom Ash		Electrostatic Precipitator Ash		Composite Fly Ash	
	Mean	Cv	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Yttrium	16.3	0.42	13.0	0.27	40.7	0.28	53.7	0.42	89.3	0.74
Zinc	32.7	0.84	55.3	0.70	61.3	0.68	180	0.24	623	0.48
Zirconium	77.3	0.41	122	0.49	150	0.13	403	0.44	523	0.52

NOTE: Elemental concentrations in samples A, B and C (Table F4-5) were used to calculate means and coefficients of variation for coal and ash material. The sample of washed coal B was not included in this statistical analysis. The coefficient of variation is the ratio of the standard deviation to the mean and expresses the relative variability of an element's concentration among the three samples.

For concentrations less than the detection limit, the detection limit was used to calculate the mean and the mean was then indicated as "less than" (<) calculated value. For concentrations greater than 1000 mg/kg, 1000 mg/kg was used to calculate the mean and the mean was indicated as "greater than" (>) calculated value.

** MC = greater than 1000 mg/kg.
NR = not reported.

types of coal used in the test burn. For this reason, mean values are used in subsequent discussions in this report. No weighting in the averaging by a coal characteristic (such as by heating value) could be justified.

Although sample variability could be relatively high for some elements, absolute values obtained for trace element concentrations are quite low. Thus, "true" concentrations are not likely to be drastically different (orders of magnitude) from average values calculated from analytical measurements. As a consequence, the mean values utilized in the discussions of this report represent an adequate baseline for impact analysis.

Since washing of coal could remove some elements, a portion of sample B coal was washed prior to pilot testing and elemental analysis was performed or resultant materials. Comparison of element values in washed and unwashed coal samples (Table F4-5) indicates that washing does not affect concentrations of most elements in the coal. Apparent decreases of elemental concentrations in the washed coal were not supported by decreases in concentrations in the ashes. Differences between trace element concentrations in crushed coal and pulverized coal are minor, and a statistical t-test indicated that differences are not statistically significant at the 95% confidence level.

Based on results listed in Table F4-5, many elements are enriched in electrostatic precipitator ash and in fly ash as compared to coal and furnace bottom ash. Several elements such as As, Cu, F, Pb, Ni, Hg, and Zn are reported to be either vaporized or converted to volatile compounds during coal combustion.[193, 194, 216, 217] As the flue gas proceeds up the stack, it cools and these vaporized quantities begin condensing on the surfaces of particles suspended in the flue gas. The model of Natusch et al.[3] postulates that since the ratio of surface area to mass increases for smaller particles, concentrations of absorbed elements are higher in the very small particles that escape the precipitator.

In evaluating enrichment of an element in ash versus coal, it must be remembered that 70 to 75% of the original coal is lost as non-ash combustion products. Therefore, concentrations of noncombustible materials in coal would be increased by a factor of three to four in the ash assuming all the non-combustible material remained in the ash. Examples of several element enrichments follow:

1. Niobium - Niobium (Nb) has a very high melting point (245°C) and is not readily volatilized during combustion. Therefore, Nb should be retained in heavier ash particles, particularly in the furnace bottom ash. Niobium concentration in coal is 8 mg/kg (average for crushed and pulverized raw coal samples), whereas in the furnace ash and precipitator ash, the average Nb content is 17 and 28 mg/kg respectively. Assuming a 30% ash content for the coal samples, coal ash would contain a calculated Nb content of 27 mg/kg if all the Nb contained in coal remains in ash after combustion. Since this calculated ash value of 27 mg/kg is reasonably close to measured concentrations of 17 and 28 mg/kg, it is concluded that Nb is being retained in collected ash.

2. Mercury - Since mercury (Hg) is a volatile element, its concentration in heavier ash particles is expected to be low. Average Hg content in raw coal is 0.12 mg/kg. If Hg was equally distributed to all ash materials, its concentration in furnace bottom ash and precipitator ash should be about 0.4 mg/kg. Measured Hg concentrations in furnace bottom ash (0.02 to 0.03 mg/kg) are about a factor of ten lower than the calculated value of 0.4 mg/kg. However, Hg concentrations in electrostatic precipitator ash (1.15 to 2.39 mg/kg) exceed not only the calculated "equal distribution" value of 0.4 mg/kg, but also values measured for fly ash (0.61 to 1.52 mg/kg). These comparisons of Hg values in coal and various ashes indicated that Hg is depleted in heavier ash (furnace bottom), and enriched in precipitator and fly ash. Contrary to expectation, lower concentrations of Hg were measured in fly ash (particles that passed through the precipitator) than in electrostatic precipitator ash. Previous studies have shown as much as 90% of the original Hg is emitted in gaseous phase.[213, 214, 215, 216] Since any gaseous Hg would have escaped detection in the test burning sample, a significant portion of the original mercury may have been emitted in the vapor phase.

3. Fluorine - Fluorine (F) values in coal average about 80 mg/kg (Table F4-5). If F was evenly distributed and retained in coal ash, the calculated F content in ash would be about 270 mg/kg for coal having a 30% ash content. Measured F values (680 to 1030 mg/kg) in precipitator ash and fly ash materials were 3 to 4 times greater than this value. Therefore, considerable enrichment of F has occurred in precipitator ash and fly ash as compared to both coal and furnace bottom ash. Additionally, some unknown percentage of F in coal was lost as gaseous emission during the pilot test.

The distribution and concentration of elements among furnace bottom ash, electrostatic precipitator ash and fly ash appears to be related to the exit temperatures during the pilot test burn because of the melting and vaporization points of the elements. It is probable that the more volatile elements were vaporized during combustion and condensing on fine fly ash particles or were emitted as gases and therefore escaped being sampled during pilot test burns. Taking the ash content of the coal into account, the composition of furnace bottom ash and coal are similar for many elements. Therefore, some elements with higher melting and vaporization points are probably not enriched in fine fly ash particulates but possibly escape as gases.

Based on CCRL test burn data, As, Cr, Cu, F, Ga, Pb, Mn, Ni, Sr, S, V, Zn, and Zr are the principal elements enriched in fly ash that would most likely be emitted by the power plant.

(ii) Battle River test burn

B.C. Hydro conducted a bulk Hat Creek coal sample test burn at the Battle River Power Plant of Alberta Power, Ltd. between August 5th and 31st, 1977.[246] The Battle River station, near Forestburg, Alberta, has a nominal capacity of 32 MW with precipitator equipment similar to that of the proposed Hat Creek power plant. During the tests, special samples were collected to investigate the emissions of selected trace elements. In particular, the emissions of potentially volatile elements, arsenic, fluorine, mercury, and selenium, were measured in both particulate and gaseous forms. The monitoring was performed by Western Research and Development (WR&D), which has completed a separate and detailed report for several trace elements from this study.[246] That report describes the test burn procedures in a manner similar to the description of the CCRL test burn given in the previous section. The sampling described below is a brief overview. Table F4-8 lists the operating conditions for the six runs during which trace elements samples were obtained by WR&D. This table also contains the element concentrations determined for various phases applicable to the collection technique utilized for that element. For example, arsenic, fluorine, mercury, and selenium were measured in both the gaseous and solid emission stage whereas 17 elements, including the above four, were measured in coal and ash stages. These concentrations and the test burn from which they were measured are presented in Table F4-8.

The most important aspect of the Battle River power plant test burn from trace element consideration is the specific sampling performed for gaseous emissions of Hg, Se, As, and F. This was accomplished with a standard sampling train including particulate filters and gaseous emission scrubbers.[246] Results from the CCRL pilot test burn did not enable experimental estimation of elemental concentrations likely to exist in the gaseous emission phase. Therefore, data from the Battle River power plant test burns were used to estimate the full-scale emissions of the porposed Hat Creek power plant.

(b) Coal Analyses

The first step in estimating trace element emissions from the power plant is to determine a representative coal to be burned during typical operations. The Hat Creek power plant is expected to consume 42,600 metric tons of blended coal per day. Although the mine has natural variability of coal characteristics, the mining, storage and feeds systems are expected to produce a reasonably blended coal. Thus a composite sample of the entire coal deposit to be mined is of the most interest for predicting trace element emissions.

(i) Mine Mean Coal

More than 200 core samples have been collected to obtain material for a detailed analyses of the coal characteristics. Eight holes were selected

Table F4-8

Operational conditions at the Battle River Power Plant test burn using Hat Creek coal

	Test date					
	August 14, 1977		August 20, 1977		August 21, 1977	
Coal firing rate (kg/hr)	16,340	16,780	25,170	27,160	15,100	22,630
Stack gas flow rate (m^3/min)	1,190	1,040	2,710	2,740	1,550	2,410
Total particulate emissions (mg/m^3)	2,500	248	140	209	22	126
Precipitation efficienty (%)	--	--	99.65	99.52	99.92	99.72
Emission concentrations* (mg/m^3)						
Arsenic-solid	<0.0314	<0.0102	--	--	--	--
-gaseous	<0.0524	<0.0170	--	--	--	--
Boron	--	--	--	--	0.0116	0.0173
Cadmium	--	--	--	--	<0.00118	0.00345
Chromium	--	--	--	--	0.00140	0.00761
Copper	--	--	--	--	0.00333	0.0131
Fluorine-solid	--	--	0.107	0.130	--	--
-gaseous	--	--	0.905	1.540	--	--
Lead	<0.0773	0.0093	--	--	--	--
Mercury-solid	--	--	--	--	<0.0011	<0.0062
-gaseous	--	--	--	--	<0.0025	<0.0093
Manganese	--	--	--	--	0.0350	0.1272
Molybdenum	--	--	--	--	<0.00161	0.00553
Nickel	--	--	--	--	0.00452	0.0235
Selenium-solid	--	--	--	--	<0.00480	<0.0036
-gaseous	--	--	--	--	<0.00146	<0.0182
Strontium	--	--	--	--	0.00151	0.0201
Vanadium	--	--	--	--	<0.00118	0.00138
Zinc	--	--	--	--	0.0752	0.0422

NOTE: Two tests were performed on each date.
-- = parameter not measured.

* Double entries include solid value (upper entry) and gaseous value (lower entry) when both were measured. Single entry is solid value.

by B.C. Hydro as representative in spacing and depth. Composite samples were produced for each hole by taking a small, equal portion from each three meters of the coal in the core. These eight composite samples were then analyzed for trace element content (Table F4-9). An arithmetic mean was calculated and these values, representative of the mine mean coal, are shown in the last column of Table F4-9.

(ii) CCRL Coal Samples

At the time of the CCRL test burn, coal was available in sufficient quantity only from shallow bucket-auger drill holes. Coal was separated by varying heat content in three classes. Coal A was classified low heat value, coal B as medium heat value, and coal C as high heat value. Obviously, such coal was not entirely representative of the coal deposit. Any conclusions drawn from the CCRL tests must be adjusted by trace element differences in mine mean coal and test burn coal.

Although it is recognized that coal characteristics other than concentrations of trace elements (such as ash or sulfur content) may have affected the trace element disposition during combustion, it is necessary to assume that a simple linear relation can be used. That is, coal from the test burn can be extrapolated to an equivalent of mine mean coal by multiplying any trace element concentration or quantity from the test burn by the ratio of the mine mean coal to the CCRL coal concentration of the particular element. In this manner, for example, a concentration of 100 mg/kg (ppm) would be simulated by taking its ratio to that measured in CCRL coal, say 200, and using the resulting factor of 1/2 to correct predictions made from CCRL data. Table F4-10 presents the mine mean coal and CCRL coal concentration and their ratio for all analyzed trace elements.

(iii) Battle River Coal Samples

As in the CCRL test burn, the coal used in the Battle River tests is not completely representative of the whole coal deposit. In contrast to the CCRL

Table F4-9

Trace element concentrations (mg/kg or ppm) in diamond drill cores that collectively represent mine mean coal

	Drill hole number								
Element	127	138	141*	152	155	156	196	202	Mean**
Aluminum	MC	MC	MC	MC	MC	MC	MC	MC	MC
Antimony	--	--	< 0.3	--	0.4	--	0.7	--	<0.47
Arsenic	9	11	8.0	3	5	4	18	4	7.8
Barium	230	460	>610	300	MC	280	700	460	>430
Beryllium	0.1	0.7	0.3	0.2	0.1	0.9	0.3	0.4	0.38
Bismuth	--	--	<0.1	--	--	--	--	--	<0.1
Boron	9	7	10	26	2	49	6	9	15
Bromine	--	--	3.0	<0.4	1	<0.5	2	<0.6	<1.2
Cadmium	0.3	0.4	0.5	<0.7	0.4	0.6	--	--	<0.48
Calcium	MC	MC	MC	MC	MC	MC	MC	MC	MC
Cerium	8	25	20	16	23	7	31	12	18
Cesium	1	0.8	2.3	0.5	3	0.8	4	0.8	1.6
Chlorine	7	4	66	8	4	4	9	12	14
Chromium	16	82	71	11	330	60	200	61	100
Cobalt	2	7	5.3	4	4	4	13	7	5.8
Copper	6	29	68	19	31	12	120	58	43
Dysprosium	--	--	<1.1	--	1	1	--	--	<1.0
Erbium	--	--	<0.3	--	--	--	--	--	<0.3
Europium	0.3	0.3	0.4	0.2	0.3	0.5	1	0.4	0.43
Fluorine	130	210	84	90	130	110	140	200	137
Gadolinium	0.6	--	0.8	--	0.6	0.8	0.8	0.6	0.53
Gallium	7	14	17	9	13	6	29	18	14
Germanium	--	0.5	0.4	<0.1	0.3	<0.2	0.6	0.3	<0.30
Gold	--	--	<0.1	--	--	--	--	--	<0.1
Hafnium	--	--	<0.4	--	--	--	--	--	<0.4

Table F4-9
(Continued)

Element	127	138	141*	152	155	156	196	202	Mean**
	Drill hole number								
Holmium	--	--	<0.5	--	0.4	1	--	--	<0.63
Indium	STD	STD	STD	STD	STD	STD	STD	STD	--
Iodine	--	--	<0.4	--	0.2	<0.3	0.3	--	<0.03
Iridium	--	--	<0.1	--	--	--	--	--	<0.1
Iron	MC	MC	MC	MC	MC	MC	MC	MC	MC
Lanthanum	7	15	21	10	24	7	18	7	14
Lead	6	12	6.7	4	6	<2	9	7	<6.6
Lithium	60	8	63	7	41	74	25	60	42
Lutetium	--	--	<0.2	--	--	--	--	--	<0.2
Magnesium	MC	MC	MC	MC	MC	MC	MC	MC	MC
Manganese	270	36	>400	180	120	27	340	220	<200
Mercury	0.09	0.19	0.2	0.14	0.12	0.07	0.2	0.1	0.14
Molybdenum	1	2	2.0	1	1	3	3	2	4.9
Neodymium	2	5	6.3	3	6	3	6	5	4.5
Nickel	4	40	22	15	32	11	110	29	33
Niobium	4	11	9.0	3	12	6	9	4	5.8
Osmium	--	--	<0.1	--	--	--	--	--	<0.1
Palladium	--	--	<0.1	--	--	--	--	--	<0.1
Phosphorus	740	730	<910	160	400	90	MC	MC	>500
Platinum	--	--	<0.1	--	--	--	--	--	<0.1
Potassium	MC	MC	MC	MC	MC	MC	MC	MC	MC
Praesodymium	1	3	3.3	2	3	3	3	2	2.6
Rhenium	--	--	<0.1	--	--	--	--	--	<0.1
Rhodium	--	--	<0.1	--	--	--	--	--	<0.1
Rubidium	4	8	12	2	10	2	23	19	10

Table F4-9
(Continued)

	Drill hole number								
Element	127	138	141*	152	155	156	196	202	Mean**
Ruthenium	--	--	<0.1	--	--	--	--	--	<0.1
Samarium	1	1	3.0	1	2	2	5	2	2.1
Scandium	1	6	10	8	7	7	7	8	6.8
Selenium	--	<0.9	<0.5	--	0.6	--	<1	--	<1.0
Silicon	MC	MC	MC	MC	MC	MC	MC	MC	MC
Silver	--	<0.6	<0.1	--	1	--	--	<0.4	<0.5
Sodium	MC	MC	MC	MC	MC	MC	MC	MC	MC
Strontium	34	69	98	57	62	42	140	110	76
Sulfur	MC	MC	MC	MC	MC	MC	MC	MC	MC
Tantalum	--	--	<0.1	--	--	--	--	--	<0.1
Tellurium	--	--	<0.1	--	--	--	--	--	<0.1
Terbium	0.2	--	0.3	--	0.2	0.3	0.3	0.3	<0.25
Thallium	--	--	<0.1	--	--	--	--	--	<0.1
Thorium	2	<2	<3.0	2	5	3	3	3	<3.0
Thulium	--	--	<0.1	--	--	--	--	--	<0.1
Tin	--	0.6	0.8	0.4	1	0.8	1	--	<0.76
Titanium	830	MC	MC	MC	MC	MC	MC	MC	MC
Tungsten	--	--	<0.1	--	--	--	--	--	<0.1
Uranium	2	<2	<2.0	2	3	3	2	3	<2.3
Vanadium	32	110	176	71	180	49	400	110	140
Ytterbium	--	--	<0.3	--	--	--	--	--	<0.3
Yttrium	5	14	15	12	10	9	22	18	13
Zinc	5	28	30	19	26	8	35	47	25
Zirconium	46	61	54	40	50	57	110	61	60

Table F4-9
(Continued)

NOTE: MC = major component (> 1000 mg/kg).

-- = not detected.

STD = internal analytical standard used for mass spectrometric analysis.

* Hole 141 is the average of three subsamples.

** For mean values with a less than (<) sign, the element concentration in one or more coal samples was not detected and the mean is reported to be less than the mean value calculated for samples with detectable concentrations. The calculated mean is thus higher than expected (conservative) whenever a not detected value occurred for one or more drill hole samples.

For mean values with a greater than (>) sign, the element concentration in one or more coal samples was reported as MC and the mean is reported to be greater than the mean value calculated for samples with measurable concentrations.

Table F4-10

Trace element concentration ratios for CCRL and Battle River test burn coals to mine mean coal

Element	Mine mean coal (mg/kg)	Average concentration in CCRL raw crushed coal (mg/kg)	Ratio MMC/ CCRL	Average concentration in Battle River coal (mg/kg)	Ratio MMC/ Battle River
Aluminum	MC	MC	--	--	--
Antimony	0.47	0.7	0.67	--	--
Arsenic	7.8	16.0	0.49	4.5	1.73
Barium	430	384	1.12	--	--
Beryllium	0.38	0.3	1.27	0.58	0.66
Bismuth	0.1	0.4	0.25	--	--
Boron	15	4.0	3.75	19.5	0.77
Bromine	1.2	1.3	0.92	--	--
Cadmium	0.48	0.5	0.96	1.5	0.32
Calcium	MC	MC	--	--	--
Cerium	18	15.6	1.15	--	--
Cesium	1.6	1.7	0.94	--	--
Chlorine	14	24.3	0.58	--	--
Chromium	100	63.3	1.58	34.5	2.90
Cobalt	5.8	6.7	0.87	--	--
Copper	43	38.3	1.12	MC	<0.043*
Dysprosium	1.0	1.0	1.0	--	--
Erbium	0.3	0.6	0.50	--	--
Europium	0.43	0.4	0.11	--	--
Fluorine	137	101	1.36	170	0.81

Table F4-10
(Continued)

Element	Mine mean coal (mg/kg)	Average concentration in CCRL raw crushed coal (mg/kg)	Ratio MMC/ CCRL	Average concentration in Battle River coal (mg/kg)	Ratio MMC/ Battle River
Gadolinium	0.53	0.9	0.59	--	--
Gallium	14	16.0	0.88	--	--
Germanium	0.30	0.4	0.75	--	--
Gold	0.1	0.1	1.00	--	--
Hafnium	0.4	1.5	0.27	--	--
Holmium	0.63	0.7	0.90	--	--
Iodine	0.03	0.3	0.10	--	--
Iridium	0.1	0.1	1.00	--	--
Iron	MC	MC	--	--	--
Lanthanum	14	13.7	1.02	--	--
Lead	6.6	3.7	1.78	12	0.55
Lithium	42	13.0	3.23	--	--
Lutetium	0.02	0.2	0.10	--	--
Magnesium	MC	MC	--	--	--
Manganese	200	138	1.45	MC	<0.20*
Mercury	0.14	0.1	1.40	0.06	2.33
Molybdenum	1.9	3.7	0.51	3.5	0.54
Neodymium	4.5	5.7	0.79	--	--
Nickel	33	19.3	1.71	75	0.44
Niobium	5.8	7.0	0.83	--	--

Table F4-10

(Continued)

Element	Mine mean coal (mg/kg)	Average concentration in CCRL raw crushed coal (mg/kg)	Ratio MMC/ CCRL	Average concentration in Battle River coal (mg/kg)	Ratio MMC/ Battle River
Osmium	0.1	0.1	1.00	--	--
Palladium	0.1	0.1	1.00	--	--
Phosphorus	500	453	1.10	--	--
Platinum	0.1	0.1	1.00	--	--
Potassium	MC	MC	--	--	--
Praseodymium	2.6	1.7	1.53	--	--
Rhenium	0.1	0.1	1.00	--	--
Rhodium	0.1	0.1	1.00	--	--
Rubidium	10	14.0	0.71	--	--
Ruthenium	0.1	0.1	1.00	--	--
Samarium	2.1	3.0	0.70	--	--
Scandium	6.8	8.0	0.85	--	--
Selenium	1.0	1.6	0.63	15.5	0.06
Silicon	MC	MC	--	--	--
Silver	0.5	0.2	2.50	--	--
Sodium	MC	MC	--	--	--
Strontium	76	99.7	0.76	290	0.26
Sulfur	MC	MC	--	--	--
Tantalum	0.1	0.1	1.00	--	--
Tellulium	0.1	0.2	0.50	--	--
Terbium	0.25	0.2	1.25	--	--
Thallium	0.1	0.5	0.20	--	--
Thorium	3.0	3.7	0.81	--	--
Thulium	0.1	0.2	0.50	--	--
Tin	0.76	0.9	0.84	--	--

Table F4-10

(Continued)

Element	Mine mean coal (mg/kg)	Average concentration in CCRL raw crushed coal (mg/kg)	Ratio MMC/ CCRL	Average concentration in Battle River coal (mg/kg)	Ratio MMC/ Battle River
Titanium	MC	MC	--	--	--
Tungsten	0.1	1.1	0.09	--	--
Uranium	2.3	2.3	1.00	8.0	0.29
Vanadium	140	85.7	1.63	265	0.53
Ytterbium	0.3	0.9	0.33	--	--
Yttrium	13	16.3	0.80	--	--
Zinc	25	32.7	0.76	83.5	0.30
Zirconium	60	72.3	0.83	--	--

NOTE: MMC = mine mean coal, see Table F4-9
MC = *major component (>1000 mg/kg).*
-- = element was not measured.

* Calculated assuming MC = 1000 mg/kg.

case, however, much larger samples, excavated by trenching, were shipped to the Battle River plant. Table F4-11 gives results of analyses of the Battle River coal for trace elements. Since all trace elements were not measured during each test burn, the trace element extrapolation to mine mean coal must be done only with the coal used for the appropriate tests. The correct analyses to use have been underlined in Table F4-11 and their averages are presented in Table F4-10 which also includes the corresponding ratios to mine mean coal.

(c) Emissions

The first step in the estimation of full-scale power plant emissions is to scale the coal analyses to a representative mine mean coal, as was described in the previous section. Secondly, estimated full-scale emissions of trace elements must be calculated. The procedure is essentially the same for the two test burns.

Emission measurements were carefully performed in the Battle River tests, with instrumentation specific to gaseous and particulate emission monitoring.[246] These samples are considered to be more reliable for emissions estimation than the earlier CCRL tests. Because the coal firing rates and emission stream parameters were all measured, it is possible to scale the coal firing rate to that of the Hat Creek plant, adjust the trace element concentrations in the coal by the aforementioned ratios, and thereby scale the emission measurements to a full-scale power plant simulation. This is also possible for the pilot scale CCRL tests, however, only the emission rates of solid trace elements can be scaled by coal concentrations and total particulate matter emitted.

(i) CCRL Emissions

The primary purpose of analyses presented thus far has been to determine the ultimate fate of trace elements in coal consumed at the power plant. In principle, any element introduced as part of the coal to the boilers of the

Table F4-11
Battle River test burn coal analyses for trace elements (mg/kg)

Element	Test Dates					
	August 14, 1977		August 20, 1977		August 21, 1977	
Arsenic	8	1	11	12	23	7
Beryllium	0.7	0.3	1	0.4	0.8	0.3
Boron	0.4	7	15	12	25	14
Cadmium	0.8	0.6	0.8	1	2	1
Chromium	72	36	40	60	41	28
Copper	140	420	530	MC	MC	250
Fluorine	100	120	180	160	84	96
Lead	13	11	13	9	20	13
Manganese	530	160	MC	66	140	MC
Mercury	0.10	0.11	0.08	0.06	0.05	0.07
Molybdenum	4	4	4	4	3	4
Nickel	29	6	11	13	90	60
Selenium	2	1	19	7	27	4
Strontium	110	84	110	170	350	230
Uranium	2	6	6	5	10	6
Vanadium	79	240	120	65	160	370
Zinc	41	41	46	38	71	96

NOTE: Two tests were performed on each date. Underlined concentrations indicate that element was measured in emissions for that test and average value in coal was used for calculating ratio of mine mean coal to Battle River coal (see Table F4-10).

MC = major component (> 1000 mg/kg).

power plant must be divided between furnace bottom ash, precipitator ash, fly ash (particulate), other ashes, or gaseous stack emission. If masses and elemental concentrations are known for each of these power plant products and the input coal, a complete balance for each element can be obtained. Such information is not completely available from results of this pilot test burn because:

1. Bottom ash was washed from the furnace and no water samples were collected.

2. Other ashes (e.g., preheater collections and wall attachments) were not analyzed.

3. Ash production rates were not all measured.

4. Gaseous emissions were not sampled.

In the absence of a complete balance, a partial balance is still useful. Operating data from pilot test burns, including the coal firing rate, flue gas flow and particulate loading, are listed in Table F4-12. Thus, from elemental concentrations of coal and fly ash, mean input and particulate emission rates of elements can be determined.

(ii) Battle River Emissions

As presented in Table F4-8, emissions from the Battle River test burn provided data on the gaseous component not attained in the CCRL test burn. Coal analyses for the Battle River test burn are presented in Table F4-11. Since different tests were completed for the various trace elements on different days, the coal burned for that particular day must be used to determine the relationship of emission concentration to coal content for the trace elements. As is seen in Table F4-11, although some variability does exist among the coal burned, in general its content is very similar for all test dates.

Table F4-12

Operating data for CCRL pilot test burn runs on three samples of Hat Creek coal

Test number*	Coal Charge Rate (kg/hr)	Heat Content (BTU/lb dry)	Efficiency (%)	Flue Gas Rate (std m^3/hr)	Fly Ash Loading (g/std m^3)	Fly Ash Emission Rate** (g/hr)	Fly Ash Emission Rate at 99.7% eff.*** (g/hr)
2.2	156	5542	96.2	597	40.3	914	72.2
4.2	132	8030	92.0	696	11.6	646	24.2
6.2	104	8720	94.0	561	8.16	275	13.8
Average	130	7430	94.1	618	20.0	612	36.7

*Coal used in various tests described in Table F4-4. Tests performed by CCRL.[245]

**Defined as (fly ash loading) x (gas flow) x $(1 - \frac{\text{efficiency}}{100})$.

***Assumed full-scale electrostatic precipitator efficiency (Conceptual Design Report)[232].

(iii) Power Plant Emissions

To extrapolate results from the test burns for full-scale emission estimates for the Hat Creek power plant, a four-step process is necessary:

1. Measure the input coal and corresponding emissions from the test burn.

2. Correct the results by accounting for any differences in the coal burned and the coal expected to be available for the full-scale plant.

3. Correct the test burn sampling results for differences in operating procedures.

4. Extrapolate the emissions to full-scale.

The first step has been discussed in subsection (a). The coal used for test burns was readily accessible surface coal at the Hat Creek site and its trace element content should be corrected to represent coal from the coal deposit. This has been described in subsection (b). Eight diamond drill core samples were selected by B.C. Hydro as representative of the coal deposit (i.e., "mine mean coal") and composite samples from these cores were prepared. Average trace element concentrations for these eight cores are assumed to be indicative trace element levels of blended coal that would be burned at the plant. A ratio of mine mean coal to test burn coal trace elements content was calculated and used to correct test burn projections (Table F4-10). Step three of the full-scale emission calculations is to correct for varying operational methods between test burns and the planned Hat Creek power plant. It will be assumed here that no significant differences (such as precipitator efficiency) exist. Finally, full-scale operations are defined as the consumption at Hat Creek of 42,600 metric tons per day of mine coal.

Extrapolations to full-scale trace element emissions are calculated as a product of:

1. Ratio of mine mean coal (MMC) to test burn coal concentrations,
2. Ratio of Hat Creek power plant coal firing rate (42,600 metric tons per day) to test burn coal firing rate,
3. Particulate or gaseous emission rate from test burn,
4. Trace element concentration (particulate only) in test burn emissions.

All of the input values are in tables in this chapter and are included or referenced in Table F4-13. Emissions are given in kg/day for both extrapolations from the CCRL and Battle River test burns. The table footnotes again summarize the mathematical calculations.

Data from the Battle Creek power plant test burns were used to project full-scale stack emissions of various trace elements that are likely to exist in significant percentages as gaseous forms in flue gas (Table F4-13). Several studies have indicated that as much as 90% of the available Hg in coal is emitted as gaseous vapor.[213,214,215,216] Andren[217] reports that nearly 13% of the Se in coal is emitted as gaseous vapor. Also, Klein et al.[194] reports that most Cl and Br in coal are emitted from power plants as vapors. Some F escapes as a vapor, but the actual percentage is difficult to determine due to problems in sampling (Klein, personal communication). In an EPA study conducted by Radian Corporation[193] at a coal-fired power plant with pollution control measures similar to those proposed for the Hat Creek development, F emissions from the stack were estimated at 8% of the total F input. However, the portion of this 8% that was gaseous emission was not determined. Based on the Battle River power plant test burns, it is projected that four trace elements will have measurable gaseous phase emission from the Hat Creek power plant. These elements and the fraction of total stack emissions in the gaseous state are: arsenic (62%), fluorine (94%), mercury (52%), and selenium (48%) (Table F4-13).

The emissions rates for mercury, selenium, and arsenic are all maximum values as determined by Western Research & Development.[246] This resulted from the short test duration which did not allow sufficient sample to be col-

Table F4-13
Projected emissions of trace elements from Hat Creek Power Plant based on CCRL and Battle River test burn analyses

				Power plant emissions (kg/day)			
				Solid		Gaseous††	Total†††
Element	Ratio MMC/CCRL*	Concentration in fly ash-CCRL (mg/kg)***	Ratio MMC/Battle River*	CCRL***	Battle River†	Battle River	Battle River
Aluminum	----	MC	----	------	------	---	------
Antimony	0.67	11.3	----	0.0910	------	---	------
Arsenic	0.49	403	1.73	2.37	6.45	10.7	17.2
Barium	1.12	MC	----	------	------	---	------
Beryllium	1.27	0.4	----	0.0061	------	---	------
Bismuth	0.25	1.3	----	0.0039	------	---	------
Boron	3.75	16.0	0.77	0.722	6.3	---	6.3
Bromine	0.92	5.0	---	0.0553	------	---	------
Cadmium	0.96	2.3	0.32	0.0266	0.35	---	0.35
Calcium	----	MC	----	------	------	---	------
Cerium	1.15	77.7	----	1.07	------	---	------
Cesium	0.94	8.3	----	0.0938	------	---	------
Chlorine	0.58	59.3	----	0.414	------	---	------
Chromium	1.58	240	2.90	4.56	5.20	---	5.20
Cobalt	0.87	57	----	0.596	------	---	------
Copper	1.12	440	<0.043	5.93	<0.15	---	<0.15
Dysprosium	1.0	5.3	----	0.0637	------	---	------
Erbium	0.50	1.6	----	0.0096	------	---	------
Europium	0.11	1.3	----	0.0017	------	---	------
Fluorine	1.36	753	0.81	12.3	18.7	262	280.7
Gadolinium	0.59	3.3	----	0.0234	------	---	------
Gallium	0.88	235	----	2.49	------	---	------
Germanium	0.75	9.0	----	0.0812	------	---	------
Gold	1.00	< 0.4	----	< 0.0048	------	---	------
Hafnium	0.27	7.0	----	0.0227	------	---	------

Table F4-13 (Continued)

				Power plant emissions (kg/day)			
				Solid		Gaseous††	Total†††
Element	Ratio MMC/CCRL*	Concentration in fly ash-CCRL (mg/kg)***	Ratio MMC/Battle River*	CCRL***	Battle River†	Battle River	Battle River
Holmium	0.90	2.0	----	0.0216	------	---	------
Hydrogen	----	---	----	------	------	---	------
Indium	----	STD	----	------	------	---	------
Iodine	0.10	1.0	----	0.0012	------	---	------
Iridium	1.00	<0.4	----	<0.0048	------	---	------
Iron	----	MC	----	------	------	---	------
Lanthanum	1.02	52.1	----	0.639	------	---	------
Lead	1.78	74.7	0.55	1.60	4.36	---	4.36
Lithium	3.23	10.3	----	0.400	------	---	------
Lutetium	0.10	0.6	----	0.000722	------	---	------
Magnesium	----	MC	----	------	------	---	------
Manganese	1.45	>756	<0.2	>13.2	<7.15	---	<7.15
Mercury	1.40	1.0	2.33	0.0168	3.36	3.71	7.07
Molybdenum	0.51	28.0	0.54	0.172	0.86	---	0.86
Neodymium	0.79	34.3	----	0.325	------	---	------
Nickel	1.71	293	0.44	6.03	2.49	---	2.49
Niobium	0.83	69.7	----	0.695	------	---	------
Osmium	1.00	<0.4	----	<0.00481	------	---	------
Palladium	1.00	<0.4	----	<0.00481	------	---	------
Phosphorous	1.10	MC	----	------	------	---	------
Platinum	1.00	<0.4	----	<0.00481	------	---	------
Potassium	----	MC	----	------	------	---	------
Praseodymium	1.53	12.3	----	0.226	------	---	------
Rhenium	1.00	<0.4	----	<0.00481	------	---	------
Rhodium	1.00	<0.4	----	<0.00481	------	---	------

Table F4-13 (Continued)

Element	Ratio MMC/CCRL*	Concentration in fly ash-CCRL (mg/kg)***	Ratio MMC/Battle River*	Power plant emissions (kg/day)			
					Solid	Gaseous††	Total†††
				CCRL***	Battle River†	Battle River	Battle River
Rubidium	0.71	58.0	----	0.495	------	---	------
Ruthenium	1.00	<0.4	----	<0.00481	------	---	------
Samarium	0.70	17.0	----	0.143	------	---	------
Scandium	0.85	40.3	----	0.412	------	---	------
Selenium	0.63	12.3	0.06	0.0932	0.172	0.186	0.331
Silicon	----	MC	----	------	------	---	------
Silver	2.50	1.0	----	0.0301	------	---	------
Sodium	----	MC	----	------	------	---	------
Strontium	0.76	580	0.26	5.30	0.953	---	0.953
Sulfur	----	>843	----	------	------	---	------
Tantalum	1.0	<0.4	----	<0.00481	------	---	------
Tellurium	0.50	<0.4	----	<0.00240	------	---	------
Terbium	1.25	0.8	----	0.0120	------	---	------
Thallium	0.20	<1.7	----	<0.00409	------	---	------
Thorium	0.81	11.7	----	0.114	------	---	------
Thulium	0.50	0.6	----	0.00361	------	---	------
Tin	0.84	13.7	----	0.138	------	---	------
Titanium	----	MC	----	------	------	---	------
Tungsten	0.09	<2.3	----	<0.00249	------	---	------
Uranium	1.00	6.0	----	0.0722	------	---	------
Vanadium	1.63	>823	----	16.1	------	---	------
Ytterbium	0.33	3.3	----	0.0131	------	---	------
Yttrium	0.80	89.3	----	0.859	------	---	------
Zinc	0.76	623	0.30	5.69	12.9	---	12.9
Zirconium	0.83	523	----	5.22	------	---	------

NOTE: Emissions simulated for 2,000 MW Hat Creek power plant burning 42,600 metric tons per day of mine mean coal (MMC) with no control of gaseous emissions.

(footnotes on following page)

Table F4-13 (Continued)

MC = major component (>1000 mg/kg).

STD = internal analytical standard.

-- = not measured.

< (less than) values for emissions reflect use of maximum MMC/Battle River ratio (see Table F4-10).

* From Table F4-10.

** From Table F4-7.

*** Calculated as:

$$\frac{\text{42,600,000 kg/day Hat Creek coal}}{\text{130 kg/hr X 24 hr/day (the CCRL test burn coal firing rate from Table F4-12)}}$$

$$\text{X } \frac{\text{36.7 g/hr X 24 hr/day (the fly ash emission rate from Table F4-12)}}{\text{1000 g/kg}}$$

X Column 1, the ratio MCC/CCRL

$$\text{X } \frac{\text{Column 2, the concentration of the element in CCRL fly ash}}{10^6\text{ mg/kg}}$$

† Calculated as the average of two computations as follows for the two tests on the day corresponding to the element of concern, as in Table F4-8:

$$\frac{\text{42,600,000 kg/day Hat Creek coal}}{\text{Battle River test burn coal firing rate, kg/hr (Table F4-8) X 24 hr/day}}$$

X Battle River test burn particulate emission rate, mg/m^3 (Table F4-8)

X Battle River test burn gas flow rate, m^3/min (Table F4-8)

$$\text{X } \frac{\text{1440 min/day}}{10^6\text{ mg/kg}} \text{ X column 3, ratio MMC/Battle River}$$

$$\text{X } \frac{\text{100-99.7 (design precipitator efficiency)}}{\text{100-precipitator efficiency (\%, Table F4-8)}}$$

Table F4-13 (Continued)

†† Calculated as the average of two computations as follows for the two tests on the day corresponding to the element of concern, as in Table F4-8:

$$\frac{\text{42,600,000 kg/day Hat Creek coal}}{\text{Battle River test burn coal firing rate, kg/hr (Table F4-8) X 24 hr/day}}$$

X Battle River test burn gaseous emission rate, mg/m^3 (Table F4-8)

X Battle River test burn gas flow rate, m^3/min (Table F4-8)

X $\frac{\text{1440 min/day}}{10^6\ \text{mg/kg}}$ X column 3, ratio MMC/Battle River

††† Total of previous two columns, Battle River particulate plus gaseous emissions.

lected for detection with spark source mass spectrometry, therefore the minimum detectable limit for the respective element was used as a conservative maximum. In the case of fluorine sufficient sample was collected to allow analysis within the detectable range of the analytical technique used, and therefore, the reported emissions from the test burn are subject to normal analytical variation.

Emissions given in Table F4-13 are the result of calculations performed using data from the Battle River test burn as published.[246] Some numbers differ from previously calculated values, which have been referenced in other volumes of the ERT report "Air Quality and Climatic Effects of the Hat Creek Project" to which this report is an appendix. The differences are judged insignificant to conclussions noted in later chapters of this appendix and in other appendices to the ERT report.

For trace elements measured in both test burns, data from the Battle River power plant test burns projected higher full-scale stack emission rates for arsenic, boron, cadmium, chromium, fluorine, lead, mercury, molybdenum, selenium, and zinc than did data from the CCRL pilot test burn. However, the CCRL pilot test burn data projected higher full-scale stack emissions for copper, manganese, nickel, and strontium. In subsequent report sections that evaluate the environmental distribution and impact of trace elements, the higher of the two projected emission rates was considered. Thus, environmental evaluation and impact assessment considered the worst-case condition based upon available data from two different test burns.

F5.0 RECEPTOR AND TRANSMISSION MEDIA ANALYSIS

The trace element composition of coal is geochemically similar to that of the earth's crust[1]. Thus, coal contains almost all of the naturally occurring elements. A review of numerous published references (Section F11.0) on trace element ecology (including distribution of elements in coal, ash, soil, air, water and living organisms; toxicity potential of trace elements; and mobility and accumulation characteristics of trace elements) enabled the selection of trace elements most likely to be of environmental importance at the site of a coal-fired power plant.

Initially, environmental samples (receptors) from the Hat Creek area were examined to include all of the elements analyzed by the methodologies of spark source mass spectroscopy and plasma emission spectroscopy. In both cases, concentrations for over 60 elements were obtained. From these analyses, common elements normally found in relatively high concentrations in ecosystem materials and which are relatively nontoxic were eliminated from additional consideration. Typical elements in this group are aluminum (Al), calcium (Ca), iron (Fe), magnesium (Mg), and manganese (Mn). Similarly, those elements in minute to non-detectable quantities were also eliminated from additional consideration. Typical elements in this group are gold (Au), holmium (Ho), palladium (Pd), and ytterbium (Yb). A complete listing of the elements analyzed and their concentrations in receptor materials are presented in Addenum A to this appendix report. From this list, 21 elements (Table F5.1) were selected for detailed environmental review. These 21 elements, which are the focus of discussion in this report section, have one or more of the following characteristics: relatively high concentrations in Hat Creek coal or ash; volatilized during coal combustion; potentially most toxic to Hat Creek receptors; present in relatively high concentrations in Hat Creek sources or receptor materials as compared to values reported by others in similar ecosystem materials; or regulated by governmental agencies (Table F5-1). Information for this selection process came from literature sources referenced in Sections F4.0, F5.0, and F6.0, and from coal analyses and test burn results presented in Section F4.0. Included in the survey was the status as far as a particular element's regulatory stature or proposed standard level as promulgated by United States or Canadian authorities. Regulatory standards are described in the main

Table F5-1

Characteristics of trace elements selected for detailed environmental review

Element	Symbol	High concentration in coal or ash	Volatilized during combustion	High potential toxicity	High concentration in receptors	Regulated guideline*
Antimony	Sb	X			X	
Arsenic	As	X	X	X	X	X
Beryllium	Be			X		X
Boron	B	X			X	
Cadmium	Cd			X	X	X
Chromium	Cr	X			X	X
Cobalt	Co	X			X	
Copper	Cu	X		X	X	
Fluorine	F	X	X	X	X	X
Gallium	Ga	X				
Lead	Pb	X		X		X
Lithium	Li	X			X	
Mercury	Hg		X	X	X	X
Nickel	Ni				X	X
Selenium	Se		X		X	X
Strontium	Sr	X			X	
Thallium	Tl			X		
Tin	Sn	X			X	
Vanadium	V	X		X	X	X
Zinc	Zn	X			X	X
Zirconium	Zr	X			X	

* See ERT main report--Air Quality and Climatic Effects of the Proposed Hat Creek Project--and Appendix G-Epidemiology--for description of trace elements with guideline levels that are regulated by governmental agencies.

ERT report--Air Quality and Climatic Effects of the Proposed Hat Creek Project--and in Appendix G-Epidemiology.

Using factors presented in Table F5-1, the list of 21 elements was reduced to nine elements of most environmental concern. In general, if an element had checks in at least three of the five categories listed in Table F5-1, the element was selected as being of most environmental concern. A slightly biased weighting was given to three of the factors (high concentration in coal or ash, high potential toxicity, and existence of regulated guidelines) because these were considered most important for impact assessment. Using this selection criterion, Sb, Be, B, Co, Ga, Li, Ni, Se, Sr, Tl, Sn, and Zr were eliminated from additional sampling in the Hat Creek environs. Selenium, which is toxic to animals only if their principal food source contains high levels of the element (Section F5.1), was a borderline element that was not studied further because Se levels in coal and stack emissions were low (Section F4.0). Nine elements, including As, Cd, Cr, Cu, F, Pb, Hg, V, and Zn, were selected as being of most environmental concern for the Hat Creek project. These nine elements were analyzed in receptor materials collected during two subsequent samplings in the Hat Creek area (Section F5.1). Environmental distribution and impact assessment for these elements are discussed in Sections F6.0 and F7.0, respectively.

F5.1 Receptor Analysis

Descriptions of samples, including type and size, are given in Section F3.0. Soil and water, although abiotic components, are important trace element receptors and are included in the subsequent discussion. Air is the primary transmission medium of stack emissions and is discussed in Section F5.2. To facilitate comparison of specific trace element concentrations between sites and among receptors, the discussion is organized by element. For each tràce element, information gathered during a comprehensive literature review is used to determine, when possible, the following parameters:

1. comparability with "normal" concentrations in other defined ecosystem components;
2. potential for enrichment in Hat Creek receptors;

3. role in normal functioning of ecosystem components;
4. major sites and modes of uptake and accumulations; and
5. tolerance levels, toxic concentrations and toxic effects.

As different trace elements have been subjected to different kinds and intensities of research, a disparate amount of literature exists for the various trace elements under consideration for the Hat Creek project. This is necessarily reflected in the kinds and extent of information presented for each element; that is, not all the above information is provided for each element. In following discussions of trace element levels, concentrations measured in Hat Creek materials are compared to levels reported in other studies. In many cases, these other studies have compiled data from various geographical areas. Unless another explanation is given, trace element levels used for comparison are from "natural" areas (i.e., not near an industrial, mining or other project development that could contribute trace elements to the local environment).

Except for water, samples collected in October 1976 were analyzed in most detail (73 elements measured in triplicate samples). Prior to trace element analysis of receptor material collected during January and May 1977, evaluation of trace element levels in source and receptor (October 1976) materials from the Hat Creek area provided a basis for determining trace elements of major concern to this project (See Section F5.0 for a discussion of selection rationale). Important trace elements were ascertained to be As, Cd, Cr, Cu, F, Pb, Hg, V, and Zn. These elements provided the focus for January and May 1977 sample analysis and results of these analyses are presented and discussed in this section. Concentrations* of certain elements, such as As and Cd, varied considerably among sampling periods. Factors contributing to high natural variability include physical and chemical heterogeneity of sampled materials, changes in environmental factors such as soil moisture, and changing quantities and rates of decomposing plant and animal material in soil.

- Concentrations of trace elements in solid materials are reported as parts per million (ppm) throughout this chapter. Values in ppm, which is a weight to weight ratio and therefore a unitless number, are numerically equivalent to concentrations reported as mg/kg. Concentrations of trace elements in water samples are also reported as ppm, which for freshwater is equivalent to mg/l.

(a) Antimony (Sb)

Average concentrations of antimony (Sb) in receptor materials collected during October 1976 are presented in Table F5-2. A "<" (less than) or ">" (greater than) preceeding any mean value indicates the inclusion of a concentration into the computation which was either too low (e.g., <0.001 ppm) or too high (e.g., >400 ppm) for adequate estimation by the analytical technique.

Natural concentrations of Sb in Hat Creek receptors during October 1976 were generally below 1 ppm with means ranging from <0.002 ppm (water, Site 2) to 1.57 ppm (stream sediment, Site 4) in aquatic samples and from 0.17 ppm (shrub, Site 4) to 1.40 ppm (soil, Site 2) in terrestrial samples. The highest concentration of Sb were found in stream sediment and soil samples. Variability, as indicated by standard error, was generally low for all samples.

The following concentrations have been presented in the literature as representative of naturally occurring Sb levels in selected ecosystem components:

1.	water	-	<0.00033 ppm[4]
2.	soils	-	<0.43 ppm, Wyoming[5]
3.	vegetation	-	0.06 ppm[4] <0.22 ppm, Wyoming[5]
4.	animals	-	0.14 ppm, mammalian tissue[4] 0.03-0.07 ppm, deer mice, Wyoming[5]

While Hat Creek samples had slightly higher concentrations than values reported in the literature, Hat Creek Sb levels are far below those concentrations considered toxic. Bowen[4] reports the results of laboratory experiments which indicate that the lethal dose of various chemical forms of Sb required to kill 20% of the test population (LD_{20}) of a variety of mammalian specimens ranges from about 20 to 4000 ppm. Antimony is believed to exert its toxicity by acting as an antimetabolite and is generally considered as moderately toxic to all organisms.[4]

Table F5-2

Average concentration (ppm) of Antimony (Sb) in receptor materials collected during October 1976

Receptors	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aquatic **												
Water	0.003	0.001	<0.002	>0.000	0.002	0.001	0.002	0.001			<0.0022	>0.0005
Stream sediment	1.33	0.33	0.53	0.03	0.97	0.03	< 1.57	> 0.72			< 1.10	> 0.21
Fish ***	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03			< 0.18	> 0.01
Terrestrial												
Soil	< 0.53	> 0.35	< 1.40	> 0.60	< 0.27	> 0.03	< 0.27	> 0.03	< 0.40	> 0.15	< 0.57	> 0.16
Shrub	< 0.40	> 0.25	< 0.50	> 0.26	< 0.20	> 0.06	< 0.17	> 0.03	< 0.20	> 0.00	< 0.29	> 0.07
Grass	< 0.23	> 0.03	< 0.47	> 0.09	< 0.30	> 0.06	< 0.20	> 0.00	< 0.37	> 0.03	< 0.31	> 0.03
Lichen	< 0.37	> 0.03	< 0.33	> 0.13	< 0.27	> 0.03	< 0.33	> 0.03	< 0.47	> 0.12	< 0.35	> 0.04
Small mammal	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.30	> 0.50	< 0.27	> 0.07	< 0.35	> 0.12

* The less than symbol(<) indicates that one or more of the replicate measurements were below the analytical detection limit. When such analytical data occurred, means were calculated by using the detection limit as the concentration and then reporting the mean with a < symbol. Similar reasoning applies to calculation of standard error, except that a greater than symbol (>) is used. If results for all replicates were below the detection limit, the standard error is reported as >0.0000. For example, measurements of arsenic in water for three replicates were all <0.001. The mean was reported as <0.001 and the standard error as >0.000. A greater than symbol (>) for a mean indicates that one or more of the replicate measurements were above 1000 ppm.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

(b) Arsenic (As)

Average concentration of arsenic (As) in selected Hat Creek receptors collected during October 1976 are presented in Table F5-3. Arsenic concentrations ranged from <0.002 ppm in water to 10.00 ppm (stream sediment, Site 1) in aquatic samples. Arsenic levels in terrestrial samples ranged from 0.23 ppm (grass, Site 4) to 3.33 ppm (soil, Site 2). Soil and small mammals generally evidenced the highest concentrations at each site. Except for small mammals, samples from Site 2 (Lower Hat Creek) had the highest As concentrations of all sites. Arsenic concentrations in samples collected during January and May 1977 (Table F5-4) were generally higher than those collected in October 1976, especially in soil and stream sediment.

Naturally occurring concentrations of As as determined from the literature are given for a variety of ecosystem components below:

1. water - 0.0004 ppm[4]
2. soils - 0.3-38 ppm, 2.5-4.6 ppm, Oregon[6]
   - 1-40 ppm[7]
   - 6 ppm[4]
   - <7 ppm, Wyoming[5]
   - 5 ppm[9]
3. vegetation - 0.2 ppm[4]
   - 0-10 ppm[6]
   - 0.5 ppm[7]
   - 0.1-1.0 ppm, Wyoming[5]
4. animals - <0.2 ppm, highest in mammalian hair and nails[4]
   - <3 ppm, freshwater fish[7]
   - <0.45 ppm, deer mice, Wyoming[5]

Arsenic levels in small mammals collected during October 1976, and levels in soils, stream sediment and small mammals sampled during January and May 1977, appear to be higher than might be expected based on values reported in the literature. Since the effects of high As in soils and stream sediment on rooted vegetation depend on the amount of soluble As and not total As, it is difficult to determine if the natural As levels are presently stressing

Table F5-3

Average concentration (ppm) of Arsenic (As) in receptor materials collected during October 1976

Receptors	Site 1 Mean*	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
<u>Aquatic</u> **												
Water	<0.002	>0.000	<0.002	>0.000	<0.002	>0.000	<0.002	>0.000			<0.002	>0.000
Stream sediment	10.00	3.79	6.33	0.33	5.00	1.53	4.67	1.20			6.50	1.11
Fish ***	< 0.45 >	0.05	< 0.53 >	0.09			< 0.33 >	0.07			< 0.43 >	0.04
<u>Terrestrial</u>												
Soil	4.33	0.93	8.33	2.33	3.00	1.53	5.00	0.50	3.67	0.67	4.87	0.72
Shrub	< 0.60 >	0.15	< 0.97 >	0.52	< 0.37 >	0.03	< 0.60 >	0.12	< 0.47 >	0.07	< 0.60 >	0.11
Grass	< 0.50 >	0.21	< 1.83 >	1.09	0.40	0.06	0.23	0.05	0.35	0.05	< 0.66 >	0.25
Lichen	0.63	0.12	1.57	0.72	1.20	0.40	0.93	0.03	0.75	0.22	1.01	0.17
Small mammal	< 0.83 >	0.09	< 0.75 >	0.12	5.27	2.37	3.67	1.76	< 0.77 >	0.05	< 1.85 >	0.61

* See first footnote in Table F5-1 for explanation of < and > symbols

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Table F5-4

Average concentration (ppm) of Arsenic (As) in receptor material collected during January and May 1977

	January 1977*							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic**														
Water	0.0027	<0.0023	<0.0020	<0.0020		<0.0022	70.0003	<0.05	<0.05	<0.05	<0.05		<0.05	>0.0
Stream sediment	59	50	52	44		51.25	6.2	42	41	<7	48		34.50	>18.6
Fish***	- -	- -	- -	- -				2.3	1.6	- -	- -		1.95	0.5
Terrestrial														
Soil	44	67	92	94	170	93.40	47.5	52	61	146	85	40	76.80	42.1
Shrub	- -	- -	- -	- -	- -			<7	<7	<7	3.0	<4	5.60	1.9
Grass†	- -	- -	- -	- -	- -			7.0	<7	<7	- -	<7	<7.00	>0.0
Lichen	2.5	2.3	3.4	4.7	4.8	3.54	1.2	4.4	5.0	7.0	3.6	5.3	5.06	1.3
Small mammal	- -	- -	- -	- -	- -			2.9	<1.5	2.9	<3	<3	<2.66	>0.7

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* Only water, stream sediment, soil and lichen were collected during January 1977.

** There are only four aquatic sampling sites.

*** Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

† Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

the vegetation. The As levels in small mammals, however, are far below these concentrations that are considered toxic. For example, Gough and Shacklette[10] indicate a 96-hr LD_{50} for laboratory mice and rats as 11.2 ppm arsenite (As^{+3}), the most toxic form of arsenic, and 112 ppm of arsenate (As^{+5}), a less toxic form.

Arsenic is not essential to vegetation[10] but in low dose may stimulate plant growth.[8] Plants generally obtain As through the soil and As is known to accumulate in roots, especially in tips of new roots. Arsenic usually does not accumulate in tops of plants.[6] Normally, most plants can tolerate total As in soil ranging from 1-40 ppm, although some do well in soils containing much higher concentrations. For example, Douglas-fir (*Pseudotsuga menziesii*) growing in soils in the vicinity of heavy metal deposits have been found to contain total As levels as high as 8,200 ppm.[11]

Arsenic toxicity to plants is considered severe,[10] although toxicity depends on the concentration of soluble, not total As in soils. The free element is not considered poisonous while many of its compounds such as arsenite and arsenate forms are extremely lethal.[10] Studies of old orchard soils in the Yakima Valley, Washington indicate that 3.4-9.5 ppm of readily soluble As in the top 6 inches of soil caused unproductive conditions. Soluble As concentrations in the soil greater than 2 ppm causes marked damage to alfalfa and barley.[12] The greatest toxic effect of As is directed at the seedling stage of plants as high soil As concentrations arrest seed germination and reduce seed viability.[6]

Since As does not usually accumulate in above ground portions of plants, animals generally do not accumulate As via ingestion of vegetation. Rather, water is the most common transfer media causing As poisoning in man and animals, although toxicity under natural conditions is unusual.[10] As with plants, compounds of As such as arsenite and arsenate, are much more toxic to animals than elemental As. Toxic doses for a variety of As compounds to selected mammals under laboratory conditions range from LD_{10} of 4 ppm for oral doses of arsenic trioxide (As_2O_3) to LD_{50} of 1,100 ppm for oral doses of lead orthoarsenate ($Pb\ AsO_4$).[13] In addition, Gough and Shacklette[10] report that 13 ppm of As in water as As_2O_2 is toxic to livestock, while 0.4-10 ppm is toxic to man. For aquatic organisms, Malacea[14] states that minimum lethal concentrations of sodium arsenate (Na_5As) are 100 ppm for bitterling and minnow, 160 ppm for carp and 5 ppm for *Daphnia*. Median tolerance limits for minnows under laboratory conditions were found by Boschetti and McLoughlin[15] to be 45 ppm for 24 hours, 29 ppm for 48 hours, and 27 ppm for 72 hours. Fifteen ppm causes no mortality to minnows.[15]

Arsenic poisoning of domestic animals caused by point-source contaminators occurs mostly in late summer or fall.[16] Early symptoms of As poisoning in mammals are abortion[17], vomiting, diarrhea, thirst, emaciation and uncoordination.[16] Milk yield in cows can be reduced up to 75% under extreme conditions.[18] Lillie[16] has documented milk production decreases of 12.5% with an 8% decrease in butterfat as a result of As poisoning.

Pathological changes caused by As poisoning by ingestion or As dust inhalation include gastrointestinal and respiratory tract inflammation, skin lesions, degeneration of body organs, hemorrhage and lung congestion.[19] Baker[20] observes that even in cases of light As contamination, the pathologic effects are cumulative, i.e., the affected animal never recovers. Arsenic also has been shown to be carcinogenic.[4] For example, fish from the Fox River system in Illinois which contain high As levels are found to exhibit a greater frequency of tumors as compared to unpolluted Canadian waters.[21] Borgono and Greiber[22] note that prolonged consumption (12 years) of water high in As (0.3 ppm) produced cutaneous lesions in over 30% of the inhabitants of a city in Chile.

In summary, As, depending on the chemical form and mode of intake, is potentially very toxic to plants and animals. Compared to levels reported in other studies referenced above, arsenic levels in Hat Creek receptors, especially in soil, stream sediment and small mammals, appear to be high. However, no apparent effects of these high levels are presently evident in Hat Creek ecosystems.

(c) Beryllium (Be)

Average concentrations of beryllium (Be) in selected Hat Creek receptors for October 1976 are presented in Table F5-5. Averages ranged from 0.0005 ppm (water, Site 3) to 0.47 ppm (stream sediment, Site 1) for aquatic samples and from 0.10 ppm (shrub, Sites 2 and 5) to 0.53 ppm (soil, Site 1) for terrestrial materials. Stream sediment and soil evidenced the highest levels of Be among aquatic and terrestrial samples, respectively.

Naturally occurring levels of Be in a variety of ecosystem components, as determined from the literature, are given below:

1. water - <0.001 ppm[4]
2. soil - 0.1-40 ppm[4]
   - 6 ppm[9]
   - 0.34-3.1 ppm, Wyoming[5]
3. vegetation - <0.1 ppm[4]
4. animals - <0.0003-0.002 ppm, soft tissues[4]

Based on comparison with the above literature-derived values, Be levels in fish and small-mammals from Hat Creek environs appear to be slightly high. However, these seemingly high concentrations may not be abnormal but rather an indication of the paucity of information in the literature on normal Be concentrations in different ecosystem components.

Beryllium generally accumulates in plant roots and leaves and is considered very toxic to vegetation.[23] Romney et al.[23] reports that visual symptoms of Be toxicity can be observed in the roots of bean plants growing in nutrient solution of 3-5 ppm Be. They also note that Be can become injurious to higher plants if roots come in contact with Be concentration in excess of 1 ppm in the soil (the highest Be level found in Hat Creek soils was 0.53 ppm at Site 1, Pavillion Mountain).

For beans, Romney et al.[23] report that visual symptoms of Be poisoning are first apparent in the roots of seedlings. Roots turn brown within 5 days and fail to resume normal elongation. Stunting of plant foliage

Table F5-5

Average concentration (ppm) of Beryllium (Be) in receptor materials collected during October 1976

Receptors	Site 1 Mean*	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
<u>Aquatic</u> **												
Water	0.0012	0.0002	0.0012	0.0001	0.0005	0.0000	0.0007	0.0001	1		0.0009	0.0003
Stream sediment	< 0.47 >	0.27	0.10	0.00	0.10	0.00	0.27	0.17			< 0.23 >	0.08
Fish ***	< 0.20 >	0.00	< 0.17 >	0.03			< 0.17 >	0.03			< 0.18 >	0.01
<u>Terrestrial</u>												
Soil	0.53	0.24	0.43	0.28	0.30	0.10	< 0.33 >	0.15	< 0.43 >	0.17	< 0.41 >	0.08
Shrub	< 0.13 >	0.03	< 0.10 >	0.00	< 0.17 >	0.07	< 0.17 >	0.03	< 0.10 >	0.00	< 0.13 >	0.02
Grass	< 0.17 >	0.03	< 0.23 >	0.03	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.19 >	0.01
Lichen	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Small mammal	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

occurs within 10 days, although normal foliage coloration is retained. Flowers mature earlier and fruits are less mature when harvested than in the controls. Romney et al.[23] indicate also that Be may inhibit the normal function of plant phosphatase enzyme systems.

Beryllium is also considered to be very toxic to animals.[4] Toxic concentrations for several laboratory animals range from 80-146 ppm (oral dose) for different Be compounds.[13] Tarzwell and Henderson[24] report a 96-hour LC_{50} of 11 ppm Be for fathead minnows in a water of hardness 400 ppm. They suggest a safe concentration of 1.1 ppm Be for fathead minnows in water of similar hardness. However, they emphasize that 1.1 ppm in water softer than 400 ppm $CaCO_4$ would most likely be toxic (Hat Creek and Bonaparte River averaged 0.0011 ppm Be). Slonim and Slonim[25] report safe concentrations as between 0.011 ppm (100 ppm hardness) and 1.1 ppm (400 ppm hardness) Be for the common guppy.

Valkovic[8] states that high Be levels are correlated with bone, breast and uterine cancers in animals. Christensen and Lugenbyhl[13] note that Be produces neoplastic effects in pigs and is carcinogenic in experimental animals when inhaled as beryllium fluoride. Maniloff, Coleman and Miller[26] report that Be is capable of firmly attaching proteins to cell surfaces. As a result, cells are desensitized against the agglutinating action of antibodies prepared against the bound protein species, thus, reducing the animal's resistance to disease.

In summary, Be is considered very toxic to plants and animals. However, levels presently found in Hat Creek receptors are well below reported toxic concentrations.

(d) Boron (B)

Average concentrations of boron (B) in selected Hat Creek receptors sampled during October 1976 are provided in Table F5-6. Average B levels ranged from 0.015 ppm (water, Site 3) to 8.33 ppm (stream sediment, Site 1) in aquatic samples. Aquatic Site 1 (Upper Hat Creek) had the highest over-

Table F5-6

Average concentration (ppm) of Boron (B) in receptor materials collected during October 1976

Receptors	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> *												
Water	0.044	0.005	0.041	0.005	0.015	0.001	0.023	0.003			0.031	0.014
Stream sediment	8.33	3.18	1.67	0.67	3.00	1.00	6.67	3.18			4.92	1.28
Fish **	1.90	1.05	1.03	0.49			0.97	0.52			1.30	0.40
<u>Terrestrial</u>												
Soil	6.33	0.67	15.00	6.00	3.00	1.00	11.67	3.76	8.67	4.33	8.93	1.80
Shrub	10.67	2.03	11.67	0.88	46.67	13.28	16.67	3.71	111.00	40.05	39.33	12.47
Grass	2.67	0.67	3.00	1.00	2.33	0.33	5.00	1.53	2.33	0.88	3.07	0.45
Lichen	1.57	0.43	1.80	1.11	2.57	0.98	1.83	1.08	2.27	0.93	2.01	0.37
Small mammal	0.40	0.12	0.73	0.22	0.37	0.03	1.23	0.88	1.10	0.45	0.77	0.20

* There are only four aquatic sampling sites

** No fish could be collected at Site 3

all concentrations of B among sites, while stream sediment evidenced the highest B levels among samples. Average B levels in terrestrial samples ranged from 0.37 ppm (small mammals, Site 3) to 111.00 ppm (shrub, Site 5). Except for the relatively high concentration of B in shrubs at Site 3 (Arrowstone Creek) and Site 5 (Ashcroft), B levels did not differ markedly for specific materials among sites.

Naturally occurring concentrations of boron found in selected ecosystem components from other regions as determined from the literature, are summarized below:

1. water - 0.013 ppm[4]
   - 0.010 ppm[8]
2. soil - 10 ppm, range 2-100 ppm with highest levels found in saline and alkaline soils[4]
   - 20-35 ppm, Wyoming[5]
3. vegetation - 50 ppm[4]
   - 120 ppm, fruits of different plants[8]
   - 2550 ppm, legumes[7]
   - 1.5 ppm, cereal and hay[7]
4. animals - 0.5 ppm[4]
   - 0.51-1.0 ppm, cow milk[7]

Except perhaps for B-levels in shrubs at Site 5 (Ashcroft), B concentrations in Hat Creek samples are within the range of values reported in studies referenced above. Average B concentrations in Site 5 shrubs represents an apparent anomaly, as it is not consistent with B levels with other receptors at this site, especially in soil. The primary uptake of B by plants is through the soil and high B levels in soil should be reflected in high concentrations in plants. However, plants respond primarily to soil solution B independently of the amount of B absorbed by soil. Consequently, conditions affecting equilibria between absorbed and soluble B are highly relevant to consideration of plant uptake of B and plant nutrition.[27] The amount of B released and available in soil is related to the nature of the B material in the soil and type of weathering agent. Absorption by plants is highest in sandy loam and loamy soils and not in clay loam soils.[6]

Boron is an essential element for plant and algae nutrition. It plays an important role in organic translocation in plants and plant growth regulator responses (essential to the biosynthesis of auxins in plant meristems). Boron is also important to plant enzymatic responses, cell division, cell maturation, nucleic acid metabolism, phenolic acid biosynthesis and lignification, and carbohydrate metabolism (affecting cell wall metabolism such as pectin synthesis of germinating pollen).[27]

The difference between required amounts of B and toxic amounts for vegetation is reportedly very small, commonly 1-2 ppm of soluble B in soil. Kothny[27] reports that solution culture concentrations of 0.05-0.10 ppm are ordinarily safe and adequate for many plants, whereas concentrations of 0.50-1.0 ppm are frequently excessively high for B sensitive plants. Some plants, however, can accumulate high concentrations of B in foliar tissue without any toxic effect. For example, Kothny[27] notes that toxic symptoms are manifested in corn leaf tissue at 25 ppm B but cotton leaf tissue can accumulate 1,625 ppm B before toxic effects are observed.

Early stages of B excess in vegetation are characterized by leaf-tip yellowing. At moderate to acute stages, B toxicity produces a progressive necrosis of the leaf beginning at the tip and/or margins as a chlorotic yellowing and finally spreading between the lateral veins between the midrib. Swelling of nodes, gumming at internodes and bark-cracking are other symptoms.[7]

Boron has not been proven to be essential to animal nutrition. Boron in food is almost completely absorbed and excreted, largely in the urine. When high B intake does occur, similar high absorption and urinary excretion takes place, but toxic B levels may be temporarily retained in the tissues, especially in the brain.[7]

Boron levels of 0.2-2.2 ppm in drinking water or 5300 ppm of B/day dry weight of diet is reported to be toxic to lambs.[10] Bowen[4] reports an LD_{50} of 2000 ppm B for mice and that an oral dose of 0.15 mg/day is toxic to rats. Also he indicates that 50 ppm to lead fluroborate [$Pb\ (BF_4)_2$] and/or thallium fluroborate ($BF_4\ Tl$) are toxic to rats.

In summary, B is moderately toxic to plants and animals. Boron levels in Hat Creek receptors appear to be far below those levels determined as toxic.

(e) Cadmium (Cd)

Average concentrations of cadmium (Cd) in selected Hat Creek receptors collected during October 1976 are provided in Table F5-7. Average Cd levels ranged from 0.0018 ppm (water, Site 3) to 0.47 ppm (stream sediment, Site 4) in aquatic samples. Cadmium levels in stream sediment were slightly higher at sites on the Bonaparte River (Sites 3 and 4). For terrestrial samples, average Cd levels ranged from 0.27 ppm (grass, Site 1) to 1.13 ppm (soil, Site 4). Soil and shrub had the highest Cd concentration of all samples, particularly at Site 4 (Cornwall Mountain).

Concentration of Cd in selected receptors sampled during January and May 1977 are shown in Table F5-8. The results suggest high seasonal variability in stream sediment, soil and shrubs. Cadmium concentrations in these receptors were higher in January and May 1977 than in October 1976.

Naturally occurring levels of Cd in a variety of ecosystem components from other regions are summarized below:

1. water - 0.08 ppm[4]
2. soils - 0.06 ppm[4]
   - 0.15-02 ppm[28]
   - 1.5 ppm, Wyoming[5]
3. vegetation - 0.60 ppm[4]
   - 0.1-1.0 ppm, food plants[10]
   - 0.16-1.9 ppm, Wyoming[5]
4. animals - 0.50 ppm[4]
   - 0.02-0.1 ppm (wet weight) fish in New York[28]
   - 0.04-0.14 ppm, deer mice, Wyoming[5]

Table F5-7

Average concentration (ppm) of Cadmium (Cd) in receptor materials collected during October 1976

Receptors	Site 1 Mean*	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
Aquatic **												
Water	0.0032	0.0002	0.0033	0.0000	0.0018	0.0008	0.0028	0.0000			0.0027	0.0006
Stream sediment	< 0.37 >	0.15	< 0.23 >	0.03	< 0.43 >	0.09	< 0.47 >	0.22			< 0.38 >	0.07
Fish ***	< 0.30 >	0.06	< 0.17 >	0.03			< 0.30 >	0.12			< 0.26 >	0.04
Terrestrial												
Soil	< 0.57 >	0.03	< 0.43 >	0.07	< 0.33 >	0.09	< 1.13 >	0.45	< 0.43 >	0.17	< 0.58 >	0.11
Shrub	< 0.87 >	0.13	< 0.33 >	0.07	< 0.30 >	0.10	< 0.83 >	0.09	< 0.47 >	0.09	< 0.56 >	0.07
Grass	< 0.27 >	0.03	< 0.33 >	0.03	< 0.30 >	0.06	< 0.30 >	0.12	< 0.37 >	0.03	< 0.31 >	0.03
Lichen	< 0.33 >	0.03	< 0.40 >	0.06	< 0.33 >	0.03	< 0.30 >	0.00	< 0.33 >	0.03	< 0.34 >	0.02
Small mammal	< 0.40 >	0.06	< 0.33 >	0.07	< 0.37 >	0.07	< 0.60 >	0.21	< 0.60 >	0.21	< 0.46 >	0.06

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Table F5-8

Average concentration (ppm) of Cadmium (Cd) in receptor material collected during January and May 1977

	January 1977*							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic**														
Water	<0.0013	<0.0013	<0.0010	<0.0013		<0.0013	>0.0001	<0.005	<0.005	<0.006	<0.005		<0.006	>0.0
Stream sediment	5.0	6.5	7.5	6.1		6.28	1.0	6.1	<0.7	<0.7	4.8		2.83	2.6
Fish***	- -	- -	- -	- -				<0.1	<0.1	- -	- -		<0.10	>0.0
Terrestrial														
Soil	4.5	9.5	12.5	6.6	18.5	10.30	5.5	4.9	5.3	14	6.4	<0.3	<6.18	>4.6
Shrub	- -	- -	- -	- -	- -			2.0	1.1	0.5	2.0	1.1	1.34	0.7
Grass†	- -	- -	- -	- -	- -			<0.7	<0.7	<0.07	- -	<0.7	<0.54	>0.3
Lichen	0.2	0.4	0.5	0.5	<0.2	<0.36	>0.2	<0.4	0.4	0.4	0.5	0.4	0.42	0.04
Small mammal	- -	- -	- -	- -	- -			<0.3	<0.15	<0.3	<0.3	<0.3	<0.27	>0.07

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* Only water, stream sediment, soil and lichen were collected during January 1977.

** There are only four aquatic sampling sites.

*** Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

† Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

Cadmium concentrations in soil and stream sediment recorded for January and May 1977 appear to exceed levels reported in the literature. However, no toxicity to vegetation growing on high Cd substrate has ever been demonstrated under natural conditions.[10] Cadmium concentrations in other Hat Creek materials are consistent with reported Cd levels except perhaps for small mammals which exhibited levels as high as 0.60 ppm on Sites 4 (Cornwall Mountain) and 5 (Ashcroft) during October 1976. However, 0.60 ppm is well below the concentration known to result in toxic effects.

Cadmium is a non-essential element to vegetation.[4,7] However, it can be readily absorbed and consequently is detectable in most plants.[8] Plants absorb Cd from soil through root systems or from leaf surfaces through the stomata.[29]

The general toxicity of Cd is moderate to vegetation.[10] It is normally non-toxic at 1 ppm for land plants and 0.01 ppm for aquatic plants.[8,30] Fleischer et al.[28] reports that Cd levels in contaminated soils are often well below concentrations required to damage plants. Allaway[31] indicates that 3 ppm of Cd in plant tissues are necessary to depress growth. Primary effects of Cd on vegetation include a reduction in leaf transpiration and reduction in net photosynthesis through a decrease in total chloroplasts.[32] Physical symptoms of the latter effect include foliar chlorosis and necrosis. Adverse effects on ATP respiration and mitochondria function have been observed at 2 ppm Cd in culture solution for corn.[33]

Bryophytes may provide a sensitive indication of Cd pollution. A moss species, *Hypnum cupressifermel*, has been used as an index of airborne Cd pollution in Sweden. Normal Cd levels in this moss are 0.7-1.2 ppm while contamination levels approach 7.5 ppm. A lichen, *Cladonna alpestris*, is also an indicator of Cd pollution. Normal Cd levels are 0.1-0.2 ppm in this species while the contaminated level is about 1 ppm[28] (Cd levels in Hat Creek lichens were below 0.5 ppm).

Cadmium is thought to be non-essential to animals.[47] Animals are exposed to Cd through ingestion of food and water and inhalation.[28] Poisoning of herbivorous animals via ingestion of Cd in plants is unlikely since the absorption of Cd from the gastrointestinal tract is poor.[28] However, mammals eliminate ingested Cd slowly and it tends to accumulate in the liver and kidney.[10] Under such conditions Cd could exert a moderate to high toxic effect on mammals[31] although it has been used as an antihelminthic drug in swine and poultry at concentrations ranging from 30-1,000 ppm in the diet.[34]

Goodman and Roberts[35] report that grass contaminated by industrial pollution containing 9.9 ppm Cd is lethal to horses, a sensitive species. They indicated that as much as 40 ppm Cd could be accumulated by grass from industrial pollution. In fact, Cd was suspected of killing a horse which contained 410 ppm of the element in its kidney and 80 ppm in its liver.[31] Underwood[7] found that 45 ppm Cd in the diet of rats for six months caused slight toxic symptoms. Bowen[4] reports that a 500 ppm Cd per day diet is toxic to rats, whereas 1600 ppm per day is lethal. Gough and Shacklette[10] note that a subtoxic level of 5 ppm Cd in the drinking water of rats given for 180-240 days produces systolic hypertension. Other investigations show that 30-60 ppm Cd in the diet of sheep for 191 days reduces growth and food intake.[36] Toxic doses of Cd compounds to various laboratory animals range from an LD_{12} of 250 ppm cadmium fluoborate [$Cd\ (BF_4)_2$] to an LD_{50} of 72 ppm cadmium oxide (Cd O).

The primary toxic effect of Cd on terrestrial animals is inhibition of respiratory oxygen exchange.[37] However, the manifestation of Cd poisoning differs with different routes of contamination. Inhalation of Cd produces primary pulmonary disorders[16] with approximately 40% inhaled Cd retained in the animal.[38] Chronic exposure to Cd through the respiratory tract produces emphysema in experimental animals.[28] Miller[38] reports also that Cd increases error in cellular DNA replication in chromosomes.

Low level Cd concentrations may severely affect the reproductive potential of mammalian populations through an increase in embryonic mortality and/or decrease in sperm viability.[39] Schroeder and Mitchener[40] showed that 10 ppm Cd causes the loss of a mouse strain within two generations.

Another pathological effect caused by Cd is an inhibition of hemoglobin production resulting from Cd interference with incorporation of iron into hemoglobin.[41] The symptoms of this are virtually the same as iron deficient anemia. Hematocrit values decrease in all Cd-fed animals[42] and may prove to be a sensitive indicator of Cd poisoning. Cadmium can also produce hemolysis,[26] abnormal liver,[43] kidneys[44] and osteomalasia in rats similar to that of Cd induced Itai-Itai disease observed in a Japanese fishing village population.[45]

Cadmium appears to be highly toxic to aquatic organisms at low concentrations. Carter and Cameron[46] report that Cd was the most toxic trace element to aquatic invertebrates. Davies and Goettl[47] state that Cd levels as low as 0.0015 ppm in water could cause toxic effects on small rainbow trout. Accordingly, Cd could be of some concern to Hat Creek and vicinity fisheries as Cd levels in Hat Creek and Bonaparte River averaged 0.0013 ppm. More conservative estimates of Cd levels in water harmful to rainbow trout range from 0.003 to 0.01 ppm.[47,48] Bilinski and Jonas[49] report that 10 ppm of $CdCl_2$ in rainbow trout gill tissue inhibit lactate oxidation by gill filaments. Other effects of Cd toxicity on fishes include interruption of energy production by blocking oxygen uptake,[50] muscle spasm[51] and pathological changes in the intestinal tract, kidney and gills.[52]

In summary, existing Cd levels in certain Hat Creek receptors, such as soil and stream sediment, exceed concentrations reported in studies referenced above. Moreover, levels at which Cd exerts toxic effects in vegetation are not high although many species are Cd tolerant and can accumulate Cd. However, lethal effects on some animals (i.e., horses) ingesting grass with high Cd levels has been demonstrated near industrial sources.

(f) Chromium (Cr)

Average concentration of chromium (Cr) in selected Hat Creek receptor materials collected during October 1976 are presented in Table F5-9. Average Cr levels in aquatic samples ranged from about 0.01 ppm (water,

Table F5-9

Average concentration (ppm) of Chromium (Cr) in receptor materials collected during October 1976

Receptors	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean*	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> **												
Water	0.0113	0.0010	0.0149	0.0006	0.0101	0.0005	0.0123	0.0006			0.0121	0.0020
Stream sediment	61.67	18.56	261.33	100.06	293.33	158.99	> 526.67	> 241.13			> 285.75	> 88.07
Fish ***	9.83	8.59	2.67	0.88			3.53	2.74			5.34	2.85
<u>Terrestrial</u>												
Soil	88.33	11.89	154.33	39.65	530.00	162.89	82.67	37.70	380.00	240.00	247.07	68.98
Shrub	2.00	0.00	1.67	0.33	9.00	5.29	3.33	0.88	6.00	3.21	4.40	1.29
Grass	3.67	1.20	8.33	2.33	3.67	1.20	< 1.10	> 0.47	6.67	1.67	< 4.69	> 0.89
Lichen	5.67	0.67	9.67	2.67	11.33	4.26	5.00	0.00	7.00	1.53	7.73	1.10
Small mammal	3.67	0.88	3.00	0.58	2.00	0.00	4.00	1.00	5.33	2.03	3.60	0.51

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* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Site 3) to >526.67 ppm (stream sediment, Site 3). Chromium concentrations were fairly high in fish and stream sediment samples at all sites although the results were variable. Stream sediment levels increased progressively from Site 1 (upper Hat Creek) downstream to Site 4 (lower Bonaparte River). For terrestrial receptors, Cr levels ranged from <1.10 ppm (grass, Site 4) to 530.00 ppm (soil, Site 3). Soil contained the highest Cr concentration among receptors at each site but, as with stream sediment, data was highly variable. Soils at Site 3 (Arrowstone Creek) had the highest Cr levels of any site for all three sampling periods.

Chromium concentration in material collected during January and May 1977 are provided in Table F5-10. As with the results reported for As and Cd, Cr showed large variability among sampling times. However, contrary to the As and Cd temporal fluctuation, Cr concentrations appeared to decrease in receptors from October 1976 to January and May 1977.

Concentrations of Cr in different ecosystem components, as derived from the literature, are summarized below:

1. river water - 0.001-0.010 ppm[53]
2. municipal water - 0.035 ppm[53]
3. soil
    - 250 ppm as chromic oxide, higher concentrations in igneous rocks, shales and clays, and in phosphorites[53]
    - 16-46 ppm, Wyoming[5]
4. food vegetation
    - 0.020-0.080 ppm, human[53]
    - 0.59 ppm, hay[53]
5. non-food vegetation
    - 39-48 ppm, lower plants (lichens, grasses)[9]
    - 4.9-7.6 ppm, higher plants (trees, shrubs)[9]
    - 6.5-180 ppm, Wyoming[5]
6. land animals
    - 0.075 ppm[4]
    - 0.02-0.33, deer mice, Wyoming[5]

Table F5-10

Average concentration (ppm) of Chromium (Cr) in receptor material collected during January and May 1977

Receptors	January 1977[*]							May 1977						
						All Sites							All Sites	
	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic[**]														
Water	0.0167	0.0200	0.0097	<0.0067		<0.0133	>0.0025	<0.002	<0.002	<0.002	<0.002		<0.002	>0.0
Stream sediment	38	3.5	166	102		77.38	71.8	30	61	121	103		78.80	41.1
Fish[***]	- -	- -	- -	- -				2.2	2.0	- -	- -		2.10	0.1
Terrestrial														
Soil	25	44	120	8.9	9.4	41.46	46.2	24	35	187	53	14	62.60	71.0
Shrub	- -	- -	- -	- -	- -			2.8	3.5	3.3	3.2	3.8	3.32	0.4
Grass[†]	- -	- -	- -	- -	- -			5.1	4.1	6.1	- -	6.7	5.50	1.1
Lichen	5.9	8.2	10	8.8	6.2	7.82	1.7	2.2	7.6	5.6	4.6	7.4	5.48	2.2
Small mammal	- -	- -	- -	- -	- -			3.1	4.0	4.0	7.4	6.1	4.92	1.8

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[*] Only water, stream sediment, soil and lichen were collected during January 1977.

[**] There are only four aquatic sampling sites.

[***] Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

[†] Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May.

Based on the above information, it appears that Cr levels in fish and small mammals in the vicinity of Hat Creek may be high compared to data reported in the above studies. Chromium concentrations in other Hat Creek receptors are consistent with Cr levels measured elsewhere.

There are different opinions on whether Cr is an essential element to vegetation. Chapman[6] reports that the addition of Cr in soils deficient in Cr stimulates plant growth. He adds that Cr increases lettuce growth at 0.1 ppm and corn seedling growth at 0.5 ppm. Chromium can also increase nitrogen fixation in peas although the physiological mechanisms are poorly understood.[6] On the other hand, NAS[53] reports that Cr is non-essential to vegetation.

The toxicity of Cr to vegetation depends on its chemical form, solubility and concentration. Chromium may interact synergistically with Ni, Co and Mg in soil in exerting its toxic effects. Chapman[6] reports that 8-16 ppm of Cr as chromic or chromate ion produces chlorosis on sugar beets in sand culture. Chromium (Cr^{+6}) at concentrations between 0.03-64 ppm may inhibit the growth of algae.[53] Some bryophytes may act as an ion exchanger and accumulate large amounts of Cr without injury. For instance, in the region of a Swedish ferro-alloy plant, the concentration of Cr in the moss *Hypnum cupressiforine* ranges as high as 12,000 ppm compared with a normal value of 10 ppm. However, no damage to moss is reported.[53]

One or more specific organic Cr complexes (characterized by low molecular weight, water solubility and heat stability) designated as the "glucose tolerance factor" seem to be physiologically active in such a way as to meet the criteria for an essential element to animals.[53] Its deficiency results in impaired glucose metabolism due to poor effectiveness of insulin. Chromium may also be involved in serum cholesterol homeostasis. Underwood[7] indicates that Cr is necessary to incorporate several amino acids into heart protein and to enhance growth, especially in males.

Non-dietary exposure from the environment via air and water furnish a significant proportion of Cr^{+6} accumulated by animals. Highest concentrations come from air.[53] Chromium in food is generally poorly absorbed by the GI tract and is excreted in urine (80%) and feces (20%).[53]

Using low tracer doses of $CrCl_2$, NAS[53] found that the uptake of Cr in rats was highest in ovaries and spleen, followed by kidney, liver, lung, heart, pancreas and brain in decreasing order. NAS[53] also notes that the distribution of the injected glucose tolerance factor is different; liver accumulates the highest concentration followed by uterus, kidney, and bone.

The hexavalent form of Cr is more toxic than the trivalent because of its oxidizing potential and its easy penetration through biologic membranes. Concentrations of Cr in excess of 1.0 ppm are toxic in enzyme and bacterial systems.[53] At 5 ppm in drinking water, Cr^{+6} was found to accumulate in rats, but it caused no changes in growth rate, food intake or bood chemistry. However, chronic toxicity has been observed in several mammalian species' drinking water containing greater than 5 ppm Cr^{+6}. Mixed dust containing 7 mg/m^3 of CrO_3 was shown to be fatal to laboratory mice over a 10 day exposure period and is barely tolerated by rats. The same study[53] reports 500 ppm of potassium chromate in drinking water and 0.12% of zinc or potassium chromate in feed were the maximal non-toxic concentrations to rats.

Klassen, Hasfurther and Young[54] report that bluegill and several varieties of sunfish could survive for a month in water containing 50 ppm of Cr^{+6}. Rainbow trout are capable of accumulating Cr^{+6} from water containing as little as 0.001 ppm. At a concentration of 0.01 ppm Cr^{+6} and less, the uptake of Cr levels off after 10 days indicating excretion is equal to uptake. Uptake of Cr by fish is passive; the amount accumulated is dependent on the concentration in the water and the duration of exposure.[55] The amount of Cr accumulated by fish is not a measure of the lethal dose.[55] Some fish exposed to 5-10 ppm Cr survive for a limited time with a total body concentration of Cr far in excess of that accumulated by fish that die as a result of longer exposure to much lower levels. This may indicate that acute high-level exposure to Cr is less detrimental to fish than low level chronic exposure. Vinogradov[9] reports that the maximum acceptable chronic no-effect concentration of Cr^{+6} in water is 0.2-0.35 ppm for rainbow and brook trout (Hat Creek waters averaged less than 0.013 ppm Cr).

Symptoms of Cr poisoning in animals include neoplasms[13] and marked irritation and corrosion of the GI tract. Vomiting, diarrhea, gastric and intestinal hemorrhage are serious symptoms observed in dogs. Kidney lesions are the most common type of systemic damage in all species.[53] Schiffman and Fromm[56] found that the hematocrit of trout undergo highly significant increase when the fish are exposed to 20 ppm Cr.

In summary, Cr, based on information in the literature, Cr appears to be relatively toxic to both plants and animals. Chromium levels in animals collected from Hat Creek environs are higher than values reported in other studies referenced above. Values for other receptors are of the same magnitude as levels reported in these studies. All Cr concentrations measured in Hat Creek materials are far below toxic levels.

(g) Cobalt (Co)

Average concentration of cobalt (Co) in Hat Creek receptors sampled during October 1976 are provided in Table F5-11. Averages ranged from 0.003 ppm (water, Sites 1 and 3) to 22 ppm (stream sediment, Site 4) in aquatic samples and from 0.20 ppm (grass, Site 4) to 21.33 ppm (soil, Site 3) in terrestrial samples. As with previous elements, Co was highest in stream sediment and soil samples. Trends in Co concentration among sites were not apparent for other sampled receptors.

Naturally occurring concentrations of Co in ecosystem components from different regions are summarized below.

1. water - 0.0009 ppm[4]
   - 0.0058 ppm[8]
2. soils - 8 ppm[4]
   - 1-40 ppm[6]
   - 3.8-39 ppm, Wyoming[5]
3. vegetation - 0.5 ppm[4]
   - <1 ppm[6,8]
   - 0.26-2.6 ppm, Wyoming[5]

Table F5-11

Average concentration (ppm) of Cobalt (Co) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean *	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> **												
Water	0.003	0.001	0.006	0.0017	0.003	0.001	0.004	0.000			0.004	0.0014
Stream sediment	8.33	2.91	6.00	1.00	14.33	3.84	22.00	4.04			12.67	2.31
Fish ***	0.37	0.15	< 0.30 >	0.20			0.37	0.03			< 0.34 >	0.07
<u>Terrestrial</u>												
Soil	13.33	1.67	12.00	1.53	21.33	11.35	10.67	0.33	7.33	1.45	12.93	2.33
Shrub	0.43	0.12	3.93	2.56	4.00	1.53	0.93	0.07	1.43	0.01	2.15	0.66
Grass	< 0.23 >	0.05	< 0.53 >	0.24	< 0.27 >	0.07	< 0.20 >	0.00	< 0.30 >	0.06	< 0.31 >	0.05
Lichen	< 1.20 >	0.42	1.83	0.73	0.93	0.07	2.00	0.58	< 1.57 >	1.22	< 1.51 >	0.29
Small mammal	< 0.87 >	0.57	< 0.47 >	0.22	< 0.27 >	0.03	< 1.77 >	1.13	< 1.43 >	0.57	< 0.96 >	0.28

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

4. animals - 0.03 ppm[4]
- 0.02-0.22 ppm[7]
- 0.02-0.33 ppm, deer mice, Wyoming[5]

Except for small mammals, results of Co analysis on Hat Creek receptors are similar to those concentrations reported in the literature. Small mammals, characterized by high Co levels at Site 4 (Cornwall Mountain) and Site 5 (Ashcroft), exceeded levels reported in studies referenced above.

Cobalt is an essential element for blue green algae, some bacteria seed plants, and green algae because it catalyzes enzyme activation for nitrogen.[4] However, presently there is no evidence that Co is essential to higher plants.[8]

Bowen[4] reports that Co is extremely toxic to plants. Chapman[6] found that small amounts of Co in solution cultures, sometimes as low as 0.1 ppm, produces toxic effects on many crop species. He adds, however, that naturally occurring excess of Co in soils is unlikely as none yet have been reported. Symptoms of Co toxicity to vegetation include depressed growth, chlorosis, necrosis and even death of plants.[6]

Cobalt is essential for ruminant vitamin B_{12} production and is unique among trace elements in this regard; it is biologically active for the higher animals only when incorporated in a vitamin.[8] Underwood[7] reports that sheep and cattle require about 200 mg/day of Co. He adds that the element may also be essential for non-ruminants.

Ingested Co is poorly absorbed and is eliminated mainly in the feces.[7] It may accumulate in the liver, kidney, and bones of animals.[4,7,8,10]

Concentration of Co in body tissues that are non-toxic are: 2.4 ppm for rats, 10 ppm for dogs, and 3 ppm for sheep.[10] Underwood[7] states that a dietary intake of 150 ppm of Co can be tolerated by sheep for up to 8 weeks. Gough and Shacklette[10] found that sheep could tolerate 0.35% per day of Co in their diet with no ill effects.

Concentrations of Co that are considered toxic for selected organisms are summarized below.

1. cattle - 1 ppm, body weight[10]
2. sheep - 4010 ppm, diet[7]
   - 300 ppm, body weight as a soluble salt[7]
   - 40-60 ppm, body weight[7]
3. rats - 70/ ppm day, diet[4]
4. man - 670 ppm/day, diet[4]

Hem[57] found that trace amounts of Co seemed to stimulate growth of aquatic organisms but he observed a toxic effect on stickleback fish at about 10 ppm.

Cobalt poisoning may cause a severely depressed appetite, weight loss, and anemia in sheep, and has resulted in polycythemia, reticulocytosis, and increased blood volume in mice, rabbits, guinea pigs, dogs, pigs, ducks, chickens and man.[7] Petechial and ecchymotic hemorrhage in the small intestine, fatty-infiltration of the liver, slight pulmonary edema and congestion are other effects of Co toxicity in mammals.[58] Shabalina[59] found that non-toxic doses of cobalt chloride in the diet of 2 year old rainbow trout increases temperature tolerance by 1.6°C and causes body fat redistribution. Toxic doses may also produce grastrointestinal hemorrhages.

In summary, Co is moderately to severely toxic to plants and animals. Cobalt concentration in sampled Hat Creek receptors appear to be similar to values reported in the literature as referenced in the preceding discussion.

(h) Copper (Cu)

Average concentrations of copper (Cu) in Hat Creek receptors collected during October 1976 are shown in Table F5-12. Averages ranged from 0.0028 ppm (water, Site 1) to 49.00 ppm (stream sediment, Site 3) for aquatic samples. Although variability was high, the Bonaparte River (Sites 3 and 4) had higher

Table F5-12

Average concentration (ppm) of Copper (Cu) in receptor materials collected during October 1976

Receptors	Site 1 Mean	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean *	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
<u>Aquatic</u> **												
Water	0.0028	0.0006	0.0098	0.011	0.0111	0.0085	0.0041	0.0042			0.0069	0.0041
Stream sediment	26.67	3.71	25.33	9.49	49.00	16.50	33.67	7.54			33.67	5.26
Fish ***	4.67	0.88	4.33	0.67			4.00	1.00			4.33	0.44
<u>Terrestrial</u>												
Soil	40.33	21.17	58.33	11.26	37.67	20.19	34.33	12.00	65.00	52.56	47.13	11.03
Shrub	100.00	90.00	31.33	13.53	14.33	3.84	10.67	1.76	21.33	4.26	35.53	17.76
Grass	5.33	1.45	13.67	4.48	6.33	2.85	4.67	0.88	6.67	0.33	7.33	1.28
Lichen	12.00	7.51	9.67	4.26	8.67	0.88	16.33	4.70	32.33	9.33	15.00	3.26
Small mammal	70.67	54.67	11.67	2.40	171.67	164.17	23.67	12.17	13.33	7.88	58.20	33.53

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

levels of Cu in stream sediment than Hat Creek (Sites 1 and 2). No differences in Cu levels in fish were evident between the two streams. For terrestrial samples, means ranged from 4.67 ppm (grass, Site 4) to 171.67 ppm (small mammals, Site 3). Variability was extremely high for soil, shrub and small mammal samples. This precludes adequate evaluation of Cu in these samples and comparison of Cu levels between sites.

Copper concentrations in receptors sampled during January and May 1977 are provided in Table F5-13. In general, the results are similar to the October 1976 data. However, as for previous elements, the small sample size precludes formulation of definite conclusions regarding seasonal, site and receptor differences in Cu concentrations.

Concentrations of Cu as determined by the literature are shown for a variety of ecosystem components below.

1. water
   - 0.01 ppm[4]
   - 0.00083-0.00105 ppm, North America[8]
2. soil
   - 2-100 ppm[4]
   - 2-15 ppm, Western U.S. soil[6]
   - 4-300 ppm[10]
   - 6-33 ppm Wyoming[5]
3. vegetation
   - 5-20 ppm[6,8]
   - 14 ppm[4]
   - 6-12 ppm, Utah wheat[6]
   - 6-10 ppm, Oat cereals[6]
   - 1.3-20 ppm, Wyoming[5]
4. animals
   - 2.4 ppm[4]
   - 1.9-7.5 ppm, Wyoming[5]

Although data variability was extremely high, Cu concentrations in small mammals appear to be high as compared with the literature. The high variability is emphasized by comparison of results from Site 3 (Arrowstone) and 4 (Cornwall Mountain). Between October 1976 and May 1977, levels went from about 171 ppm to 10 ppm at Site 3 and increased from 24 ppm to 176 ppm at

Table F5-13

Average concentration (ppm) of Copper (Cu) in receptor material collected during January and May 1977

Receptors	January 1977[*]							May 1977						
						All Sites							All Sites	
	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic[**]														
Water	0.0057	0.0083	<0.0037	0.0070		<0.0062	≥0.0008	<0.01	<0.01	<0.01	<0.01		<0.01	>0.0
Stream sediment	48	37	25	16		31.50	14.0	28	42	4.8	26		25.20	15.4
Fish[***]	- -	- -	- -	- -				3.6	2.6	- -	- -		3.10	0.7
Terrestrial														
Soil	47	21	25	42	49	36.80	12.9	16	28	76	19	1.8	28.20	28.4
Shrub	- -	- -	- -	- -	- -			2.3	7.9	15	7.4	15	9.52	5.5
Grass†	- -	- -	- -	- -	- -			7.9	7.8	10	- -	15	10.18	3.4
Lichen	9.3	29	7.6	4.1	95	29.00	38.2	14	10	11	7.0	45	17.40	15.6
Small mammal	- -	- -	- -	- -	- -			11	7.5	9.7	176	8.5	42.54	74.6

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[*] *Only water, stream sediment, soil and lichen were collected during January 1977.*

[**] There are only four aquatic sampling sites.

[***] Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

† Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

Site 4. The implications of the high Cu observed in small mammals are unclear, although the literature as discussed below suggests that most animals can tolerate much higher concentrations of Cu.

Copper is an essential element to vegetation.[4,8,10] It is a required constituent of numerous essential enzymes and proteins, an important example of which is the cytochrome oxidase, the terminal oxidase in most plants.[26] Peterson[60] reports that Cu can be accumulated to a certain extent by plants. Williams,[61] however, indicates that the element tends to remain in roots of vascular plants making it unavailable to grazing herbivores. Several species of bryophytes (i.e., mosses and lichens) may serve as an indicator of plant exposure to high Cu levels.[4]

Copper deficiencies in agricultural soils are much more common than Cu excesses; fertilization with Cu, especially on highly organic or sandy soils, is a common practice.[10] Toxic symptoms in plants may result from approximately 20 ppm in tissues[6,8] (shrubs sampled at three different sites during October 1976 evidenced values higher than 20 ppm Cu). Copper toxicity is governed by soil pH. Chapman[6] found that spinach and gladiolus do not develop Cu toxicity at soil Cu concentrations of 93-130 ppm at pH 4.5-4.7. Seedlings of some grass species such as grass (*Agrostis* sp.) have been shown to develop a tolerance to Cu over a 10 week period.[62] Hemkes and Hartmen[63] report that some grain species can accumulate up to 15 ppm Cu which may be a hazard to grazing sheep.

Severe toxicity to snapbeans may occur when tissue levels of Cu exceed 40 ppm.[64] A reduced yield may result in tissue Cu levels of 20-30 ppm.[64] Bell and Rickard[65] in a laboratory study found that 0.5-50 ppm of copper acetate in cauliflower, lettuce, potato and carrot inhibit the growth of these species. Chapman[6] lists alfalfa, clover, poppy, spinach, gladiolus, corn, bean and squash as species sensitive to Cu. Plant toxicity to Cu is usually manifested by foliar chlorosis caused by the interference of excessive Cu with iron metabolism.[10]

Copper is also an essential element to animals. It is an important constituent of numerous enzymes and proteins ranging from hemocyanin, the oxygen carrier of numerous invertebrates, to cytochrome oxidase, the terminal enzime in the energy transport system of animals.[26] Copper is essential for the proper utilization of iron; ceruloplasmin, the blue Cu protein found in the plasma of most vertebrates, directly affects the plasma iron levels. Copper also facilitates the mobilization of iron, particularly from the reticuloendothelial system, for the rapid biosynthesis of hemoglobin. Copper plays a significant role in the enzyme machinery necessary for the biosynthesis of proteins involved in the proper constitution of the connective, dermal and elastic tissues.[26] Copper is also necessary for pigmentation maintenance for red blood cell formation, normal growth and reproduction.[7] Underwood[7] reports that sheep require 1 mg Cu per day, pigs need 6 ppm and most lab animals require 50 ppm per day to maintain normal physiological activities.

Copper is poorly absorbed from the small intestine in most mammals. Most of the Cu in blood is bound to the Cu protein ceruloplasmin. A small fraction (about 5%) is loosely bound in albumin. It is the albumin-bound fraction of the serum Cu that is in rapid equilibrium with the Cu in the tissues and it is considered to be the transportable form of Cu in the blood.[7,8] Copper can also pass readily into red blood cells. Copper in the liver is accumulated within the cell membrane and is released for incorporation into blood forming elements of various Cu-containing enzymes. Besides the liver, Cu may accumulate in the brain, adrenal gland, heart, intestine, kidney and stomach of mammals.[4,7,8] In fish, liver and gills are the concentrating organs.[66] Copper excesses are usually eliminated in bile or urine.[7]

Investigations of the effects of Cu smelter fly dust containing 2.5% Cu and a similar concentration of As_2O_3 indicates that animals as far away as 5 km from the plant are affected.[18] Hemkes and Hartmen[63] found that sheep grazing on either side and within 20 m of high tension copper tower lines become ill and die after consuming dry forage growing on soil containing Cu excesses. Toxic concentrations for a variety of animals are summarized below.

1. pigs - 7425 ppm in diet, severe toxicosis[7]
2. rats - 2000 ppm day/diet, lethal[4]
3. humans - 330-670 ppm day/diet, toxic
4. horses and sheep - 775 ppm, liver, toxic and often lethal[18]
5. sheep - 725 ppm of $CuSo_4$, lethal

Gough and Shacklette[10] note that when sheep graze on pastures of normal Cu content but low in Mo (<0.1 ppm), Cu accumulates in their liver. This accumulation sometimes results in chronic Cu poisoning, followed by death. Early chemical symptoms of Cu poisoning include conjunctivitis, stomach and intestinal catarrh, salivary secretion, miscarriage, emphysematose foeti, afterbirth retention, and reduction or complete stoppage of milk production. Also, necropsy may reveal liver enlargement.[18]

Laboratory experiments on the effects of Cu and Zn on the eggs, fry, and fingerlings of Atlantic salmon, brown trout, and rainbow trout show that there is little or no mortality during exposure for 21 days to Cu concentrations of 0.04-0.06 ppm.[68] Hazel and Meith[69] found that Cu concentrations of 0.08 ppm do not noticeably affect the hatching success of chinook salmon eggs. MacKereth and Smyly[70] observed that stone loach can survive in water containing 0.2 ppm or less of Cu. Davies and Goettl[47] determined that Cu concentrations in water of 0.012-0.019 and 0.0095-0.0175 ppm have no effect on rainbow trout and brook trout, respectively (Hat Creek waters averaged less than 0.0062 ppm Cu).

In general, 0.1 ppm of Cu in water is found to be fatal to fish. LC_{50} of Cu for rainbow trout range from 0.056-0.15 ppm in water depending on the hardness.[47,71] Hazel and Meith[69] report that 0.02-0.04 ppm Cu in water is acutely toxic to chinook salmon fry. Stone loach die within 24 hours in water containing 0.2 ppm or higher of Cu.[70] Arthur and Leonard[72] established a TLM (tolerance limit, median) for a variety of aquatic invertebrate species as 0.006-0.012 ppm. General effects of Cu poisoning on aquatic organisms, particularly fish, include renal and lateral bone lesions,[73] increased corticosteroid levels,[74] increased red blood cell production and hemetocrit,[75] reduced natality,[68] and increased blood pH.[76]

In summary, Cu is an essential element to plants and animals and is moderately toxic at high concentrations. Except for small mammals, Cu concentrations in Hat Creek receptors are similar to values reported in the literature. Although Cu levels in small mammals were high, they were far below toxic concentrations as reported in the literature.

(i) Fluorine (F)

Average concentrations of fluorine (F) in Hat Creek receptors sampled during October 1976 are provided in Table F5-14. Fluorine was not measured in October water samples. Values in other aquatic samples ranged from 63.33 ppm (fish, Site 4) to 347.00 ppm (stream sediment, Site 4). Soil and shrub had highest levels of F found in terrestrial materials. However, as with Cu, results were too variable to permit a determination of significant trends among sites or between receptor materials.

Fluorine concentrations in receptor materials sampled during January and May 1977 are provided in Table F5-15. Fluorine levels, as with previously discussed elements, were variable in seasonal samples. All materials sampled during January 1977 were characterized by higher F concentrations than in October 1976 and grass and some lichen samples were much higher in May 1977 than in October 1976. Fish and small mammal samples decreased in F content from October 1976 to May 1977.

Concentrations of naturally occurring F in selected ecosystem components as determined from the literature are shown below.

1. water - 1 ppm[4]
2. soils - 200 ppm[4]
   - 96-260 ppm, Wyoming[5]
3. vegetation - 2-20 ppm[8]
   - 0.5-40 ppm[4]
   - 20-700 ppm, Wyoming[5]

Table F5-14

Average concentration (ppm) of Fluorine (F) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean	Std err	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> **												
Water ***												
Stream sediment	202.00	83.17	72.33	26.67	156.67	17.64	> 347.00	> 326.50			> 194.50	> 78.15
Fish†	74.33	28.37	145.00	73.65			63.33	30.82			94.22	27.60
<u>Terrestrial</u>												
Soil	216.67	43.72	> 466.67	> 268.22	43.67	19.94	221.67	112.04	89.00	41.00	> 207.53	> 63.84
Shrub	263.33	78.81	110.67	19.80	78.00	37.32	> 706.67	> 293.33	115.00	37.75	> 254.73	> 81.66
Grass	29.00	12.49	24.00	1.53	22.00	6.51	14.00	1.53	13.33	2.19	20.47	2.92
Lichen	16.00	1.15	157.00	116.52	49.00	20.03	46.67	9.84	52.00	34.00	64.13	24.52
Small mammal	97.00	24.01	153.00	32.13	91.33	39.49	109.67	10.33	139.00	47.06	118.00	14.07

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** Fluorine was not measured in samples collected in October.

† No fish samples could be collected at Site 3.

Table F5-15

Average concentration (ppm) of Fluorine (F) in receptor material collected during January and May 1977

	January 1977*							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic**														
Water	0.070	1.833	0.150	0.127		0.545	0.324	0.15	0.14	0.13	0.13		0.14	0.04
Stream sediment	455	450	500	440		461.25	26.6	260	272	179	188		224.75	48.0
Fish***	- -	- -	- -	- -				14	20	- -	- -		17.00	4.2
Terrestrial														
Soil	1040	36	590	660	316	528.40	377.6	324	90	107	274	135	186.00	105.9
Shrub	- -	- -	- -	- -	- -			9.0	26	19	558	169	156.20	234.0
Grass†	- -	- -	- -	- -	- -			63	1360	1600	- -	2770	1448.25	1110.1
Lichen	555	100	106	84	54	179.80	210.7	334	11	21	21	204	118.20	145.2
Small mammal	- -	- -	- -	- -	- -			68	24	20	83	60	51.00	27.8

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* Only water, stream sediment, soil and lichen were collected during January 1977.

** There are only four aquatic sampling sites.

*** Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

† Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

4. animals - 150-500 ppm, mammalian soft tissue[4]
   - 1500 ppm, bones[4]
   - 1-2.2 ppm, Wyoming[5]

Fluorine concentrations in soils and stream sediments during January 1977 and in grass during May 1977 exceeded the range of concentrations reported in the literature. Other F levels were not highly inconsistent with the literature derived values.

Fluorine has not been proved essential to vegetation.[4] Most of the work on susceptibility of vegetation to airborne fluorides has used hydrogen fluoride (HF), as it is known to be extremely toxic to some species.[220] However, the research which has been done on fluoride (F_2), silicon tetrafluoride (SiF_4), and fluorosilicic acid (H_2SiF_6) indicates that each may be as toxic as HF.[223,224]

Gaseous fluorides are absorbed through the leaf stomata and the plant cuticle. Given adequate moisture deposits of fluoride, salts will also be absorbed but only in proportion to their solubility.[222] Once inside the leaf, the fluoride is taken into the transpirational stream and transported to the leaf tips and margins where it is known to accumulate.[225,228] Little or no movement between individual leaves or between leaves and other organs has been observed.[229]

Toxic effects on plants (and animals) generally occur within a radius of 1.5-3 km around a stationary source emanating high levels of F.[77] Gilbert[78] notes F damage to lichens at sites up to 10 km away from an aluminum smelter. He also states that there was a significant correlation between severity of damage, rate of F accumulation, and distance from the source. Agate et al.[218] reports that vegetation located within a mile of an aluminum factory in the direction of the prevailing wind was destroyed so completely that a layer of peat was exposed. Furthermore, grazing sheep and cattle exhibited slight symptoms of severe fluorosis. They note that ambient F concentration 200 yds from the factory averaged 0.22 mg/m^3 and declined to 0.042 mg/m^3 at a distance of one mile.

Chapman[6] reports that the most tolerant plants to F poisoning are usually the best accumulators. He cites as an example, buckwheat and spanish moss which are used for surveying fluoride pollution and can accumulate up to 9,900 and 2,418 ppm in foliar tissue, respectively. A general use threshold value for F concentration in the atmosphere ranges from 0.007-0.10 ppm[79] although some very sensitive species are affected by concentrations less than 0.001 ppm.[80] McCune, Temple and Witherspoon[81] established acceptable limits of F in the air as 0.005-0.010 ppm for a 2 to 4 hour peak concentration and 0.003-0.006 ppm for 30-60 day periods.

A polluted atmosphere provides the main source of toxic concentrations of F accumulated by plants. On rare occasions toxic concentrations may be absorbed from acid soil.[82] Davidson and Blakemore,[83] however, found no direct relationship of airborne F and plant accumulation. After an equilibrium concentration is reached, they note that the plant does not accumulate additional F.

Only a few reliable sensitive indicator plants are reported for fluoride poisoning; chinese and royal apricots, prune, corn, ponderosa pine, some citrus varieties and a few species of white-flowered gladioli. All of these may be damaged from exposure to 1.0-5.0 ppb F for several days. All are likely to show injury when their F content equals 50 ppm or less.[219]

Toxic effects of F include pollen growth inhibition and germination impairment, decreased fruit development, photosynthesis impairment, gradual decline of transpiration and untimely defoliation.[84] Foliar symptoms of F poisoning are marginal necrosis and interveinal chlorosis. Species sensitive to F include gladiolus and ponderosa pines.[6]

Fluorine is not essential to animals but it does promote sound teeth.[6] However, too high a fluoride intake can cause dental defects characterized by modified shape, size, color, orientation and structure of teeth (clinical symptoms of fluorosis).[7] Fluorine is rapidly and almost completely absorbed from the GI tract. Absorbed F is distributed throughout the body or the F ion is retained by bones and teeth where it accumulates. Unabsorbed F is excreted in the urine.[7] Herbivorous animals are exposed to F primarily through forage. Chances of F transfer up the food chain are remote because of its affinity for calcium and its accumulation in bones, which absorb 96% of the retained F.[82] Underwood[7] reports that sheep, cattle, and pigs can tolerate 80-100 ppm in food wihtout harmful effects. However, a study in Germany found that 40-60 ppm causes cattle to lose weight and may reduce milk production and retard growth.[85] In domestic cattle and horses, skeletal concentrations ranging from 1,450 to over 8,000 ppm have been associated with fluorosis.[86]

Mechanisms of F toxicity include interference with calcium metabolism, enzymatic processes, normal cellular respiration, and the reduction of the immune biological response of the animal to certain diseases.[16] Physical symptoms include dental defects, deformation of bones, ribs, and joints, and mineralization of tendons.[7,87]

In summary, F, particularly as the gas HF, is potentially very toxic to plants and animals. While concentrations of F in Hat Creek receptors were higher than literature values for some soil, stream sediment, and grass samples, the levels are well below those known to cause toxicity.

(j) Gallium (Ga)

Average concentrations of gallium (Ga) in Hat Creek receptors collected during October 1976 (water samples from January 1977) are shown in Table F5-16. Averages ranged from 0.0010 ppm (water, Sites 1, 2, and 3) to 29.33 ppm (stream sediment, Site 3) for aquatic samples and from 0.13 ppm (shrub, Sites 1 and 3) to 31.67 ppm (soil, Site 3) for terrestrial samples. Gallium concentrations were highest in stream sediments and soils for aquatic and terrestrial samples, respectively.

Concentrations of Ga as determined from the literature provided for a variety of ecosystem components are presented below.

1. water - 0.001 ppm[4]
2. soil - 0.4-300 ppm[4]
   - 6.0-13.0 ppm, Wyoming[5]

Table F5-16

Average concentration (ppm) of Gallium (Ga) in receptor materials collected during October 1976

Receptors	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aquatic **												
Water ***	< 0.0010 >	0.0000	< 0.0010 >	0.0000	< 0.0010 >	0.0000	< 0.0013 >	0.0003			< 0.0011 >	0.0001
Stream sediment	18.67	3.28	13.67	3.71	29.33	4.84	27.33	4.91			22.25	2.64
Fish †	< 0.80 >	0.60	< 0.33 >	0.15			< 0.43 >	0.13			< 0.52 >	0.20
Terrestrial												
Soil	21.67	3.33	18.67	0.33	31.67	16.23	25.33	12.14	14.67	5.36	22.40	3.91
Shrub	0.13	0.03	< 0.17 >	0.03	0.13	0.03	0.27	0.17	< 0.20 >	0.10	< 0.18 >	0.04
Grass	0.33	0.03	0.40	0.06	0.43	0.09	0.20	0.00	0.47	0.17	0.37	0.04
Lichen	0.40	0.10	0.83	0.17	0.47	0.07	0.40	0.10	< 0.60 >	0.21	< 0.51 >	0.07
Small mammal	1.33	0.33	6.27	4.88	1.33	0.33	6.67	4.67	0.83	0.17	3.29	1.31

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** Gallium was not analyzed in October water samples; values reported are for January 1977 samples.

† No fish could be collected at Site 3.

3. vegetation - 0.06 ppm[4]
- 0.3-4.8 ppm, Wyoming[5]

4. animals - 0.04 ppm, dry mammalian tissues[4]
- 0.75-1.5 ppm, deer mice, Wyoming[5]

Although the Ga levels in Hat Creek samples exceed levels in fish and small mammals reported in the above studies, the paucity of information in the literature precludes any valid conclusion concerning the potential toxicity of Hat Creek Ga levels.

Bowen[4] reported that Ga is non-essential for plants and animals. It has a low order of toxicity, although it can be moderately toxic to mammals if injected intravenously.[4]

(k) Lead (Pb)

Average concentrations of lead in selected Hat Creek receptor materials sampled during October 1976 are provided in Table F5-17. Averages ranged from 0.0567 ppm (water, Site 4) to 4.67 ppm (stream sediments, Sites 3 and 4) for aquatic receptors. Within-site variability of Pb in aquatic samples was low. Averages of Pb concentrations in terrestrial materials ranged from 2.00 ppm (small mammal, Site 3) to 53.33 ppm (lichen, Site 2). Excluding grass samples at Site 2 (Lower Hat Creek) within-site data variability was also low for terrestrial samples. Lead concentrations were highest at terrestrial Site 2 (Lower Hat Creek) during October 1976. This site is in close proximity to a highway and the comparatively high Pb level could result at least in part, from automobile emissions.

Lead concentrations in selected receptors collected during January and May 1977 are given in Table F5-18. Although Pb levels varied among samples, Pb does not appear to exhibit the high seasonal variability shown by previously discussed elements. As in October 1976, high Pb concentrations were observed in lichens at terrestrial Sites 2 (lower Hat Creek) and 5 (Ashcroft).

Table F5-17

Average concentration (ppm) of Lead (Pb) in receptor materials collected during October 1976

Receptors	Site 1 Mean*	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
<u>Aquatic</u> **												
Water	0.00667	0.0058	0.0700	0.0010	0.0633	0.0058	0.0567	0.0058			0.0641	0.0056
Stream sediment	< 4.33 >	0.33	< 4.67 >	0.67	< 4.67 >	0.67	< 4.00 >	0.00			< 4.42 >	0.23
Fish ***	< 2.00 >	0.00	< 2.17 >	0.17			< 2.50 >	0.50			< 2.22 >	0.17
<u>Terrestrial</u>												
Soil	10.00	1.00	7.67	0.33	4.00	0.58	11.33	0.67	5.67	0.33	7.73	0.76
Shrub	5.67	1.20	10.00	4.04	< 3.00 >	0.58	< 3.00 >	1.00	5.00	0.58	< 5.33 >	1.01
Grass	< 4.00 >	0.00	< 21.67 >	15.71	< 4.00 >	0.00	< 4.00 >	0.00	< 4.00 >	0.00	< 7.53 >	3.26
Lichen	29.33	1.76	53.33	6.01	17.67	1.67	14.67	2.73	36.67	4.63	30.33	4.00
Small mammal	< 2.67 >	0.67	< 2.50 >	0.29	< 2.00 >	0.00	< 10.33 >	6.44	< 8.50 >	5.77	< 5.20 >	1.74

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Table F5-18

Average concentration (ppm) of Lead (Pb) in receptor material collected during January and May 1977

	January 1977[*]							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic[**]														
Water	<0.0500	<0.0500	<0.0500	<0.0500		<0.0500	>0.0000	<0.05	<0.05	<0.05	<0.05		<0.05	>0.0
Stream sediment	<2	<2	<2	<2		<2.00	>0.0	<3	<3	<3	<3		<3.00	>0.0
Fish[***]	- -	- -	- -	- -				3.6	2.6	- -	- -		3.10	0.7
Terrestrial														
Soil	<2	<2	<2	<2	<2	<2.00	>0.0	<3	<3	<3	<3	<3	<3.00	>0.0
Shrub	- -	- -	- -	- -	- -			1.6	2.6	5.4	4.8	5.8	4.04	1.8
Grass[†]	- -	- -	- -	- -	- -			12	4.1	7.1	- -	8.0	7.80	3.3
Lichen	19	45	32	21	26	28.60	10.9	14	36	18	22	30	24.00	8.9
Small mammal	- -	- -	- -	- -	- -			3.1	1.5	<2	7.8	2.9	<3.46	>2.5

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[*] Only water, stream sediment, soil and lichen were collected during January 1977.

[**] There are only four aquatic sampling sites.

[***] Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

[†] Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

Concentrations of Pb in selected ecosystem components as derived from the literature are presented below:

1. water - 0.005 ppm[4]
   - 0.005 ppm[88]
2. soils - 2-200 ppm (mostly unavailable)[6]
   - 0.05-5 ppm (available)[6]
   - 10 ppm, humus[4]
   - 16 ppm[1,8]; 8.9-58 ppm, Wyoming[5]
3. vegetation - 0.4 ppm[88]
   - 2.7 ppm[4]
   - 3 ppm, dried pine needles[89]
   - 0.3-1.5 ppm, young pasture grass[7]
   - 10-40 ppm, mature pasture grass[7]
   - 7100 ppm, lead contaminated soils[7]
   - 14-160, Wyoming[5]
4. animals - 2 ppm[4]
   - 0.03 ppm[88]
   - 0.2-0.04 ppm, cows milk[7]
   - 0.02-0.07 ppm, deer mice, Wyoming[5]

~~Lead levels in water and small mammal samples appear to exceed those values reported in the literature.~~ Lead concentrations in other receptor materials are consistent with the literature.

Lead is found in all plants[8], although it is considered non-essential to vegetation.[6,10] Although Pb accumulates markedly in the soil, the accumulation is virtually permanent as it is not easily leached out by rainfall or absorbed by plant roots. Pb generally enters plants through leaf stomata and accumulates in the leaf, particularly leaf surfaces.[10,90,91] The rougher or more hairy the surface, the greater the accumulation.[90,92] Relatively little translocation of Pb takes place within the plant.[88] Within the leaf cells, Pb seems to be bound to poly-uronic acids of the cell wall. Organelles such as mitochondria, chloroplasts and nuclei often show high concentrations of Pb. In general, plant organs which show an intensive gas exchange with the atmosphere contain more lead than storage tissues.[90]

There are no reports of definite toxicity symptoms in plants that grew in areas of natural enrichment of Pb only. Gough and Shacklette[10] report that Pb, Zn, and other heavy metals often occur together in mineralized outcrops; therefore, it is difficult to associate observed toxicity symptoms in plants at these sites with only Pb. Holl and Hampp[90] found, however, that Pb content in plants decreases with increasing distance from a Pb emission source. They also found that, in general, plants which grow leeward to a Pb source exhibit higher concentrations of the heavy metal than those growing on the windward side.

Many plants will tolerate high levels of Pb but others show retarded growth at 10 ppm in solution culture.[8] No significant effect on plant growth of grape, apple and orange seedlings were found at soil concentrations up to 150-200 ppm[6] (Hat Creek soils averaged less than 10 ppm Pb). Some plants may absorb large amounts of Pb without exhibiting toxicity symptoms; concentrations in stems of certain shrubs may be as high as 350 ppm Pb with no visible adverse effects[10] (Sampled Hat Creek vegetation averaged less than 53 ppm Pb). Leaves of corn growing 75 yards from a smelter were found to contain 3200 ppm dry weight.[88] Lettuce can accumulate over 2 ppm Pb (fresh washed weight) without showing toxic symptoms.[92] Gough and Shacklette[10] found no toxicity symptoms in cedar trees containing 2% Pb in ash.

Toxic concentrations of Pb to various plant species are summarized below.

1. French beans - 30 ppm lead sulfate, damaged plants[10]
2. sheep fescue - 10 ppm Pb in solution culture reduced root growth[10]
3. corn plants - 20 ppm Pb in nutrient solution, growth retarded when phosphate was deficient; 200 ppm Pb reduced growth regardless of phosphate concentration[10]

Lead exerts its toxic effects on plants by increasing the stomatal resistance, thereby reducing the photosynthetic potential of the plant.[90,93] Lead ions also affect the process of photosynthesis by reducing CO_2 fixation of isolated chloroplasts. Lead also inhibits the electron transport of photosystem II between the site of primary electron donor and water oxidation. Lead may affect enzyme activity by blocking sulfhydryl groups of proteins and effecting a change of phosphate levels in living cells.[90]

In animals, Pb may be taken in by inhalation, ingestion and dermal translocation, although it is considered a non-essential element.[6,10] Ingested Pb is poorly absorbed and is excreted mainly in the feces. Alimentary absorption of water soluble Pb is approximately 10% and food Pb is approximately 5% in man. Absorbed Pb enters the blood bound to erythrocytes and plasma proteins and reaches the bones and soft tissues. It is eliminated via bile into the small intestine. Up to a point, ingestion will equal excretion so retention is negligible. In sheep, if less than 3 ppm Pb (dry weight) is ingested daily, none is retained. Drinking water containing 5 ppm Pb resulted in Pb accumulation in rats, but no deleterious effects on the rats were observed.[7]

Uptake of Pb from the lungs is more complete as approximately 32% of inhaled Pb is absorbed.[88] Egan and O'Cuill[94] found that inhaled Pb results in higher blood and tissue concentrations more quickly than do greater amounts obtained by ingestion. Lead is highly concentrated on lung depositable particles of 0.5 μm in diameter or less.[8] As particle size decreases solubility will increase; the proportion passing into the blood will increase with respect to the amount cleared from the lungs by phagocytosis lymph drainage.[7] Absorption through the skin is of importance only in the case of organic compounds of Pb, particularly Pb alkyls and lead naphthenates.[7] Animals' tissue that may accumulate Pb are bone, liver, kidney, muscle and hair.[4,7] Gills, bones and kidneys show the highest accumulation in fish.[95,96]

The maximum safe value for portable water supply for animals is 0.5 ppm.[16] The World Health Organization drinking water standard is 0.05 ppm.[88] Gough and Shacklette[10] report that Pb^{+2} concentrations of 0.5-0.8 ppm in the blood are the threshold for acute Pb poisoning. The minimum cumulative fatal dose for cows is 6-7 ppm body weight per day.[94] Schmitt et al.[97] states that young horses have a high susceptibility to high Pb levels in forage.

Toxic doses of Pb to animals are dependent upon the Pb compound ingested and the sensitivity of the animal affected (e.g., horses are more susceptible to Pb poisoning than are cattle).[98] Horses grazing on contaminated hay are affected by a consumption rate of 2.4 ppm/day, while cattle are affected by 6-7 ppm/day.[99] Stoefen[100] notes that 1 ppm/day Pb intake for cattle will produce effects in fetuses before physiological effects in adults can be recognized. Prenatal exposure to 0.34 ppm Pb levels in maternal sheep blood will affect lambs visually.[101] Egan and O'Cuill[94] report that the following blood Pb concentrations are fatal:

1. horse - 0.38 ppm
2. cattle - 0.4 ppm
3. dogs - 0.8 ppm
4. pigs - 1.2 ppm

Schroeder and Mitchner[40] indicate that 25 ppm of Pb will cause the loss of a mouse strain within two generations. Accumulation to 42 ppm Pb in the breast tissue and 168 ppm in the liver is reported to be fatal to pheasants.[102] Del Bono and Buggiani[103] found that death occurs in wild ducks when blood levels of Pb exceed 6 ppm.

Symptoms of Pb poisoning in animals are derangement of the central nervous system, GI tract, musculature, and the nematopoetic system.[99] Dairy cows near a Pb source may show a very high incidence of milk fever, infertility, ovarian cysts, and osteopetrosis.[104] Tesink[105] reports that chronic exposure to Pb can also cause anemia and the degeneration of brain and nerve tissue. Christensen and Luginbyh[13] state that lead nitrate is teratogenic in pregnant rats. Valkovic[8] found Pb to be a renal carcinogen and a poison in animals and is correlated with mortality from kidney cancer, leukemia, lymphomas and stomach, intestinal and ovarian cancers.

Lead poisoning may account for a reduction in the resistance of mice, rats and chicks to bacterial infection by decreasing the numbers of antibody forming cells.[88,106,107] Lead also aggravates viral diseases.[108] Warren[109] reports a high correlation of abnormally high Pb levels and multiple sclerosis.

He adds that there is a relationship between incidence of swayback in lambs and the Pb content of pasture grass, and evidence also suggests that Pb has an inhibiting effect on Cu metabolism.

There is a great variation among fishes in their ability to tolerate Pb. For example, goldfish seem to be resistant to Pb poisoning probably because of abundant gill secretion which washes away the film of coagulated mucus from the body and gills which would otherwise result in anoxia.[88] In general, 2.8 ppm[16] and 0.1-50 ppm[10] of Pb in water are given as lethal to fish (Hat Creek waters averaged less than 0.05 ppm). Other investigations have revealed that 0.1 ppm is lethal to minnows,[88] 0.01-1.0 ppm (as lead chloride) is lethal to *Daphnia*[10] and 5 ppm is toxic to aquatic invertebrates.[110]

Acute Pb poisoning of fish is characterized by the destruction of gill epithelium and inner organs resulting in fish suffocation.[96] A lead concentration of 1.25 ppm in water retards growth, increases mortality and delays sexual maturity in guppies.[111]

To summarize, Pb is moderately toxic to plants and animals, although no toxicity has been reported under natural conditions. Except for high Pb levels in water and small mammals, Pb concentration in Hat Creek receptors are similar to values reported in studies referenced above. No Pb levels in any receptor presently approach toxic concentrations.

(1) Lithium (Li)

Average concentration of lithium (Li) in selected Hat Creek receptors collected during October 1976 (water samples from January 1977) are shown in Table F5-19. Averages ranged from 0.0010 ppm (water, Site 3) to 37.33 ppm (stream sediment, Site 1) for aquatic samples and from 0.10 ppm (shrubs, Sites 2 and 3; small mammals, Sites 1, 2 and 3) to 31.33 ppm (soil, Site 1). Stream sediments and soils contained the highest levels of Li of all receptors sampled, although data variability was high for both materials.

Table F5-19

Average concentration (ppm) of Lithium (Li) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aquatic **												
Water ***	< 0.0013	> 0.0003	0.0020	0.0006	< 0.0010	> 0.0000	< 0.0020	> 0.0006			< 0.0016	> 0.0002
Stream sediment	37.33	31.38	2.60	1.25	4.00	1.53	3.67	2.19			11.90	8.05
Fish †	< 0.10	> 0.00	< 0.10	> 0.00			< 0.13	> 0.03			< 0.11	> 0.01
Terrestrial												
Soil	31.33	24.88	13.67	6.69	7.00	2.65	11.60	7.49	8.33	2.67	14.39	5.15
Shrub	< 0.13	> 0.03	< 0.10	> 0.00	< 0.10	> 0.00	0.43	0.28	0.27	0.12	< 0.21	> 0.06
Grass	< 0.14	> 0.06	< 0.27	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.17	> 0.03	< 0.19	> 0.02
Lichen	0.67	0.18	0.57	0.23	0.53	0.12	0.60	0.21	< 0.37	> 0.09	< 0.55	> 0.07
Small mammal	< 0.10	> 0.00	< 0.10	> 0.00	0.10	0.00	< 0.13	> 0.03	< 0.17	> 0.03	< 0.12	> 0.01

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* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** Lithium was not analyzed in samples collected in October; values reported are for January 1977 samples.

† No fish could be collected at Site 3.

Naturally occurring levels of Li in other ecosystem components, as determined from the literature, are summarized below.

1. water - 0.0011 ppm[4]
   - 0.002-0.003 ppm[6]
2. soil - 30 ppm[4]
   - 8-400 ppm[6]
   - 5-136 ppm, North America[10]
   - 16-28 ppm, Wyoming[5]
3. vegetation - 0.1 ppm[4]
   - 0.85 ppm, monocots[6]
   - 1.3 ppm, dicots[6]
   - 0.33 ppm, Wyoming[5]
4. animals - 0.02 ppm[4]

~~Lithium values in Hat Creek receptors are consistent with results reported for similar components in different ecosystems.~~

Lithium is a non-essential element for higher plants and animals. However, it is an essential trace element for some microorganisms.[10]

The main influx of Li to plants is from the soil through root systems and Li is known to accumulate in roots. However, total Li in soils is not related to its availability to plants. Li toxicity is not known to occur naturally except in the case of citrus.[6] Many plants are tolerant of high Li levels in the soil,[112] although some crops are susceptible to injury when Li is applied to the soil in the form of soluble salts. Acidification of some neutral or alkaline soils high in Li also tends to produce Li toxicity.[113]

Lithium is the most toxic of the alkali metal salts to vegetation. One study found Li salts to be toxic in amounts greater than 30 ppm and stimulating in amounts not exceeding 20 ppm[6] in soil (Hat Creek soils averaged less than 15 ppm of total Li). Injurious effects are produced on soybean, tomato, white mustard, hemp, sunflower, flax, vetch and corn in decreasing degree by the addition of 0.2% of Li_2SO_4 to the complete nutrient solution in sand culture. Soil Li concentrations of 16 ppm produce necrotic spots in leaves of potted avocado seedlings.[6] Toxic effects of Li poisoning in plants are mainly expressed in a reduction of growth. Symptoms include leaf and tip burn and chlorosis of the entire plant.[6]

There are no reports of Li toxicity to animals under field conditions. In a laboratory study, lithium (lithium carbonate and lithium chloride) produced teratogenic effects in pregnant rats.[13]

In summary, Li is moderately to severely toxic to plants and animals. It is non-essential to plant and animal and no cases of natural Li poisoning have been reported. Lithium concentration in sampled Hat Creek receptors are within the range of values reported in literature.

(m) Mercury (Hg)

Average concentration of mercury (Hg) in selected Hat Creek receptor materials collected during October 1976 are shown in Table F5-20. Average Hg levels ranged from <0.0001 ppm (water, all sites) to 0.16 (stream sediment, Site 1). Mercury levels in stream sediment appeared to decrease progressively downstream from Site 1 (Upper Hat Creek) to Site 4 (Lower Bonaparte River). For terrestrial receptors, averages ranged from 0.02 ppm (small mammals, Sites 1, 2, 3, and 4) to 0.58 ppm (lichen, Site 1). Highest observed mercury levels were found in samples from Site 1 (Pavillion Mountain). Lichens had the highest Hg concentration of all materials at each terrestrial site.

Mercury levels in receptors sampled during January and May 1977 are provided in Table F5-21. Mercury concentration appeared to increase in most receptors from October 1976 to January and May 1977. The increase was largest in grass, small mammal and fish samples.

Concentrations of Hg in selected ecosystem components from different regions, as derived from the literature, are presented below.

1. water - 0.0008 ppm[4]
   - 0.00004 ppm[27]
   - <0.0001 ppm, surface waters[114]
   - <0.002 ppm, all natural waters[114]
   - 0.0001-0.017 ppm, U.S. surface waters[114]
   - 0.00005 ppm[115]
   - 0.00001 ppm[116]
   - 0.0005 ppm[117]

Table F5-20

Average concentration (ppm) of Mercury (Hg) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aquatic **												
Water	< 0.0001	> 0.0000	0.0001	>0.0000	< 0.0001	> 0.0000	< 0.0001	> 0.0000			< 0.0001	> 0.0000
Stream sediment	0.16	0.02	0.14	0.01	0.13	0.02	0.11	0.00			0.14	0.01
Fish ***	< 0.08	> 0.04	0.06	0.02			< 0.02	> 0.00			< 0.05	> 0.01
Terrestrial												
Soil	0.16	0.02	0.07	0.03	0.07	0.01	0.09	0.01	0.04	0.00	0.09	0.01
Shrub	0.07	0.00	0.10	0.01	0.04	0.00	0.05	0.01	0.10	0.02	0.07	0.01
Grass	0.19	0.03	0.12	0.02	0.18	0.08	0.12	0.01	0.08	0.00	0.14	0.02
Lichen	0.58	0.15	0.25	0.03	0.48	0.03	0.56	0.11	0.47	0.08	0.47	0.05
Small mammal	< 0.02	> 0.00	< 0.02	> 0.00	< 0.02	> 0.00	< 0.02	> 0.00	< 0.04	> 0.02	< 0.03	> 0.00

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* See first footnote in Table F5-2 for an explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Table F5-21

Average concentration (ppm) of mercury (Hg) in receptor material collected during January and May 1977

	January 1977[*]							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic[**]														
Water	<0.0001	0.0002	<0.0001	<0.0001		<0.0001	>0.0000	<0.001	<0.001	<0.001	<0.001		<0.001	>0.0
Stream sediment	0.1	0.1	<0.1	<0.1		<0.10	>0.1	0.11	0.10	0.09	0.19		0.12	0.1
Fish[***]	- -	- -	- -	- -				0.40	0.37	- -	- -		0.39	0.0
Terrestrial														
Soil	0.3	0.1	0.2	0.2	0.1	0.18	0.1	0.19	0.09	0.07	0.15	0.13	0.13	0.1
Shrub	- -	- -	- -	- -	- -			0.19	0.41	0.27	0.29	0.52	0.34	0.1
Grass†	- -	- -	- -	- -	- -			0.40	0.30	3.86	- -	0.71	1.32	1.7
Lichen	1.4	0.8	0.9	0.9	1.4	1.08	0.3	0.32	0.59	0.93	1.48	0.80	0.82	0.4
Small mammal	- -	- -	- -	- -	- -			0.37	0.39	0.25	0.32	0.30	0.33	0.6

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[*] Only water, stream sediment, soil and lichen were collected during January 1977.

[**] There are only four aquatic sampling sites.

[***] Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

[†] Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

2. soils
   - 0.03-0.8 ppm[6]
   - 0.030-0.5 ppm[114]
   - 0.2 ppm, igneous rocks[114]
   - <0.200 ppm, limestone and sandstone[114]
   - 0.1-0.3 ppm[7]
   - 0.071 ppm[10]
   - <0.02 ppm, Wyoming[5]
3. lake sediment
   - 0.070-0.100 ppm[118]
4. vegetation
   - 0.015 ppm[4,118]
   - 0.005-0.035 ppm, fruits, vegetables and cereal grains[119]
   - 0.010-0.200 ppm[119]
     <0.500[114]
   - 0.500-3.5 ppm, high Hg areas[114]
   - 0.08-0.12 ppm, Wyoming[5]
5. animals
   - 0.045 ppm[4]
   - 0.02-0.18 ppm, fish[7]
   - 0.11-1.13 ppm, fish[120]
   - 0.44 ppm, fish, New York State[121]
   - 0.05-0.07 ppm, deer mice, Wyoming[5]

~~Naturally occurring Hg levels in Hat Creek receptors are similar to values reported in the literature.~~

Mercury is non-essential for plants[10] although plants will accumulate Hg in seeds and roots.[27] Mercury may also influence the absorption and transport of Ca, Zn and Cd.[7] Soil-bound Hg is generally not available for plant uptake, although many plants have no barrier against uptake of gaseous Hg through the roots.[122] Furthermore, any effects upon vegetation caused by Hg may be masked or completely eliminated by the strongly antagonistic action of sulfur.[123]

Mercury is not concentrated to a great extent, if at all, in the tissues of most plants that grow in normal soils.[10] Most higher vascular plants are remarkedly resistant to Hg poisoning although they may accumulate high concentrations of Hg in their tissues. For example, Labrador tea shows no toxicity symptoms with 3.5 ppm Hg in tissues.[10] Levels as high as 140 ppm have been reported in the freshwater alga *Nitella*.[118]

Little information is available concerning Hg concentrations that cause toxicity in higher plants. Bell and Rickard[65] noted that applications of 0.5-50 ppm of $HgCl_2$ inhibit growth of cauliflower, lettuce, potato and carrot. At a $HgCl_2$ concentration of 3.5 ppm, chlorophyll synthesis is 98% inhibited and galactolipid synthesis is 50% inhibited in the unicellular alga *Ankistrodesmus braumii*. Significant inhibition of both synthesis processes is detected at $HgCl_2$ levels less than 1.0 ppm. A 2.0 ppm level of methyl mercuric chloride inhibits 98% of galactolipid synthesis. This Hg compound has also been shown to specifically inhibit the galactosyltransferase activity in *Euglena* chloroplasts.[124] Other investigations show that 0.1 ppm Hg reduces phtosynthesis and growth of algae.[125,126] D'Itri[118] reports that 0.027 ppm Hg (as $HgCl_2$) is toxic to *Phaeodactylum tricoinutum, Chlorella* sp. and *Chlamydomonas* sp. at concentrations greater than 0.9 ppm Hg. Phenylmercury acetate is toxic to these three species at concentrations as low as 0.00006 ppm. Toxicity in both instances is manifested as growth inhibition.

Mercury is non-essential to animals.[10] Route of entry of Hg into terrestrial animals is by ingestion and inhalation and it accumulates in kidneys, liver, hair, skin, nails, and lungs for mammals, as well as feathers for birds.[7,27] In fish, high levels of Hg may occur in spleen, muscle, kidneys, and liver.[128,129] Animals excrete ingested Hg primarily in the feces and very little in urine.[7]

Bowen[4] reports that consumption of 800 ppm/day Hg^{2+} in dry weight diet is lethal to rats. Other investigators have found that a cumulative consumption of 24.7 mg of methylmercury is fatal to ring-necked pheasants with signs of poisoning occurring between 13 and 17 mg.[131] Egg production of pheasant hens is impaired at these latter Hg levels as well. Also phenylmercury and methylmercury can adversely effect hatchability; consumption of over 4 mg decreases hatchability, while 16 mg methylmercury results in cessation of egg production.[130] Stoewsand et al.[131] found that feeding Japanese quail 1-3 ppm $HgCl_2$ results in production of eggs with thinned shells. Parkhurst and Thaxton[132] discovered that young chickens, fed more than 250 ppm $HgCl_2$, show suppressed immunological responsiveness, decreased nutritional uptake, high rate of mortality, and increase in heart and adrenal gland weight and a decrease in liver, spleen and bursa weight. Stoewsand et al.[131] report that egg shell thickness of quail diminished as the concentration of $HgCl_2$ in the diet increases from 1 to 8.0 ppm Hg. Evans, Laties and Weiss[133] found that visual impairment is manifested in monkeys after subacute and chronic exposure to methylmercury resulted in blood Hg concentration of 1-5 ppm. Toxic oral doses of mercury compounds to laboratory animals range from an LD_{50} of 18 ppm for HgO to an LD_{50} of 388 for $HgNO_3$.

Mercury vapors can be toxic to mammals especially in poorly ventilated areas. Symptoms include coughing, dyspena, nasal discharge, hemorrhage and loss of appetite. Pathological change includes nephrosis, degeneration in liver and lungs, hypocardia and skin damage. Behavioral patterns can also be affected.[8,16]

Valkovic[8] reports that metallic and ionic Hg generally has a lower toxicity than organic Hg compounds. Organic Hg is accumulated in the body and attacks the nervous system. This form can penetrate the blood barrier easily whereas inorganic Hg is excreted.[134] When symptoms of poisoning by Hg compounds are observed, it is often fatal.[8] Methylmercury also advances senility.[135,136]

Mercury has adverse effects on mammalian reproduction as it is transmitted transplacentally to developing fetuses. Pregnant females fed organic Hg may exhibit reduced litter size and/or weight, morphological lesions and damage to the fetus's central nervous system. Inhalation of Hg may produce the same symptoms after a short exposure period.[137]

Huckabee and Blaylock[138] note that as much as 50% of Hg emitted from coal combustion may find its way to aquatic systems where 99% accumulates in sediments. With regard to the toxicity of inorganic Hg as the mercuric ion, short term studies have indicated that concentrations of about 1 ppm are fatal to fish. For long term exposures of 10 days or more, Hg levels as low as 0.010-0.020 ppm have been shown to be fatal. D'Itri[118] reports that 0.010 and 0.020 ppm of mercury are fatal to *Phoxinies* in 80-92 days and 19-32 days, respectively. Lesperance[139] reports a toxic concentration for Hg as low as 0.001 ppm.

D'Itri[118] also reports that the lowest concentration of $HgCl_2$ that is fatal to brook trout within 24 hours is 12.5 ppm. He notes that 10 ppm of $HgCl_2$ kill rainbow trout in 15 minutes. The minimum lethal threshold for bitterling is 0.04 ppm, 0.05 ppm for gudgeon, 0.3 ppm for carp, 0.02 ppm for minnows and 0.03-0.15 ppm for *Daphnia*.[14,118] Steelhead trout fry and 3 inch blueback salmon are able to survive in 10 ppm of pyridye mercuric acetate for one hour with no toxic effect.[118] Bioassay tests (120 hours) conducted on minnows (*Netropis* sp) show that minimum lethal concentrations of pyridyl mercuric acetate, pyridyl mercuric chloride, phenyl mercuric acetate, and ethyl mercuric phosphate are 0.15, 0.040, 0.20, and 0.8 ppm respectively. Ethyl mercuric phosphate concentrations of 0.125 ppm are toxic to rainbow trout in one hour.[118]

McIntyre[140] reports that concentrations of methyl mercuric chloride greater than or equal to 1 ppm reduce sperm viability in rainbow trout. Hinton, Kendall and Koenig[141] note that 15 ppm Hg alter gill structure in channel catfish and 0.67 ppm alter gill cells of channel catfish. Birge et al.[39] found that methyl or inorganic Hg at a concentration of 0.01 ppm produces 100% mortality in rainbow trout embryos (Hat Creek waters averaged less than 0.0001 ppm Hg).

The acute toxic action of mercuric ions on fish results from damage to the gill tissues and the formation of a film of coagulated mucus that fills the interlameller spaces and prevents the normal movement of the gill filaments. Therefore, the necessary contact between the gill tissues and the water is interrupted and the gaseous exchange is impeded to such an extent that fish die from asphyxiation. Mercuric ion also inhibits the active uptake of sodium into the gills of goldfish and thereby causes an increased Na loss from the fish. Since freshwater fish are hypertonic, they must continually dispose of the water they absorb osmotically and replace the salts that are lost by diffusion as well as excretion. Accordingly, toxic effects could result in fish due to impaired osmoregulation and excretion.[118] Chronic sublethal effects to fish from Hg poisoning include tumorigenesis, reduced swimming function, enzyme inhibition and reduced natality. Fish from the highly polluted Fox River Illinois System (Hg, Pb, As, tolulene, etc.) are found to exhibit a greater frequency of tumors than fish in unpolluted water.[21] Lindahl and Schwanbon[142] report that decrease in resistence to tumors is found to be linearly correlated to the amount of Hg per unit net weight of muscle in fish. McIntyre[140] notes that sexual development of fish was arrested at levels as low as 0.00025 ppm Hg.

In summary, the effect of Hg on plant and animals, especially aquatic organisms have been well documented in the literature. Hg is a non-essential element to plants and animals and certain chemical forms can be very toxic. Concentrations of Hg in Hat Creek receptors appear to be of the same magnitude as levels reported in studies referenced above.

(n) Nickel (Ni)

Average concentrations of nickel (Ni) in sampled Hat Creek receptors collected during October 1976 are provided in Table F5-22. For aquatic samples, averages ranged from 0.0070 ppm (water, Site 4) to 156.33 ppm (stream sediment, Site 3). Values in fish ranged from about 1 to 4 ppm. Nickel concentrations in the Bonaparte River (Sites 3 and 4) were higher than levels measured in Hat Creek (Sites 1 and 2). In terrestrial samples, Ni concentrations ranged from 1.35 ppm (grass, Site 3) to 60 ppm (soil, Sites 2 and 3). Although data variability was high, soil contained the highest Ni levels for terrestrial materials sampled in October 1976.

Naturally occurring concentrations of Ni in a variety of ecosystem components, as determined from the literature, are shown below.

1. water
   - 0.01 ppm[4]
   - 0.0048 ppm, tap water supplied in U.S.[143]
   - 0.01-5.77 ppm, surface water in Ontario[143]
   - 0.05 ppm, tap water in Ontario[143]

Table F5-22

Average concentration (ppm) of Nickel (Ni) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean	Std err	Mean	Std err *	Mean *	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aquatic **												
Water	0.0073	0.0006	0.0163	0.0145	0.0063	0.0015	0.0070	0.0060			< 0.0092 >	0.0047
Stream sediment	32.00	11.79	29.33	5.78	156.33	45.17	118.33	36.78			84.00	20.91
Fish ***	4.00	2.00	0.93	0.03			3.67	1.20			2.87	0.85
Terrestrial												
Soil	42.33	7.31	60.00	30.45	60.00	30.45	36.33	13.78	29.00	6.43	45.53	8.51
Shrub	2.67	0.33	9.33	5.33	10.67	5.04	5.33	0.88	12.67	4.06	8.13	1.73
Grass	3.00	0.58	9.00	1.53	1.35	0.65	< 2.73 >	2.15	4.00	1.00	< 4.02 >	0.86
Lichen	3.33	0.88	4.67	1.20	6.00	2.00	6.67	1.33	6.33	1.67	5.40	0.65
Small mammal	3.67	1.20	3.00	0.58	< 4.00 >	1.00	9.00	7.00	4.33	1.20	< 4.00 >	1.36

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* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

2. soils - 5-500 ppm[4]
- 16-5,000 ppm[6,143]
- 9.8-26 ppm, Wyoming[5]

3. vegetation - 0.05-5 ppm[143]
- 3 ppm[6]
- 4-134 ppm, grasses and oats[143]
- 250-6,000 ppm, plants on serpentine soils[143]
- 0.15-0.35 ppm, tubers, fruits and grain[7]
- 0.96-35 ppm, Wyoming[5]

4. animals - 0.8 ppm[4]
- 0.03-0.10 ppm, cow's milk[7]
- 0.02-4.5 ppm[144]
- 0.07-0.39 ppm, deer mice, Wyoming[5]

Other than for the possible exception of Ni levels in small mammals, concentrations of Ni in Hat Creek receptors are consistent with the range of values reported in the literature.

Nickel is not essential to plants. Nickel enters the plant primarily through the root system and is translocated in the xylem and deposited in the leaves.[6,145]

Generally, Ni concentrations above 50 ppm in plants are toxic, although plants endemic to serpentine soils may contain up to 6,100 ppm[143] (Sampled Hat Creek vegetation generally contained less than 13 ppm of Ni). Actual concentrations of Ni which reduce yields are: 60 ppm in oat grain (500 ppm in soil), 28 ppm in oat straw and 44 ppm in alfalfa. Nickel is relatively toxic to many crops: 8 ppm of Ni in culture solution kills barley quickly; 0.5 ppm and 2 ppm produces chlorosis in buckwheat and ben, respectively.[6]

Excess Ni generally produces a chlorosis that is usually described as resembling the symptoms of iron deficiency. With cereals, the chlorosis is the form of white or of yellow and green stippling; in the case of the dicotyledon, it is mottling. In cases where toxicity is severe, the chlorosis is followed by necrosis and death of the plant.[6] In general, symptoms of Ni excess are like those of iron deficiency in so many plants that symptoms alone are of little use in determining toxicity. Leaf chemical analysis provides the only sure means of detecting excessive Ni in soils. Nevertheless, accumulator plants that can provide an indication of plant exposure to high Ni levels include birch trees and conifers.[6]

Nickel may be essential to animals. It activates several enzyme systems although these activities are not specific to Ni. It is always present in RNA and may help maintain the configuration of the protein molecule. Nickel may also play a part in melanin pigmentation and is also essential to hepatic metabolism in chicks.[7,143]

Nickel enters animals via ingestion and inhalation. Ingested Ni is poorly absorbed and excreted mostly in the feces. It may accumulate in the lungs.[146]

Nickel is relatively nontoxic to animals. Dogs and cats can tolerate daily doses of 4-12 ppm of Ni for 200 days with no ill effects. Nickel carbonate, nickel soaps, and nickel catalyst administered in the diet of young rats at 250, 500, and 1,000 ppm for 8 weeks do not have any significant effect on their growth rate. Mice can tolerate 5 ppm nickel acetate in their drinking water over their lifetime although mice fed 1,600 ppm nickel acetate show a reduction in growth and lowered food consumption. Young chicks fed on diets containing Ni (as either sulfate or the acetate) show significantly decreased growth rates at 700 ppm Ni and above.[7]

Mammals appear to have a mechanism to prevent accumulation of Ni from intestinal absorption and, thus, reduce toxicity. Gough and Shacklette[10] report that Ni salts irritate the mucosal lining of the gut more than they cause inherent poisoning. Acute toxicity of nickel carbonyl may derive in part from inhibition of ATP utilization. Also, nickel carbonyl may produce a metabolic block at the level of messenger RNA.[143]

Major symptoms of acute Ni toxicity consist of hyperglycemia and gastrointestinal and central nervous system disorders. Kidney abnormalities have developed in calves fed $NiCO_3$. Nickel chloride fed to young male rabbits decreases liver glycogen, increases muscle glycogen and produces prolonged hypoglycemia after a galactose dose. Nitrogen retention is reduced in chicken feed containing more than 500 ppm Ni as the sulfate or acetate. Nickel dust, nickel sub-sulfide (Ni_3S_2), NiO, nickel carbonyl and nickel bicyclopentadiene are carcinogenic in experimental animals after inhalation although there is no evidence of carcinogenicity after oral exposure.[143]

In summary, Ni is a non-essential element to vegetation but is essential to certain physiological functions in animals. It is less toxic to animals than to vegetation. Nickel levels in Hat Creek receptors are well below previously reported toxic concentrations.

(o) Selenium (Se)

Average concentrations of selenium (Se) in selected Hat Creek receptors collected during October 1976 (water samples from January 1977) are shown in Table F5-23. Averages ranged from 0.002 ppm (water, Site 2) to 2.83 ppm (stream sediment, Site 1) for aquatic samples and from 0.030 ppm (shrub, Site 2) to 6.67 ppm (grass, Site 5) for terrestrial materials. Concentrations were highest in stream sediment for aquatic materials and grass and soil for terrestrial samples.

Concentrations of Se in selected ecosystem components, as derived from the literature, are discussed below.

1. water - 0.0002 ppm[4]
   - 0.00011-0.00035 ppm, seven U.S. rivers[27]
   - 0.00032 ppm, polluted river[27]
2. soils - 0.2 ppm[6]
   - 0.1-6 ppm, Saskatchewan and Manitoba[6]
   - 0.01 ppm[9]
   - 0.1-0.8 ppm, Wyoming[5]
3. lake sediment - 0.5 ppm, Lake Michigan[147]

Table F5-23

Average concentration (ppm) of Selenium (Se) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> **												
Water ***	< 0.0027 >	0.0003	< 0.0020 >	0.0000	< 0.0023 >	0.0003	< 0.0023 >	0.0007			< 0.0023 >	0.0002
Stream sediment	2.03	1.30	< 1.13 >	0.47	1.67	0.67	2.53	1.30			< 2.04 >	0.47
Fish †	< 0.70 >	0.15	< 0.67 >	0.17			< 0.70 >	0.21			< 0.69 >	0.09
<u>Terrestrial</u>												
Soil	< 2.97 >	2.02	2.00	1.00	2.33	0.88	< 1.27 >	0.37	2.33	0.33	< 2.10 >	0.44
Shrub	< 0.40 >	0.15	< 0.30 >	0.00	< 0.43 >	0.19	0.40	0.06	< 0.43 >	0.03	< 0.39 >	0.04
Grass	< 2.23 >	1.30	< 2.30 >	0.70	< 3.33 >	1.33	< 0.93 >	0.54	< 6.67 >	2.33	< 3.09 >	0.74
Lichen	< 1.07 >	0.47	< 1.47 >	0.53	< 1.17 >	0.43	< 0.67 >	0.07	< 1.10 >	0.45	< 1.09 >	0.17
Small mammal	0.57	0.03	< 0.67 >	0.16	< 0.83 >	0.03	< 0.77 >	0.19	< 0.60 >	0.12	< 0.69 >	0.06

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* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic-sampling sites.

*** Selenium was not measured in samples collected in October; values are for January 1977 samples.

† No fish could be collected at Site 3.

4. vegetation - 0.2 ppm[4]
   - 3-4 ppm, Alberta, Saskatchewan and Manitoba[6]
   - 0.05-0.24 ppm, algae[27]
   - 0.02-0.26 ppm, forages in U.S.[27]
   - 0.13-0.70 ppm, Wyoming[5]
5. animals - 1.7 ppm[4]
   - 0.1-0.35 ppm, animal blood[8]
   - 0.08-0.22 ppm, deer mice, Wyoming[5]
   - 0.049-0.067 ppm, cow milk in Oregon[7]

Selenium in water and stream sediments from Hat Creek and the Bonaparte River are slightly higher than values reported in the literature. Concentrations of Se in other receptors are consistent with Se levels reported for similar ecosystem components.

Selenium is non-essential to plants in general but is essential to a few angiosperms.[4,10] Chapman[6] reports that at low concentrations, Se may stimulate plant growth. The absorption and accumulation of Se by plants depends upon the concentration and distribution of Se in the soil, the chemical nature of Se seasonal variation in rainfall, plant species, stage of growth (young plants accumulate more Se per unit of dry matter than old ones), physiological condition of the plant and presence of other soil components such as colloids (soil colloids fix Se and reduce toxicity of Se in soil), available sulfur, proteins and amino acids. Variation in the Se content of plants seem to exceed that of nearly every other trace element as the quantity absorbed may vary from traces to 15,000 ppm. Accordingly, a general Se toxicity level cannot be given for plants.

Astragalus spp. and *Conopsis* spp. thrive on soils which contain high levels of Se. Valkovic[8] indicates that it is not uncommon for these plants to accumulate 10,000 ppm of Se. Lakin[148] states that certain species of *Astragalus* utilize Se in an amino acid peculiar to these species. Chapman[6] reports that corn grown in culture solutions containing 5 ppm of selenite or organic selenium accumulates 200 and 1,000 ppm Se, respectively.

Although no generalized threshold value of Se exists for various plants, toxic concentrations for chrysanthemum, sargho, tomato and wheat range from 101-1350 ppm in leaf foliar tissues. In Ireland, Se toxicity symptoms occur to plants growing on soils containing Se levels of 30-325 ppm, as compared to less than 2 ppm in adjoining healthy areas[6] (Hat Creet soils averaged less than 3 ppm Se).

Excessive Se commonly produces a snow-white border chlorosis of the leaves of cereal plants. Less severe injury is indicated by stunting of the plants. A progressive diminution of chlorosis is apparent in successive leaves as wheat plants grow to maturity. A pinkish coloration in selenite injured roots accompanies snow-white chlorosis of wheat leaves. A garlic-like odor emanates from some of the more highly seleniferous forage plants in range areas. As a diagnostic criterion, the odor is quite specific.[6]

Plants belonging to the Compositae, Cruciferae, and Papihonaceae families, or genuses *Astragalus, Conopsis, Stanleya, Xylorrhiza, Aster,* and *Atriplex* accumulate Se in large amounts and apparently require it for healthy growth.[4,6] These plants are important in locating and mapping seleniferous areas, since they thrive only on soils which contain Se. The Se content of an indicator plant from a seleniferous soil also provides a quantitative index of the capacity of these soils to produce vegetation toxic to herbivores.[6] A lichen, *Parmelia chlorochroa*, has been suggested as a monitor plant for Se emission from power plants.[149]

Selenium is an essential element for animals. It can replace vitamin E and occurs in a few amino acids and many proteins. Se is necessary for animal growth and for fertility. It is required to prevent white muscle disease in lambs, calves and fowl and hepatosis dietetica in pigs. Selenium promotes growth, improves fertility, and reduces postnatal losses in sheep. A dietary intake of 0.1 ppm for sheep and cattle is sufficient to prevent Se deficiency. Elemental Se is poorly absorbed but inorganic salts of Se such as selenate, selenite, and selenium analogs of cystine and methionine are absorbed much better.[7] Kothny[27] indicates that Se is required at 0.040 ppm in animal diets.

Selenium compounds are inhaled through the lungs in dust or fumes, absorbed through the skin or ingested.[10] Selenium is rapidly and efficiently absorbed with the duodenum being the main absorption site. Selenium is eliminated at first rapidly and then slowly. It is excreted in feces and urine and expired; the amounts and proportions being dependent upon the level and form of intake.[7,8]

The tolerance level of animals to different levels of Se is determined by the chemical forms in which it occurs.[8] Selenium levels of 3-4 ppm in feed is not adverse to hens and eggs, although 5 ppm reduces hatchability. Chapman[6] reports that Se poisoning may occur when an animal consumes feed containing 5-40 ppm of Se for several days or weeks (0.6 ppm in feed is not toxic to sheep in 15 months).[7] Kothny[27] states that Se is toxic to most animals at a concentration of 4 ppm in feed. Rats and dogs are chronically poisoned after ingestion of 5-10 ppm Se; at 20 ppm of Se in food, animals may refuse to eat and death occurs. Young pigs fed 10-15 ppm Se may develop selenosis in 2-3 weeks. Selenium concentrations of 8 ppm in sheep diets may result in food consumption and body weight reductions after 5-6 months of treatment and 16 ppm can eventually result in death. The minimum toxic level for grazing livestock is 5 ppm.[7]

Soil containing more than 0.5 ppm is potentially dangerous to livestock. These soils can produce herbage containing 4-5 ppm Se or more. (Sampled Hat Creek soils contained less than 3 ppm Se although sampled vegetation exhibited Se levels as high as 7 ppm). Depending on the nature of the diet (i.e., protein and sulfate content), 3-4 ppm Se may accumulate in tissue and eventually produce toxic symptoms.[7] Sauchelli[150] reports that as little as 1 ppm Se in the soil permits the growth of wheat but when the same grain (containing 8-10 ppm Se) is fed to rats it retards growth and kills them after a few weeks.

Chronic poisoning of livestock could result from daily ingestion of cereals and grasses containing 5-20 ppm Se.[10] (Se in Hat Creek grasses ranged from about 2-7 ppm). Underwood[7] states that "a dietary intake of 0.1 ppm (in dry feeds) provides a satisfactory margin of safety against any dietary variable or environmental stress likely to be encountered by grazing sheep and cattle".

Lethal threshold for rainbow trout is 3.1-10.4 ppm in water with 30-36 ppm hardness and temperature of 9-12°C. The maximum acceptable toxicant concentration (MATC), the level of no chronic effect, is 0.04-0.08 ppm over a 12 month exposure period in water hardness of 20 ppm[47] (Hat Creek waters averaged less than 0.0023 ppm Se).

There are marked variations between and within animal species in their response to Se at what may be considered toxic levels.[10] Chronic Se poisoning is characterized by dullness and lack of vitality; emaciation and roughness of coat; loss of hair from mane and tail of horses and body of pigs; soreness and sloughing of hoofs; stiffness and lameness due to joint erosion in long bones; heart atrophy; cirrhosis of the liver; and anemia. Acute Se poisoning is characterized by blindness, abdominal pain, salivation, grating of the teeth,and a degree of paralysis. Respiration is impaired and this is often the cause of death. Death may also ensue from starvation and thirst because the lameness and pain from hoofs are so severe as to prevent the animal from moving about to eat and drink. This applies to horses, cattle, and pigs. Sheep show loss of appetite and weight loss only. In rats and dogs, food consumption is decreased together with anemia and cirrhosis of the liver. This occurs in conjunction with microcytic, hypochronic anemia. Chicks exhibit reduced food intake and growth rate and hens show decreased egg production with low hatchability, and often deformed embryos. Embryonal development is impaired by Se in rats, pigs, sheep, cattle,and horses.[7]

In summary, Se tends to accumulate in plants and animals, although toxicity to the former appears to be uncommon. Animals appear to be more susceptible to Se poisoning, especially livestock feeding on vegetation growing on seleniferous soils. While Se levels in Hat Creek receptors appear to be comparable with literature values, concentrations in soils and grasses at certain sites suggest a potential hazard to herbivores. However, small mammals, the only herbivore sampled, exhibited Se levels well below those considered toxic.

(p) Strontium (Sr)

Average concentrations (ppm) of strontium (Sr) in selected Hat Creek receptors collected during October 1976 are given in Table F5-24. Means ranged from 0.172 ppm (water, Site 3) to 653.33 ppm (stream sediment, Site 3) for aquatic samples and from 13.33 ppm (grass, Site 4) to 566.67 ppm (soil, Site 3) for terrestrial samples. Strontium concentrations were highest in soil and shrubs for terrestrial materials sampled and in stream sediment for aquatic samples.

Naturally occurring concentrations of Sr in a variety of ecosystem components, as derived from the literature, are shown below.

1. water - 0.08 ppm[4]
2. soils - 50-.,000 ppm[4]
   - 480-740 ppm, Wyoming[5]
3. vegetation - 26 ppm[4]
   - 1-200 ppm[8]
   - 6-150 ppm, Wyoming[5]
4. animals - 14 ppm[4]
   - 0.01-0.5 ppm[8]
   - 0.73-2.2 ppm, deer mice, Wyoming[5]

Except for small mammals and fish, which appear to have higher than expected levels of Sr, concentrations of Sr in Hat Creek receptors are not remarkably different than levels found elsewhere.

Valkovic[8] notes that Sr is non-essential to plant and animals, although Bowen[4] states that Sr may be essential as a structural element in lower animals. Bowen[4] also reports that Sr is scarcely toxic to vegetation unless calcium is absent. Experimentally determined toxic doses for laboratory mice and rats range from 123-958 ppm.[13]

Chronic Sr poisoning may be manifested as esophageal cancer in humans.[151] Strontium can also inhibit mineralization of newly formed bone tissue.[152] Strontium poisoning causes morphological changes in the cardiovascular,

Table F5-24

Average concentration (ppm) of Strontium (Sr) in receptor materials collected during October 1976

Receptors	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean *	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> **												
Water	0.292	0.004	0.322	0.027	0.172	0.008	0.204	0.012			0.248	0.071
Stream sediment	> 560.00	> 224.80	340.00	110.00	> 653.33	> 211.53	523.33	43.33			> 519.17	> 78.38
Fish ***	98.67	80.80	22.00	4.93			28.67	7.69			49.78	26.48
<u>Terrestrial</u>												
Soil	483.33	226.00	233.33	43.33	> 566.67	> 227.47	206.67	54.87	400.00	115.47	> 378.00	> 69.65
Shrub	26.33	1.76	101.67	29.28	87.00	7.51	44.33	11.84	273.33	63.33	106.53	26.37
Grass	19.00	2.52	45.67	18.09	19.00	5.00	13.33	1.86	27.33	8.25	24.87	4.72
Lichen	14.33	5.90	29.00	12.66	46.00	8.96	19.00	6.66	23.67	4.91	26.40	4.29
Small mammal	50.67	24.67	34.67	6.36	42.17	21.03	15.17	7.38	34.33	10.93	35.40	6.78

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

hematopoietic and nervous systems, in respiratory organs, liver, kidneys, and it affects metabolism in general.[153] Strontium as the nitrate or chloride has a pronounced irritating effect on the skin and a mild irritating effect on mucous membranes of the eye. As the hydroxide, Sr has a marked effect on the eye.[154]

In summary, Sr levels in environmental samples collected near Hat Creek are not greatly different from values reported at other locations in the literature cited above. Levels of this relatively non-toxic element were also below concentrations likely to be detrimental to ecosystem components.

(q) Thallium (Tl)

Average concentrations of thallium (Tl) in Hat Creek receptors collected during October 1976 (water samples from January 1977) are shown in Table F5-25. Averages ranged from 0.0010 ppm (water, Sites 1, 2, and 3) to 0.30 ppm (stream sediment, Sites 3 and 4) for aquatic samples and from 0.10 ppm (shrub, Sites 2 and 5) to 0.50 ppm (soil, Site 2) for terrestrial samples. Soil and stream sediment evidenced the highest concentrations of Tl in sampled receptors for terrestrial and aquatic systems, respectively. Data variability was low and little difference in Tl levels was apparent between sites.

Concentrations of Tl as determined from the literature for different ecosystem components are shown below.

1. water - 0.00001 ppm[4]
2. soil - 0.1 ppm[4]
3. vegetation - 2-100 ppm, ash of trees and shrubs in Rocky Mountain region[10]
   - 1 ppm, spinach and rye[10]
4. animals - 20.4 ppm[4]

Thallium concentrations in Hat Creek receptors are of a similar magnitude as levels reported in studies referenced above.

Table F5-25

Average concentration (ppm) of Thallium (Tl) in receptor materials collected during October 1976

Receptors	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean*	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
<u>Aquatic</u> **												
Water ***	< 0.0010 >	0.0000	< 0.0010 >	0.0000	< 0.0010 >	0.0000	< 0.0013 >	0.0003			< 0.0011 >	0.0001
Stream sediment	< 0.27 >	0.09	< 0.20 >	0.00	< 0.30 >	0.06	< 0.30 >	0.10			< 0.27 >	0.03
Fish †	< 0.20 >	0.00	< 0.17 >	0.03			< 0.17 >	0.03			< 0.18 >	0.01
<u>Terrestrial</u>												
Soil	< 0.30 >	0.00	< 0.50 >	0.25	< 0.20 >	0.06	< 0.27 >	0.03	< 0.27 >	0.03	< 0.31 >	0.05
Shrub	< 0.13 >	0.03	< 0.10 >	0.00	< 0.17 >	0.07	< 0.17 >	0.03	< 0.10 >	0.00	< 0.13 >	0.02
Grass	< 0.17 >	0.03	< 0.23 >	0.03	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.19 >	0.01
Lichen	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Small mammal	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** Thallium was not analyzed in samples collected in October; values are for January 1977 samples.

† No fish could be collected at Site 3.

Thallium is non-essential for plant and animals.[10] Thallium rich soil provides poor substrate for vegetation. Thallium concentrations in ash of herbaceous plants from a region in Yugoslavia noted for high levels of Tl in soils ranged from 10 to 17,000 ppm in a variety of species.[10,155] McMurtrey and Robinson[113] report that Tl compounds have been widely used for controlling rodent and predators because of the extremely toxic effects of these compounds. They add that when poisoned bait is scattered on the soil, its effects persist for several years.

Toxic concentrations of Tl to a variety of animals range from 0.8 ppm to 50 ppm per day when administered orally. Bowen[4] reports that 750 ppm/day of Tl in the diet is lethal to rats.

Experiments of the toxicity of Tl to fish and other aquatic organisms show that concentrations causing damage within 3 days are: 10-15 ppm for rainbow trout, 60 ppm for perch, 40-60 ppm for loach, 204 ppm for *Daphnia*, and 4 ppm for *Gammarus*.[156] Zitko et al.[156] estimate an incipient lethal level at about 0.03 ppm to coho salmon in water with a hardness of 14 ppm. Concentrations of 0.015 ppm, however, appear to be safe (Hat Creek waters averaged less than 0.0011 ppm Tl).

In summary, Tl levels in Hat Creek receptors are not unusually different from values reported in other studies and are below levels considered as being toxic to ecosystem components.

(r) Tin (Sn)

Average concentrations of tin (Sn) for selected Hat Creek receptors sampled during October 1976 are shown in Table F5-26. Averages ranged from 0.0437 ppm (water, Site 3) to 646.67 ppm (stream sediment, Site 3). Stream sediments evidenced relatively high concentrations at both Site 1 (Upper Hat Creek) and Site 3 (Upper Bonaparte River). Data variability was high for stream sediments at all sites. Average of Sn in terrestrial samples ranged from 10.33 ppm (grass, Site 1) to 883.33 ppm (shrub, Site 2). Shrubs, lichens and small mammals contained the highest concentration of Sn over all sites. There appeared to be no consistent trends among Sn within receptors at each site, although the high data variability may have obscured any real trends.

Table F5-26

Average concentration (ppm) of Tin (Sn) in receptor materials collected during October 1976

Receptors		Site 1 Mean*		Site 1 Std err		Site 2 Mean		Site 2 Std err		Site 3 Mean		Site 3 Std err		Site 4 Mean		Site 4 Std err	Site 5 Mean	Site 5 Std err		Overall Mean		Overall Std err
<u>Aquatic</u> **																						
Water	<	0.0723	>	0.0023	<	0.0737	>	0.0023	<	0.0437	>	0.0012	<	0.0567	>	0.0031			<	0.0616	>	0.0142
Stream sediment	>	561.67	>	264.83		49.67		22.81	>	646.67	>	191.95		111.67		89.34			>	342.42	>	107.72
Fish***	<	0.20	>	0.00	<	0.27	>	0.07						3.67		1.67			<	1.38	>	0.75
<u>Terrestrial</u>																						
Soil	>	337.33	>	351.33		24.33		14.44		23.33		9.91		5.33		2.60	35.67	25.10	>	85.20	>	65.62
Shrub	>	345.00	>	327.61	>	883.33	>	116.67		61.33		33.22	>	398.67	>	305.32	25.33	22.34	>	342.73	>	113.02
Grass		10.33		4.98		131.33		65.38		31.02		29.50		23.67		11.41	161.33	149.40		71.54		32.64
Lichen	>	380.67	>	312.22		51.00		34.53	>	354.00	>	323.35		304.67		193.91	239.00	133.84	>	265.87	>	91.56
Small mammal		46.00		27.59		50.33		28.03	>	385.33	>	310.13	>	342.00	>	329.05	177.00	146.89	>	200.13	>	89.15

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* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Concentrations of tin in selected ecosystem receptors as determined from the literature are presented below:

1. water - 0.00004 ppm[4]
2. soils - 2-200 ppm, strongly absorbed by humus[4]
   - 0.40-1.5 ppm, Wyoming[5]
3. vegetation - 0.3 ppm, higher in lichens[4]
   - 0.85-24 ppm, Wyoming[5]
4. animals - 0.15 ppm[4]
   - 0.16 ppm, Wyoming[5]

A large anomaly exists between Hat Creek Sn levels and those reported in the literature. A possible explanation for extremely high levels of Sn in biological samples (in fact, Sn concentrations in receptors are the highest of all elements considered in this study) is sample contamination. However, all aspects of sample preparation and analysis were rechecked and no possible Sn sources were discovered. The fact that Sn was high in a number of different kinds of receptors which were collected by different tools and techniques seems to preclude contamination during sample collection as well. The alternative explanation then is that Sn is naturally high in Hat Creek receptors.

Little information concerning the toxic effects of Sn on biotic systems is available in the literature. Bowen[4] reports that tin is very toxic to plants and green algae and is moderately toxic to mammals (gaseous tin hydride is very toxic). Experimentally determined toxic oral doses for various laboratory animals range from 40-1200 ppm. Toxic effects of Sn on animals include general circulatory disturbance, extensive pulmonary hemorrhage and CNS edema. Rabbits given 20 ppm/day orally of dibutyl tin chloride experience a decrease in peripheral rbc's, depressed weight gain and mild gastroenteritis. Tin also affects the liver, kidney and spleen.[158] Toxic concentrations of Sn also affect the nervous system[159] and may cause growth retardation and decreased food utilization efficiency.[160]

In summary, Sn values in Hat Creek receptors were 10 to 1000 times higher than values reported elsewhere. The cause of these comparably high levels is not known; however, any detrimental effects of these Sn levels were not apparent.

Table F5-27

Average concentration (ppm) of Vanadium (V) in receptor materials collected during October 1976

Receptors	Site 1 Mean	Site 1 Std err	Site 2 Mean*	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
<u>Aquatic</u> **												
Water	0.0058	0.0018	0.0063	0.0021	0.0033	0.0001	0.0059	0.0035			0.0059 >	0.0013
Stream sediment	56.33	11.72	184.00	113.00	189.00	106.60	186.67	39.30			154.00	38.25
Fish ***	0.97	0.55	1.23	0.88			0.27	0.03			0.82	0.33
<u>Terrestrial</u>												
Soil	386.67	124.14	277.67	108.04	376.67	107.45	194.00	125.04	253.00	158.50	297.60	51.56
Shrub	0.27	0.03	< 0.17 >	0.03	0.43	0.23	0.37	0.12	0.27	0.09	< 0.30 >	0.05
Grass	0.43	0.09	1.60	0.70	< 0.27 >	0.07	0.80	0.60	0.67	0.24	< 0.75 >	0.20
Lichen	2.33	0.33	6.00	2.08	3.67	1.20	3.00	0.00	2.33	0.33	3.47	0.55
Small mammal	0.33	0.03	0.27	0.07	< 0.23 >	0.03	0.20	0.06	< 0.20 >	0.00	< 0.25 >	0.02

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* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** No fish could be collected at Site 3.

Table F5-28

Average concentration (ppm) of Vanadium (V) in receptor material collected during January and May 1977

	January 1977*							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic**														
Water	0.0020	<0.0010	0.0023	<0.0020		<0.0018	>0.0002	0.007	0.009	0.006	<0.005		<0.007	>0.002
Stream sediment	51	62	71	63		61.75	8.22	52	61	73	74		65.00	10.5
Fish***	- -	- -	- -	- -				0.3	0.4	- -	- -		0.35	0.07
Terrestrial														
Soil	45	63	81	113	122	84.80	32.61	40	45	107	65	39	59.20	28.7
Shrub	- -	- -	- -	- -	- -			0.2	<0.3	<0.4	0.6	<0.4	<0.38	>0.2
Grass †	- -	- -	- -	- -	- -			0.9	<0.4	<0.7	- -	<0.7	<0.68	>0.2
Lichen	1.5	3.9	3.5	2.9	2.6	2.88	0.92	1.4	3.7	3.0	2.5	1.7	2.46	0.9
Small mammal	- -	- -	- -	- -	- -			0.3	<0.15	0.2	0.3	<0.3	<0.25	>0.7

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* Only water, stream sediment, soil and lichen were collected during January 1977.

** There are only four aquatic sampling sites.

*** Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

† Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

(s) Vanadium (V)

Average concentrations of vanadium (V) in selected Hat Creek receptors sampled during October 1976 are given in Table F5-27. Averages ranged from 0.0033 ppm (water, Site 3) to 189.00 ppm (stream sediment, Site 3) for aquatic samples and from 0.17 ppm (shrub, Site 2) to 386.67 ppm (soil, Site 1) for terrestrial samples. Vanadium concentrations were quite high in stream sediment and soil materials at all sites, although the high variability in these samples precludes adequate evaluation of trends or differences between sites. Within-site variability in other receptors appears acceptable.

Vanadium levels in receptors collected during January and May 1977 are provided in Table F5-28. Soil and stream sediment V concentrations decreased substantially in January and May 1977 samples. Other receptors sampled in 1977 exhibited V levels similar to October 1976 concentrations.

Naturally occurring concentrations of V in selected ecosystem components as determined from the literature, are shown below.

1. water - 0.001 ppm[4]
2. soil - 3-500 ppm[6]
   - 100 ppm, humus in alkali soils[4]
   - 16-59 ppm, Wyoming[5]
3. vegetation - 0.27-4.2 ppm[6]
   - 1.6 ppm[4]
   - 0.18-8.9 ppm, Wyoming[5]
4. animals - 0.15 ppm[4]
   - 0.01-0.59 ppm[5]

Vanadium levels observed in Hat Creek receptors are consistent with those levels reported in the literature.

Vanadium is generally non-essential for higher plants and most higher animals, although it is reported to be a beneficial trace element for some fungi, algae, bacteria, chicks and rats.[4,6,8,10] Chapman[6] reports that V plays a role in enzyme activation in nitrogen fixation by soil microorganisms and may replace molybdenum as an essential element required by some N_2-fixing bacteria. In animals, the highest concentrations of V are seen in hair and bone.[4]

There are no reports of either toxicity or deficiency of V to plants under field conditions.[6] Gough and Shacklette[10] note that some food plants may accumulate high levels of V without exhibiting toxicity symptoms as is shown by the following data: snap bean, 600 ppm (maximum found in ash); cabbage, 50 ppm; tomato fruits, 30 ppm; and asparagus, 30 ppm.

Scharrer and Schropp[161] found V to be toxic to germinating seeds, but was even more toxic to plants at later growth stages. Chiu[162] reports that 500 ppm of V in culture solution is toxic both to roots and tops of barley. Injury to barley may be produced when 1 mg of V, as vanadium chloride, is added to solution and sand cultures. Chapman[6] notes that 10 ppm of V added as calcium vanadate to a sandy soil results in decreased growth of orange seedlings; at 150 ppm of V all plants died. In all cases seedling leaves had less than 1 ppm V.

Chapman[6] suggests that V toxicity may be indicated by 2 ppm V (dry weight basis) in the tops of pea or soybean plants. He concludes that concentrations greater than 0.5 ppm in nutrient solutions are toxic to plants, and that additions of the element to soils has produced toxicity to a variety of crop plants. Schroeder, Balassa and Tipton[164] report that as soluble V the following solution concentrations are slightly toxic: 10-20 ppm for soybeans, 26 ppm for beets, 40 ppm for barley, 20 ppm for wheat, and 22 ppm for oats.

Vanadium is a relatively non-toxic metal to animals and man.[10] Underwood[7] reports that chicks can tolerate 20-35 ppm. Humans fed 4.5 mg V/day for 16 months suffer no apparent toxicity.[164] Experiments with ammonium vanadyl tartarate given orally to six subjects for six to ten week produces no toxic effects other than some cramps and diarrhea at the larger dose levels.[7]

Valkovic[8] reports that 25 ppm sodium vanadate produces toxic symptoms in rats, 30 ppm calcium vanadate depresses weight gain and 200 ppm results in high mortality. Schroeder et al.[164] states that 160 ppm in the diet of rats over a period is lethal due to gastrointestinal irritation. Bowen[4] reports that 50 ppm V^{+5} (vanadate) per day dry weight diet is toxic to rats and 150 ppm is lethal. Underwood[7] indicates that 25 ppm is toxic to rats, whereas 50 ppm causes diarrhea and increased mortality. He notes as well that greater than 20 ppm V in the diet results in growth depression in chicks. Toxic effects of V intake include diarrhea, enzyme system dysfunction, growth depression and irritation to the lungs when inhaled.[7,10] It is generally accepted that a large fraction of particles approximately 0.5 mm or smaller in diameter can be deposited in lungs. Since particles less than 0.5 mm contain the highest percentages of V, the element poses an inhalation threat. The V inhalation threat increases with decreasing aerosol size.[27,165]

In summary, V is generally non-essential to higher plants and animals. It is moderately toxic to vegetation, although no reports of either V toxicity or deficiency to plants under field conditions have been reported. Vanadium is generally non-toxic to animals. Levels of V in Hat Creek receptors are similar to literature derived values.

(t) Zinc (Zn)

Average concentrations of zinc (Zn) in selected Hat Creek receptors sampled during October 1976 are shown in Table F5-29. Average Zn concentrations ranged from 0.0098 ppm (water, Site 3) to 94.33 ppm (fish, Site 2) for aquatic samples. Concentrations of Zn in fish and stream sediment over all sites were similar, although within-site variability was high for both aquatic and terrestrial receptors. Stream sediment showed higher concentrations of Zn in the Bonaparte River (Sites 3 and 4) than in Hat Creek (Sites 1 and 2). For terrestrial samples, averages ranged from 14.00 ppm (grass, Site 3) to 383.33 ppm (shrub, Site 5). Of terrestrial receptors, Zn levels were highest in shrubs although within-site variability was high for all samples.

Table F5-29

Average concentration (ppm) of Zinc (Zn) in receptor materials collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
Receptors	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aquatic *												
Water	0.0153	0.0022	0.0247	0.0118	0.0098	0.0010	0.0153	0.0017			0.0162	0.0061
Stream sediment	42.33	4.06	36.33	4.67	92.00	16.77	118.00	36.56			72.17	13.47
Fish **	81.67	23.51	94.33	37.97			67.33	24.26			81.11	15.10
Terrestrial												
Soil	115.67	42.69	92.33	19.97	225.67	130.60	220.00	68.07	82.00	0.00	147.13	31.06
Shrub	186.67	38.44	156.67	3.33	69.00	30.99	313.33	63.33	383.33	47.02	221.80	33.94
Grass	20.67	3.84	23.33	3.28	14.00	4.93	35.67	5.36	16.67	4.81	22.07	2.64
Lichen	25.33	2.33	31.00	9.02	55.33	17.61	57.67	16.90	67.00	51.51	47.27	10.68
Small mammal	146.33	81.18	165.00	72.63	126.67	57.32	93.33	3.76	92.00	25.51	124.67	22.61

* There are only four aquatic sampling sites.

** No fish could be collected at Site 3.

Zinc concentrations in receptors collected during January and May 1977 are given in Table F5-30. Except for lichens there were no large changes in Zn levels at Sites 2 (lower Hat Creek), 3 (Arrowstone Ridge) and 4 (Cornwall Mountain) from October 1976 to January 1977. Zinc levels at Sites 1 (Pavillion Mountain) and 5 (Ashcroft) were low during January. Lichen collected during May 1977 were similar to their October 1976 Zn levels.

Naturally occurring concentrations in different ecosystem components, as determined from the literature are presented below:

1. water - 0.01 ppm[4]
   - 0-215 ppm, North American rivers[166]
2. soil - 10-300 ppm, surface soil[6]
   - 50 ppm[4]; 44 ppm[10]; 40-84 ppm, Wyoming[5]
3. vegetation - 100 ppm[4]
   - 25-150 ppm[8,10]
   - 28-74 ppm, pine needles[89]
   - 1-10, 200 ppm[6]
   - 20 ppm, many plants[6]
   - 6-88 ppm, Wyoming[5]
4. animals - 160 ppm[4]
   - 28-45 ppm, pig[7]
   - 26-49 ppm, deer mice, Wyoming[5]

Except perhaps for Zn concentration in lichens collected at three sites during January 1977, Zn levels in Hat Creek receptors are similar to those reported in the literature.

Zinc is an essential trace element for bacteria, fungi, blue-green and green algae and animals.[4,8] In vegetation, Zn is absorbed primarily by the roots and translocated to leafy parts of plants[167], although Zn accumulation is generally greater in roots. Most accumulated Zn tends to be tied up in insoluble form in the cell wall and, therefore, exerts only limited metabolic activity.[168]

Table F5-30

Average concentration (ppm) of Zinc (Zn) in receptor material collected during January and May 1977

	January 1977*							May 1977						
						All Sites							All Sites	
Receptors	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev	Site 1	Site 2	Site 3	Site 4	Site 5	Mean	Std Dev
Aquatic**														
Water	0.0123	0.0130	0.0467	0.0170		0.0223	0.0164	0.076	0.032	0.070	0.031		0.05	0.02
Stream sediment	45	67	225	42		94.75	87.55	54	45	<0.3	17		29.08	24.8
Fish***	- -	- -	- -	- -				86	53	- -	- -		69.50	23.3
Terrestrial														
Soil	155	119	100	66	56	99.20	40.23	197	123	193	128	0.3	128.26	79.6
Shrub	- -	- -	- -	- -	- -			64	160	82	135	105	109.20	38.9
Grass†	- -	- -	- -	- -	- -			34	25	43	- -	32	33.50	7.4
Lichen	<0.5	330	3.0	468	<0.5	<160.4	>223.21	25	35	40	75	37	42.40	19.1
Small mammal	- -	- -	- -	- -	- -			94	0.2	71	145	99	81.84	53.0

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* Only water, stream sediment, soil and lichen were collected during January 1977.

** There are only four aquatic sampling sites.

*** Fish were not collected at Sites 3 and 4 (Bonaparte River) during May 1977 due to high water levels.

† Due to overgrazing and limited plant growth, a suitable grass sample was not available at Site 4 (Cornwall Mountain) in May 1977.

Vegetation species that may provide a sensitive indication of high Zn levels in the soil may be found in the Caryophyllaceae, Compositae, Cruciferae, Gramineae, Phymbaginaceae, Rutaceae and Violaceae families. Gough and Shacklette[10] report that a good indication of Zn mineral outcrops is the presence of luxuriantly growing ragweed (*Ambrosia* sp.; family Compositae) when other vegetation is stunted.

Gough and Shacklette[10] note that 12.5% total Zn in the soil will stunt most vegetation. Chapman[6] reports that amounts greater than 400 ppm in dry matter may indicate a Zn excess, although the concentration varies with species. Chapman[6] adds that toxicity occurs at 1700-7500 ppm of Zn in leaves of oats, while toxicity levels range from 526-1489 ppm and 200-300 ppm for tomatoes and oranges, respectively. For cowpeas and corn, toxic levels as reported by Chapman[6], are 500 lbs/A and 700 lbs/A, respectively. They emphasize that the toxicity will vary with the type of soil, being most toxic in sandy soil and least toxic in clay loamy soil. In some New York peat soils it is found that toxic concentrations of Zn to vegetable crops such as carrots, spinach and lettuce ranged from 0.43 to 10.16%.[6]

Weaver and Brock[169] found that under laboratory conditions, plant growth is inhibited at concentrations of 0.5-50 ppm of $ZnCl_2$. Kusaka, Maekawa and Sono[170] state that the yield of turnips growing under laboratory conditions is decreased by 30% with 200 ppm of Zn in soil. Excess Zn in soil often produces plant chlorosis by interfering with required iron uptake.

Zinc has been implicated in a reduction of the dehydrogenase activity and the microbial nitrogen mineralization process in soil.[168] This in turn may inhibit the growth of some important detritus microorganism.[171] Zinc effects on soil can have serious implications when considering that even a slight decrease in soil Zn content can mediate nutrient cycling and that Zn contamination of soils appears to be virtually permanent.[172]

In regard to animals, Zn is essential for growth, bone growth, wound healing, reproduction, carbohydrate metabolism and learning behavior.[7] It is required for the production, activity and structure of many enzymes, and it is involved in RNA and protein synthesis.[7,8,26] Underwood[7] reports that rats need at least 60 ppm Zn/day, pigs 100 ppm/day, poultry 35 ppm/day and ruminants 18-33 ppm/day.

Animals are exposed to Zn through air, water and food.[8] Zinc absorption occurs mainly in the small intestine and is excreted in the feces. Zinc can also be eliminated in sweat. Absorbed Zn is slow to be taken up by bones or the CNS, but once bound, it remains so for long periods of time; Zn in hair is never recovered by the body. Zinc may combine with plasma proteins and with the intracellular proteins of blood cells to form a plasma zinc pool. Plasma zinc is distributed throughout the body's soft tissues and is eliminated. Accumulator organs include eye choroid, prostate, bone, kidney and feathers, as well as blood (especially red bood cells), and snake venom.[4,7,26]

Zinc is relatively non-toxic to birds and mammals and a wide margin of safety exists between normal intakes and those likely to produce deleterious effects. Rats, pigs, poultry, sheep and cattle exhibit considerable tolerance to high intakes of Zn, the extent of the tolerance depending upon the composition of the basal diet, particularly its content of minerals known to affect Zn absorption and utilization, such as Cu, Fe,and Cd.[7] Gough and Shacklette[10] report that rats with dietary intakes of 2500 ppm Zn, weanling pigs with dietary intake of 1000 ppm Zn, steers fed a diet of 500 ppm or less of Zn, and chickens fed 1200-1400 ppm of Zn evidence no ill effects.

Underwood[7] reports that 5000 ppm zinc chloride fed to rats depresses growth and produces severe mortality in young animals. Ingestion of 5000-10,000 ppm $ZnCO_3$ produces severe anemia in young rats in addition to subnormal growth, anorexia,and death at 10,000 ppm. Female rats fed 4000 ppm Zn resorb fetuses. Zinc concentrations of 4000-8000 ppm cause high mortality in weanling pigs. Levels of 3000 ppm cause growth and appetite depression in chickens. For lambs, Underwood[7] reports that 1500 ppm zinc oxide causes depressed feed consumption, 1000 ppm decreases feed efficiency and increased mineral block consumption, 900 ppm causes reduced weight gain and lowered feed efficiency, and 1700 ppm induces depraved appetites as characterized by excessive mineral and salt block consumption and wood chewing.

Janda[173] found that the LD_{50} of zinc phosphate (Zn_3P_2) to pheasants and partridges (determined under field conditions) is 8-27 ppm. He reports also that consumption of small doses may cause severe disorders of the blood, nervous system, liver and kidneys. Gasaway and Buss[174] state that under laboratory conditions 3000-12,000 ppm of $ZnCO_3$ in food is toxic to mallard ducks. Toxic effects include reduction in pancreas and gonads relative to body weight and an increase in the ratio of adrenals and kidneys to body weight. Extreme anemia occurs after 45 days and death generally results after 60 days.

Valkovic[8] reports that the hazard to lungs could be serious due to the tendency of Zn to concentrate in lung tissue with decreasing particle size. Inhalation could lead to fever and depression. Lebetseder et al.[175] note that another non-specific symptom associated with Zn inhalation is a significant reduction in dairy cow milk production of about 0.64 1/animal/day.

Valee[176] reports that 4 ppm of Zn bound to serum albumin produces lassitude, decreased tendon reflexes, blood enteritis, diarrhea, and pausis of hind legs. Furthermore, he notes that 1 ppm Zn decreases the leucocyte count in dogs which may decrease resistance to disease.

Long term toxicity tests with rainbow trout in water with hardness of 26 ppm indicate a maximum allowable tolerance concentration (MATC) between 0.36-0.71 ppm (eggs not exposed) and between 0.14-0.26 ppm (eggs exposed) (Hat Creek water averaged less than 0.02 ppm Zn). In hard water, the MATC is slightly lowered. MATC for fathead minnows is between 0.03-0.18 ppm in water with hardness of 203 mg/1.[177]

Davies and Goettl[47] report that a lethal threshold (lowest concentration that killed fish) for rainbow trout is between 0.24-7.21 ppm depending on water hardness, water temperature, and fish size. Sprague and Ramsey[178] found that the lethal threshold of mixing Cu and Zn as their sulfates in water of hardness of 14 mg/l was 0.42 ppm to salmon fry. Sprague[179] reports that the lethal threshold for young Atlantic salmon in soft water is 0.6 ppm. Grande[68] experimented with fry in the yolk sac stage of Atlantic salmon, brown trout and rainbow trout and found there was little or no mortality during exposure for 21 days to concentrations up to 0.5-1.0 ppm of Zn. Sprague, Elson and Saunders[180] report that many aquatic insect larvae, including *Diptera* sp., can tolerate Zn concentrations up to 60 ppm.

In summary, zinc is an essential element to most plants and animals. Zinc is moderately toxic to vegetation and relatively non-toxic to birds and mammals. For the most part Zn concentrations in sampled Hat Creek receptors was similar to values reported in the literature.

(u) Zirconium (Zr)

Average concentrations of Zirconium (Zr) in Hat Creek receptors are shown in Table F5-31. Averages ranged from 0.0017 ppm (water, Site 1) to 157.00 ppm (stream sediment, Site 3) for aquatic materials and from 0.33 ppm (shrub, Sites 1, 2, 4; grass, Site 4) to 385 ppm (soil, Site 4) for terrestrial samples. As with most trace elements surveyed, Zr concentrations were highest in stream sediment and soil samples. With respect to stream sediment, Zr levels were higher in the Bonaparte River (Sites 3 and 4) than in Hat Creek (Sites 1 and 2).

"Naturally" occurring concentrations of Zr in a variety of ecosystems, as determined by the literature, are presented below.

1. water - 0.003-0.8 ppm[4]
2. soil - 50-1000 ppm[4]
   - 1200-3300 ppm, Wyoming[5]
3. vegetation - 0.64-20 ppm[4]
   - 6.1-88 ppm, Wyoming[5]
4. animals - 0.3-5 ppm[4]
   - 0.3-0.99 ppm, deer mice, Wyoming[5]

Zr concentrations in Hat Creek receptors are within the range of values reported in the literature.

Table F5-31

Average concentration (ppm) of Zirconium (Zr) in receptor materials collected during October 1976

Receptors	Site 1 Mean*	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
<u>Aquatic</u> **												
Water ***	< 0.0020	> 0.0006	0.0017	0.0007	0.0027	0.0003	0.0023	0.0003			< 0.0022	> 0.0002
Stream sediment	86.33	37.09	77.33	16.33	157.00	62.07	121.00	31.37			110.42	19.61
Fish †	0.67	0.18	< 0.60	> 0.21			< 0.47	> 0.09			< 0.58	> 0.09
<u>Terrestrial</u>												
Soil	103.67	21.53	76.00	22.48	155.33	107.34	> 385.00	> 308.48	60.67	11.84	> 156.13	> 63.95
Shrub	0.33	0.07	0.33	0.09	0.50	0.17	0.33	0.09	0.63	0.15	0.43	0.06
Grass	0.63	0.09	0.87	0.13	0.80	0.12	0.33	0.09	1.50	0.76	0.83	0.17
Lichen	2.33	0.67	26.67	22.67	3.67	0.88	3.67	0.67	1.67	0.67	7.60	4.61
Small mammal	3.33	0.88	2.67	0.33	2.33	0.33	< 5.33	> 2.40	1.33	0.33	< 3.00	> 0.57

* See first footnote in Table F5-2 for explanation of < and > symbols.

** There are only four aquatic sampling sites.

*** Zirconium was not analyzed in samples collected in October; values are for January 1977 samples.

† No fish could be collected at Site 3.

Zirconium is only moderately toxic to vegetation and is poorly absorbed.[4] Zirconium is of low toxicity to animals.[4,8] Toxic doses to a variety of laboratory animals range from 98-3500 ppm for different chemical compounds of Zr.[13]

F5.2 Transmission Media Analysis

Air is the primary medium of transport of trace elements in fugitive dust and stack emissions and is the focus of this report section. Soil and water, secondary transmission media for trace elements in air that intercept Hat Creek substrates and primary media for material storage and disposal pile leachates were discussed in Section F5.1. Biota important in the transport of certain trace elements via the food chain were also discussed in the previous section.

Air samplers were not installed and operational until spring 1977. Results of selected trace element analysis of total suspended particulates (TSP) collected in high vol samples during spring 1977 are presented in Table F5-32. Highest trace element concentrations in air were observed at Site 1 (Cache Creek) and Site 3 (B.C. Hydro Hat Creek Office). Both of these sites are proximal to moderate to heavy vehicular traffic and associated higher dust (TSP) levels. Copper and lead evidenced the highest levels in samples from each site.

Concentrations of selected trace elements in air as reported in the literature are listed below.

As - <0.00001 ppm/m^3[4]
Cd - Not Reported
Cr - 0.00001 ppm/m^3, nonurban areas[53]
Cu - <0.02 $\mu g/m^3$[4]
Pb - 0.0005 - 0.2 $\mu g/m^3$[4,88]
Hg - 0.03 - 50 $\mu g/m^3$[118]
V - <0.001 $\mu g/m^3$[4]
Zn - <0.07 $\mu g/m^3$[700]

TABLE F5-32

Results of Selected Trace Element Analysis of TSP Collected in High Volume Samplers During Spring 1977

Element	Site 1 Cache Creek Office N	 Mean	 Std.Dev.	Site 2 Highway 12 N	 Mean	 Std.Dev.	Site 3 B.C. Hydro Office N	 Mean	 Std.Dev.	Site 4 Milner's Ranch N	 Mean	 Std.Dev.	Site 5 Cascade* N	 Mean	 Std.Dev.
Arsenic (As)	3	<0.002	>0.002**	3	<0.002	>0.001	2	<0.005	>0.005	2	<0.002	>0.0007	0		
Cadmium (Cd)	3	<0.0003	>0.0001	3	<0.0004	>0.0	2	<0.0004	>0.0	2	<0.0004	>0.0	0		
Chromium (Cr)	3	<0.001	>0.0006	3	<0.001	>0.0	2	<0.002	>0.0007	2	<0.001	>0.0	0		
Copper (Cu)	3	0.18	0.23	3	0.06	0.03	2	0.16	0.16	2	0.08	0.05	0		
Lead (Pb)	3	0.05	0.06	3	<0.003	>0.0	2	0.06	0.08	2	<0.003	>0.0	0		
Mercury (Hg)	3	<0.001	>0.0	3	<0.001	>0.0	2	<0.001	>0.0	2	<0.001	>0.0	0		
Vanadium (V)	3	0.004	0.003	3	<0.002	>0.0001	2	0.0008	0.0	2	<0.002	>0.003	0		
Zinc (Zn)	3	<0.001	>0.0	3	<0.001	>0.0	2	<0.001	>0.0	2	<0.001	>0.0	0		

*Quantities of trace elements were too small to detect after digestion of collection filters.

**See first footnote in Table F5-2 for explanation of < and > symbols.

Concentrations of the above elements in Hat Creek are below levels reported in the literature; that is, Hat Creek air is relatively clean. Lack of large population centers and heavy industrial development are perhaps the primary factors for the low levels of trace elements in sampled Hat Creek air.

F6.0 TRACE ELEMENT MOVEMENT AND ACCUMULATION

Trace elements naturally existing in coal, overburden and waste rock will be released to the environment during coal mining and power generating operations. Based on trace element concentrations in various source materials in the Hat Creek area and different biogeochemical characteristics for various trace elements, certain trace elements were selected for additional discussion in this report. This section discusses the major sources and processes that will release these trace elements to the environment and the most probable paths that these elements will take through local air, soil and water media. A schematic chart is used to summarize the flow pathways. Processes such as element recycling, direct absorption of airborne trace elements by plant or animal tissue, and interchange between aquatic and terrestrial systems are not explicitly depicted in these charts. These processes do occur, but are even less understood than trace element transfer from air to soil and water with subsequent accumulation of elements in biological organisms. Also, indicated pathways represent only most likely environmental routes for each element based on known source of media (air, soil, water) characteristics in the Hat Creek area. Numerically ranked flows do not indicate mass transmission rates of the element, but qualitatively rate the most likely pathways for element movement through the environment. For example, the flow of As from gas stack to air and from bottom sediments to aquatic organisms are both described as major pathways. However, the mass transport of As exiting the stack to the atmosphere will far exceed the mass transport of As from bottom sediments to aquatic organisms. Therefore, the primary purpose of these charts is to provide a graphical summary of trace element movement subsequent to release to the environment.

F6.1 Trace Elements Of Concern

Using a process described in Section F5.0, nine trace elements were selected as being of most environmental concern. Trace elements selected include those that have been studied in sufficient detail to define their potential environmental distribution, toxicity, bioaccumulation potential and other ecological characteristics. A brief description of these elements follows:

1. Arsenic - concentrated on fly ash particles; estimated emission from gas stack is about 17 kg/day; concentration in leachates from coal, overburden, waste rock, and ash materials range from about 1 to 4 mg/kg; arsenic is mobile in alkaline media; has a high potential for bioaccumulation; is relatively toxic.

2. Cadmium - slightly concentrated on fly ash particles; it has no known micro-nutrient value to either plants or animals; has a high bioaccumulation potential; is moderately toxic.

3. Chromium - concentrated on fly ash particles; estimated emission from gas stack is about 5 kg/day; concentration in leachates from coal overburden, waste rock, and ash materials range from 0.1 to 1.3 mg/kg; most forms of element can be oxidized to the toxic hexavalent state; moderate potential for bioaccumulation.

4. Copper - concentrated on fly ash particles; estimated emission from gas stack is about 6 kg/day; concentration in leachates from coal, overburden, waste rock, and ash materials range from 0.2 to about 6 mg/kg; copper has moderate potential for bioaccumulation; more toxic to vegetation than to animals.

5. Fluorine - concentrated on fly ash particles; estimated emission from gas stack is about 280 kg/day; concentration in leachates from coal, overburden, waste rock, and ash materials range from 0.4 to 55 mg/kg; potential for bioaccumulation of airborne fluorides; gaseous forms relatively toxic.

6. Lead - concentrated on fly ash particles; estimated emission from gas stack is about 4 kg/day; potential for bioaccumulation of airborne lead compounds; relatively toxic.

7. Mercury - major fraction of mercury in coal emitted from gas stack in vapor phase; estimated stack emission is about 7 kg/day; high potential for bioaccumulation; relatively toxic.

8. Vanadium - estimated emission from gas stack is about 16 kg/day; concentration in leachates from ash range from about 1 to 4 mg/kg; mobile in alkaline media; potential for bioaccumulation; moderately toxic.

9. Zinc - concentrated on fly ash particles; estimated emission from gas stack is about 13 kg/day; concentration in leachates from coal, overburden, waste rock, and ash materials range from about 10 to 80 mg/kg; high potential for bioaccumulation; moderately toxic.

F6.2 Principal Sources Of Trace Elements From The Coal Mine And Power Plant

The principal mechanisms that may result in mobilization of trace elements to the environment are exposure of mine-associated materials (coal ore, overburden and waste rock) to surface erosional forces, emission of fine particulates and gases from the power plant stack, and leaching of trace elements from power plant waste materials (primarily bottom and fly ash, and boiler and cooling tower blowdown) placed in storage basins or piles. Trace elements will also be transported to the local environment as cooling tower drift is deposited on land and washed into streams during rainfall.

(a) Coal Mine

Top soil, overburden and waste rock will be stored in stockpiles. The size and nature of these piles will continually change as both mining and reclamation progress. Much of the material in these piles will be freshly exposed to various surface stresses or uses (e.g., surface erosional forces and reclamation efforts) for the first time.

Trace element concentrations in soils, overburden and waste rock often vary due to local differences in mineralogy and erosional history. Weathering of rocks not only results in formation of more stable mineral compounds, but also converts trace elements into more mobile forms. Surface and near surface deposits, which have long been exposed to weathering, may have a much lower content of potentially mobile trace elements than deeper overburden and waste rock. Therefore, as once-buried overburden and waste rock are exposed to weathering, certain trace elements may be mobilized into other sectors of the ecosystem. To estimate potential amounts of water-soluble trace elements in various source materials, leachate tests were performed on Hat Creek coal, waste rock, and overburden as well as upon various source materials related to power plant activities. The results of these tests were discussed in Section F4.1 and summarized in Table F4.1. Concentrations of Al and Fe, elements commonly found in levels exceeding trace amounts in most soils and rocks, are included in Table F4-1 for comparison to concentrations of common trace elements. Concentrations of As, Cu, and Zn are relatively high in Hat Creek coal, waste rock and overburden leachate compared to concentrations of such common elements as Al and Fe.

The mobility (exchangeability or availability) of a particular trace element in soils is often related to soil alkalinity and cation exchange capacity (CEC). Most trace elements that can form basic oxides (Cd, Co, Cu, Ni, Zn, etc.) are much more mobile in acid soil than in basic soil. Other trace elements that can form acid oxides (As, Mo, Se and V) are fairly mobile in alkaline soils. A few trace elements (Pb and Be) form extremely insoluble compounds (metal carbonates and hydroxides) and are very immobile under most soil conditions. Soils with high cation exchange capacities, such as montmorillonite clays or peaty soil, also retain trace elements. Therefore, trace elements in soils with high cation exchange capacities are relatively immobile; however, the elements are available for uptake by plants growing on these soils. Soils, overburden and waste rock from the Hat Creek coal mine are moderately or strongly alkaline with pH values ranging from nearly neutral to basic (Tables F6-1 and F4-1). Soils also have moderate CEC's and organic content and can be characterized as loamy sand to sandy loam (Table F6-1). Soils at higher elevations in the study area, such as Sites 1 and 4, have higher CEC's and organic contents than soils at lower elevations in the Hat Creek valley. Therefore, many trace elements naturally occurring in stockpiles of soils, overburden or waste rock should remain relatively

Table F6-1

Soil characteristics in Hat Creek study area (October 1976)

Terrestrial Location *	pH	CEC** (meq/100g)	Organic Material (%)	Texture
Site 1	6.7	45	23	Loamy sand
Site 2	8.0	14	8	Loamy sand
Site 3	7.1	24	4	Loamy sand to sandy loam
Site 4	6.7	55	25	Sandy loam
Site 5	7.3	17	3	Sandy loam

* See Figure F3-1 for location of sampling sites.

** Cation exchange capacity

immobile. However, certain elements such as As and V are fairly mobile in alkaline soils and also appear to exist in comparatively high concentrations in soil, coal or overburden found in the Hat Creek region (Sections 4 and 5). These elements could therefore be of special environmental significance in the Hat Creek area.

Similar factors control the solubility of trace elements in both soil and water. Many trace elements form insoluble carbonates or hydroxides in basic water and precipitate out of solution. Many elements are complexed or adsorbed on fine clay particles or on organic materials commonly found in streams. As with soils, water and stream sediments (Table F6-2) in the Hat Creek area are basic. Therefore, those elements of environmental concern in soils should also be of concern in waters.

In addition to stockpiles of waste rock and overburden, other potential sources of trace elements associated with the mine include leaching of trace elements from the following: (1) exposed rock and coal seams in the pit, (2) coal stockpiles at the plant, and (3) crushed coal as it is washed during processing. Trace element concentrations in leachate from coal and wash plant tailings were listed in Table F4-1. Fugitive coal dust from crushing, pulverizing and conveying operations may also be an additional source of trace elements to both aquatic and terrestrial environments. Most trace elements in coal exist as insoluble organic complexes or inorganic compounds (e.g., sulfides of As, Cd, Co, Cu, Pb, Hg, Ni, Se, and Zn, and carbonates of Fe). However, insoluble carbonates can be solubilized as bicarbonates in the presence of carbon dioxide, which is invariably contained in rainwater, and poorly soluble sulfides can be oxidized to water soluble sulfates if sufficient aeration occurs. Therefore, even though trace elements in coal mostly exist in very insoluble and immobile forms, common surface weathering actions (oxidation and rainfall) can change these immobile trace element forms into compounds that are water soluble and available for uptake by biological components of the environment.

(b) Power Plant

The burning of processed coal in the power plant will result in emissions of fine particulates and gases from the stack and accumulations of large amounts

Table F6-2

Stream sediment characteristics in Hat Creek study area (October 1976)

Aquatic Location*	pH	CEC** (meq/100g)	Organic Material (%)	Texture
Site 1	7.8	28	13	Sandy loam
Site 2	8.0	18	13	Sandy loam
Site 3	8.0	14	2	Sandy
Site 4	8.0	12	3	Sandy

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* See Figure F3-1 for location of sampling sites.

** Cation exchange capacity.

of waste ash in storage basins. The particulates, gases and ashes will all contain a variety of trace elements that can be transferred to other components of the environment.

Trace elements in coal are not partitioned equally among all combustion products. Certain compounds that are sufficiently volatilized during combustion exit the stack either in the gaseous phase or recondensed on the surface of fine fly ash particulates. Mercury is typically considered to be the most volatile trace element in coal and 90% or more of the original Hg content of the coal often exits the plant via the stack, primarily in the gas phase.[193,194] Several potentially toxic trace elements are concentrated on small outlet fly ash particles (typically less than 10 microns in diameter) in comparison to precipitated fly ash or slag. Arsenic, Se, Cd, Cu, Pb, Mo, Se, Tl and Zn can concentrate on surfaces of small fly ash particles and exit the plant with these small particles as they pass through particulate collection devices.[3,194] Chromium, F, Ni and V appear to be associated with precipitated fly ash, but varying quantities of these environmentally important elements exit the plant through the stack.[193]

Results of test burns of Hat Creek coal samples have previously been presented and discussed (Section F4.3). Elements most likely to be enriched in fly ash or gaseous emissions from the power plant are As, Cr, Cu, F, Pb, Hg, V and Zn.

These elements will ultimately be deposited to the terrestrial or aquatic environment. Small particles containing the elements will either settle out directly or be washed out of the atmosphere by rainfall. Most of the gaseous Hg that leaves the stack will be adsorbed on atmospheric particulate matter. Atmospheric Hg, both particulate and gaseous, usually returns to the earth in rainfall. However, near industrial sources of atmospheric Hg that are located in regions of low annual rainfall, more Hg will be locally deposited by dry fallout than by rainfall.[195]

Even though concentrations of many elements are enriched in stack gas emissions, the relatively low fly ash emission rate means that the absolute amount of most elements that are retained in collected ashes will greatly exceed the amount exiting from the stack. The environmental distribution of the trace element fraction that is contained in bottom and precipitated fly ash can be controlled to a much greater extent than the fraction that exits the plant from the stack. However, salt extraction tests on fly and bottom ash indicate that relatively high concentrations of As, V and Zn can be leached from these precipitated ashes (Table F4-1). Ashes will be placed in storage piles, and proper design, construction and maintenance of these basins will prevent seepage of trace elements into surface and groundwaters or wind-caused dispersion of ash from the basins onto neighboring lands.

Various maintenance and cleaning activities in the plant may require large amounts of chemical products that contain toxic elements. Corrosion and scale inhibitors used for cleaning operations often contain chromates, and corrosion products often contain soluble salts of Cu and Zn. These compounds will leave the plant in cooling tower, condenser and boiler blowdowns that will be routed to waste basins. As with ash basins, proper design, construction and maintenance of these effluent basins will prevent migration of any trace elements to neighboring terrestrial or aquatic environments.

Drift from cooling towers will contain those salts naturally existing in makeup water, but at concentrations higher by a factor of 14 due to recirculation.[242] The mineral content of the Thompson River (the potential source of cooling tower makeup water) is very low, usually 70 to 100 mg/l total dissolved solids.[196] Cooling tower drift will be a secondary and more localized source of trace element contamination compared to coal combustion, mine spoil piles and waste storage basins. Trace element concentrations in Thompson River water near Ashcroft and predicted trace element concentrations in cooling tower drift were listed in Table F4-3.

F6.3 Environmental Pathways And Ultimate Fate Of Trace Elements

Different environmental distributions and fates will likely occur for various elements that are released by mining or power plant activities.

Certain elements may remain immobilized in their original state with little or no change occurring in their natural form or distribution. Other elements will be incorporated into collected power plant wastes and stored in waste basins where elemental migration can be controlled. Certain elements will be more widely distributed through the environment with increased potential for toxicity or bioaccumulation effects. Environmental pathways and fates for various elements are discussed below.

(a) Arsenic (As)

Due to its comparatively high concentration in Hat Creek overburden, coal and fly ash (Tables F4-1 and F4-12) as well as its mobility in alkaline soils, As may have environmental significance in the Hat Creek area. Potential pathways of As in the Hat Creek area subsequent to project development are summarized in Figure F6-1. This schematic flow diagram indicates that As will be distributed to a variety of ecosystem components. Arsenic from mine spoils or from airborne particulates that fall out on the land may form soluble As compounds that can migrate into plants, especially if suitable complexing agents (e.g., low molecular weight organic acids) are present. However, the entry of any mobile trace element into plants is determined by interacting factors that include accumulator properties of the particular plant species, electrolyte concentration in the soil solution and climatology of the region. Bohn[197] reported that many trace elements, including As, that are emitted from industrial sources tend to accumulate in soils with only small proportions being absorbed by plants. Various oxides of iron and manganese are nearly ubiquitous in soils and stream sediments, and these oxides apparently act as sinks of many trace elements.[198] In semi-arid regions where soil moisture is low, migration through soils and diffusion into plants of even soluble trace elements are limited.

Both soil and stream sediment microorganisms have enzymes capable of interconverting oxidation states of trace elements. An aerobic microorganism can reduce and methylate inorganic As compounds to give dimethyarsine and trimethylarsine, both extremely toxic compounds. These volatile compounds

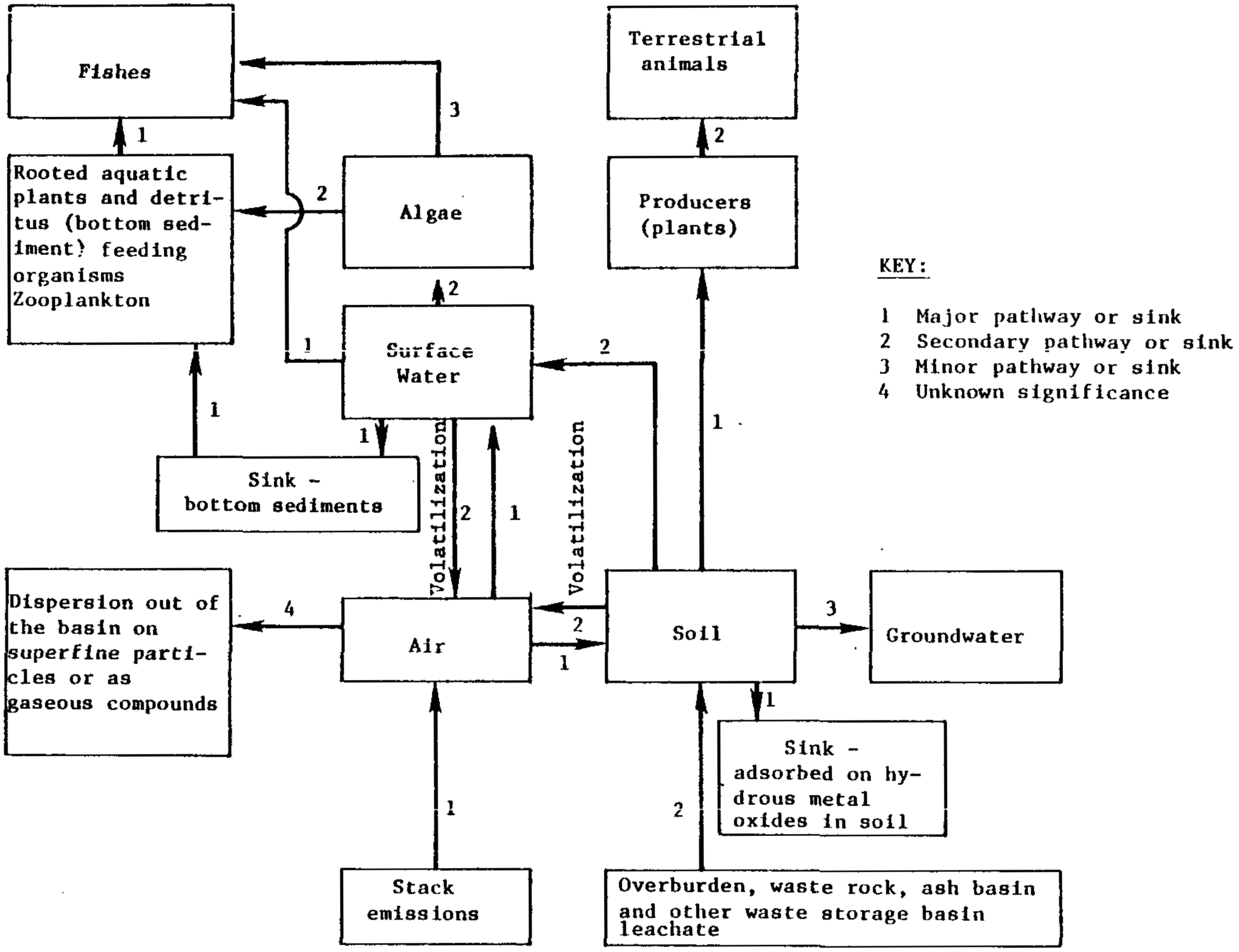


Figure F6-1. Potential pathways of Arsenic (As) movement through Hat Creek ecosystem components are rapidly oxidized to less toxic substances, such as methylated arsenic acids. Alkylarsenic compounds can be absorbed by aquatic organisms, so potential pathways do exist for As transfer through the food chain.[199]

In summary, most of the terrestrially based As (As in mine or power plant spoil or waste piles and As from stack emissions that is deposited on land) will likely be confined to narrow zones around deposition sites (e.g., waste rock piles or areas of maximum land deposition of stack emitted arsenic). A portion of this As may undergo any of the following: (1) oxidation to volatile As compounds that will excape to the atmosphere; (2) accumulation in roots of plants that grow in depositional sites; and (3) leaching into surface waters or into near-surface groundwaters. Any As contained in airborne particulates that reach surface waters in the Hat Creek areas will mostly be adsorbed by organic compounds or iron oxides in bottom sediments, which are basic and have moderate cation exchange capacities (Table F6-2). Other studies have reported accumulations of As in rooted aquatic plants and benthic organisms, both of which utilize sediments for nutritional sources.[200] Principal mechanisms for potential transport of As out of the immediate site area are distant aerial dispersion of superfine stack particles or gaseous compounds and methylation with subsequent biotic uptake of As aquatic organisms.

(b) Cadmium (Cd)

Cadmium will be released to the environment chiefly by emission of fine particles from the stack. Figure F6-2 is a schematic flow diagram that summarizes the relative significance of Cd movement through Hat Creek ecosystem components after project development begins. Although this trace element is never beneficial to plants or animals,[4,7,201] it is commonly accumulated in biotic components of both terrestrial and aquatic systems. Cadmium ions are readily adsorbed by clay minerals, especially in alkaline soils. Using radioisotope techniques to trace Cd through the environment, Van Hook et al.[202] found that only small percentages (less than 7%) of Cd fallout on land are incorporated in living vegetation, and that vegetation growing on alkaline soils adsorb less Cd than vegetation growing on neutral or acidic soil. Other elements

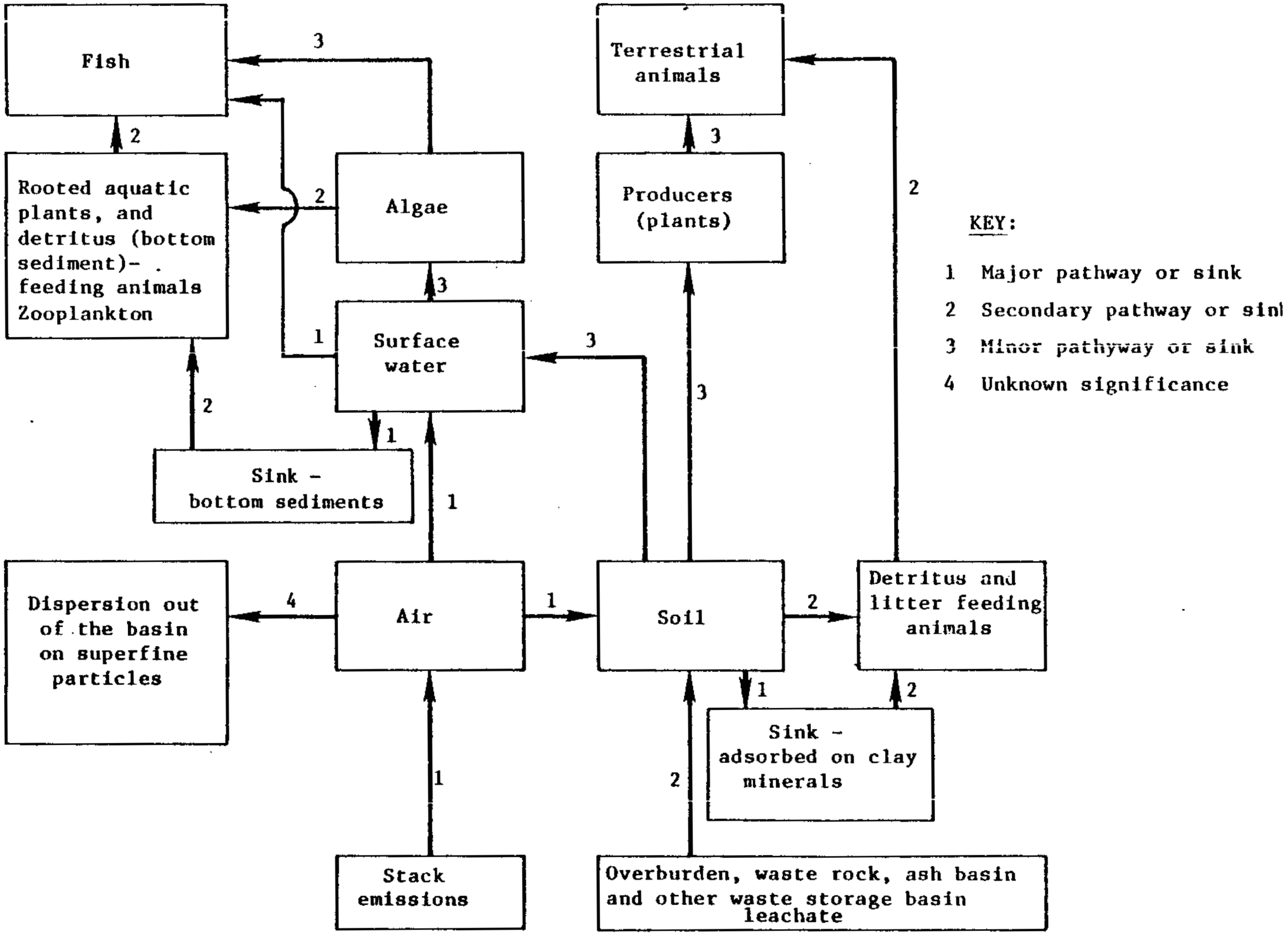


Figure F6-2. Potential pathways of Cadmium (Cd) movement through Hat Creek ecosystem components appear to affect the physiological ability of plants to uptake Cd. For example, selenium significantly reduces the amounts of Cd adsorbed by vegetation whereas Zn enhances Cd uptake.[202] High Pb concentrations in soil may increase both the plant Cd concentration and total Cd uptake.[203] The antagonistic effect of Se and Zn on Cd uptake by plants is likely due to complex physiochemical and biochemical interactions between the elements. Since Se, Zn and Pb will be deposited on soils as components of particulates emitted from the gas stack, the combined influence of these three elements on Cd uptake by plants in the Hat Creek area is not predictable.

Since most of the Cd deposited on terrestrial systems remains in surface soils, litter and detritus, Cd is most available to animals whose food base is litter or detritus.[202] Cadmium is rapidly accumulated by animals, but tissue levels reach steady states as body intake and excretion of Cd equilibrate. Values for Cd half-lives in animals range from 7 days for insects to 100 days for birds and predacious arthropods.[202] Therefore, animals have biological mechanisms for returning Cd to, as well as removing it from, the environment.

Van Hook et al.[202] found that only 4% of the Cd applied to an experimental ecosystem was transported to the aquatic portion of the system, and 75% of this Cd was contained in sediments. All types of aquatic organisms (rooted and non-rooted plants, algae and fish) are known to accumulate Cd.[200,202] However, since Cd is not methylated in aquatic systems,[199] its accumulation in aquatic organisms and mobility through aquatic food chains are less than compounds such as Hg.

In the Hat Creek area, Cd contained in overburden and waste rock piles should remain immobilized through adsorption on inorganic mineral complexes. Only limited uptake by vegetation is expected. Principal animal uptake of Cd will be by invertebrates, such as worms and some insects, that feed upon soil detritus containing Cd deposited with atmospheric fly ash fallout. Deposition of stack particles on surface waters and surface runoff containing suspended sediment will be the main sources of Cd to aquatic systems in the Hat Creek area. Most of this Cd will remain associated with stream sediment in the immediate area where deposition occurred. Aquatic organisms in this area will likely maintain steady state concentrations (some equilibrium concentration determined by uptake and excretion rates) of Cd.

(c) Chromium (Cr)

Chromium can exist in several different oxidation states in natural environments and mobility of each oxidation state is different. Figure F6-3 summarizes the relatively wide distribution that may characterize Cr movement through Hat Creek ecosystems following project start-up. In soils, Cr usually occurs as chromic oxide (+3 oxidation state), an amphoteric oxide (i.e., properties of both an acidic and basic oxide) that can form somewhat mobile compounds in basic soils. Oxidation of chromic oxides results in hexavalent Cr salts (chromates) that can penetrate biological membranes relatively easily. Chromium uptake by plants commonly occurs, especially if soils contain rather high Cr concentrations.[204] However, no evidence that Cr is necessary for plant nutrition exists. Animals do require small amounts of Cr for metabolism, so absorption and excretion of Cr by animals is documented.[53] Due to the rather ubiquitous distribution of Cr in nature, pathways and sinks for Cr released by the Hat Creek project are difficult to predict. Both mining and power plant operations will likely be significant sources of Cr to the local environment. Any freshly exposed Cr minerals in overburden and waste rock may be oxidized to plant-available chromates. Leachate tests indicate that the water soluble fraction of Cr minerals in overburden is 1.3 mg/kg (Table F4-1). Chromium compounds may be emitted from the gas stack at rates of about 5 kg/day (Table F4-13). Once these compounds are deposited on land or water, they may become available for biotic uptake, especially if oxidation to hexavalent Cr occurs. As will occur with several other trace elements, a large portion of the Cr released by mining or power plant operations will likely be adsorbed on hydrous metal oxides in soil and stream sediment.[198]

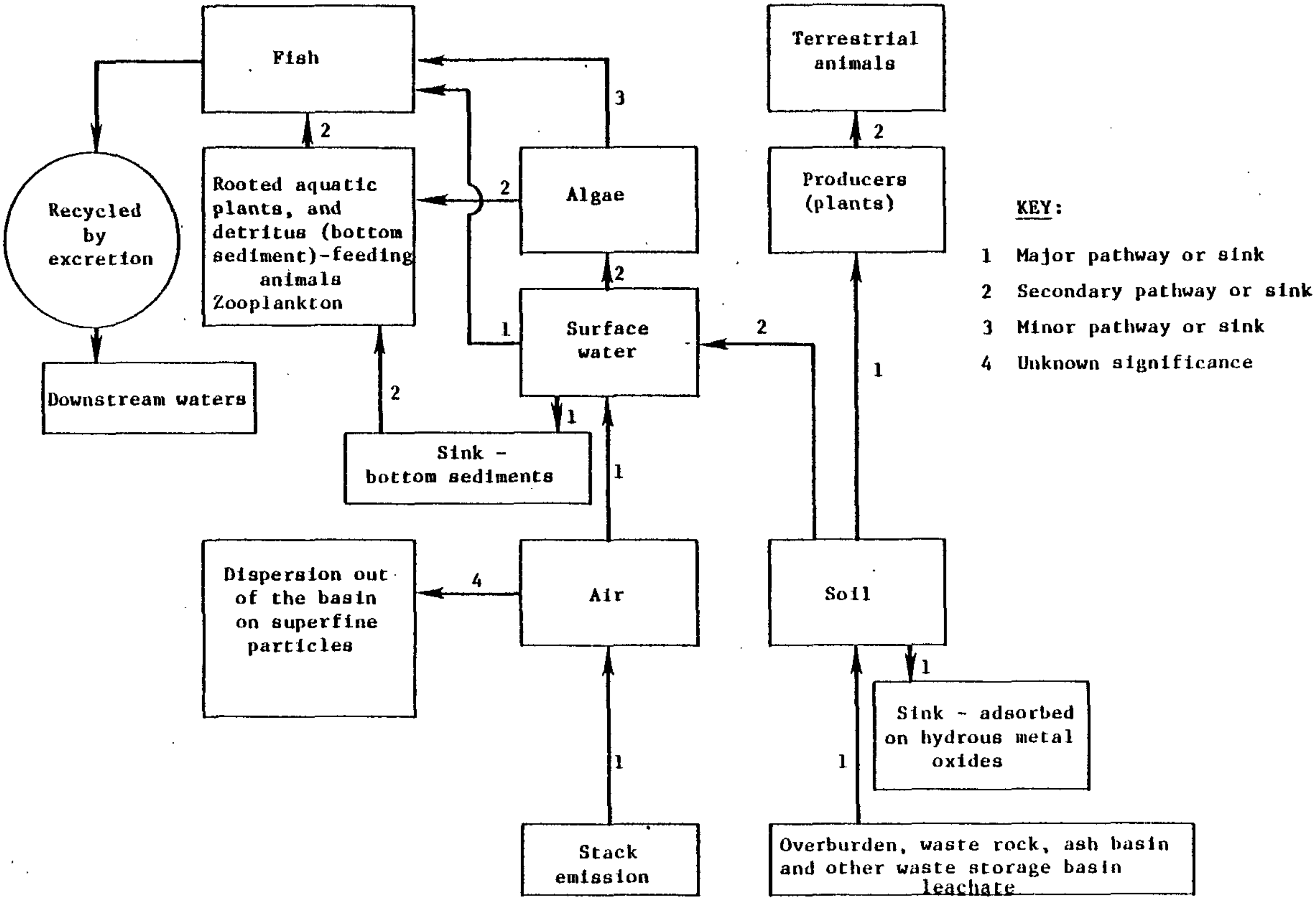


Figure F6-3. Potential pathways of Chromium (Cr) movement through Hat Creek ecosystem components

(d) Copper (Cu)

Varying concentrations (3 to 6 mg/kg) of Cu can be leached from coal, overburden and waste rock from the Hat Creek valley (Table F4-1). Figure F6-4 summarizes the potential distribution of Cu among various Hat Creek ecosystem components subsequent to project start-up. Test burns of coal samples indicate that about 6 kg/day of Cu may be emitted from the gas stacks at the power plant (Table F4-13). However, Bohn[197] reports that Cu is one of the most highly soil-adsorbed trace elements and is nearly unavailable to plants. Soil holds Cu best at pH value between 7 and 8[6] which is the general range of pH conditions of sampled Hat Creek soils (Table F6-1). In alkaline water, Cu ions rapidly precipitate as carbonates or hydroxides. However, Cu is a functional constituent of most cells, and Cu uptake mechanisms must therefore exist for plants and animals. Copper concentrations in algae may be 1000 to 5000 times as great as the concentrations occurring in the surrounding water.[205] Various tissues, especially liver, in fish accumulate Cu during long-term exposure (several weeks) to various concentrations of dissolved Cu.[206] In animals, Cu is mostly excreted and absorbed only with difficulty across gut walls. Any Cu that is absorbed by animals tends to accumulate in soft tissue organs.[4]

In summary, most of the Cu released by mining and power plant activities in the Hat Creek area will be tied up in local soils and stream sediments. Some Cu accumulation will likely occur in lower plants, such as lichens, that are directly exposed to fly ash fallout. Aquatic algae apparently can accumulate Cu even when surrounding concentrations in water are low, so certain aquatic organisms may exhibit elevated concentrations of Cu.

(e) Fluorine (F)

Fluorine usually exists in concentrations of several parts per million (ppm) in soils, plants and animals, and is, therefore, actually not a "trace element". The likely distribution of fluorine in the Hat Creek environs after project start-up is illustrated in Figure F6-5. Assuming an average F content in Hat Creek coal of 137 mg/kg (Table F4-9) and a coal firing rate of 42,600 metric tons/day, about 6 metric tons/day of

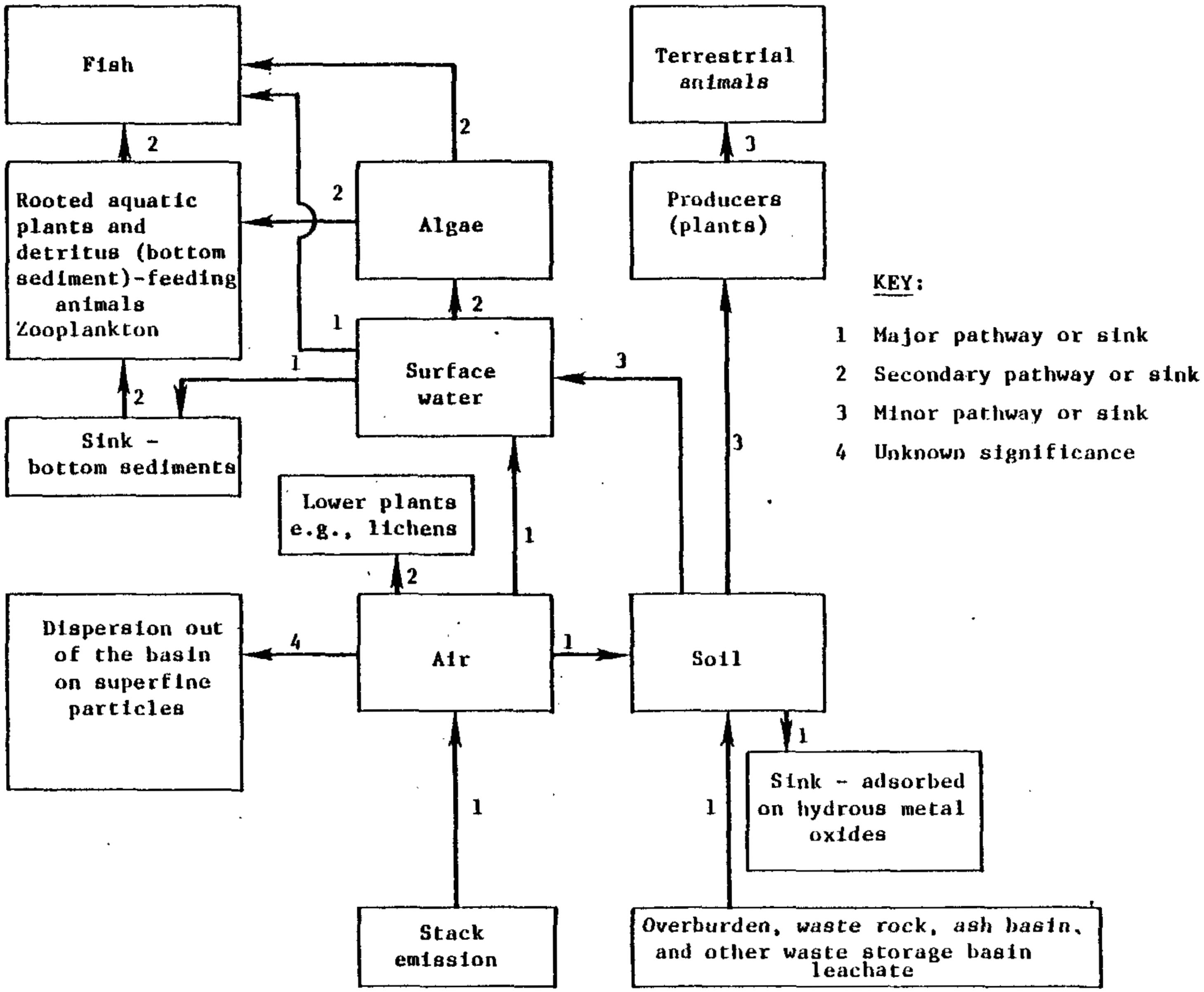


Figure F6-4. Potential pathways of Copper (Cu) movement through Hat Creek ecosystem components

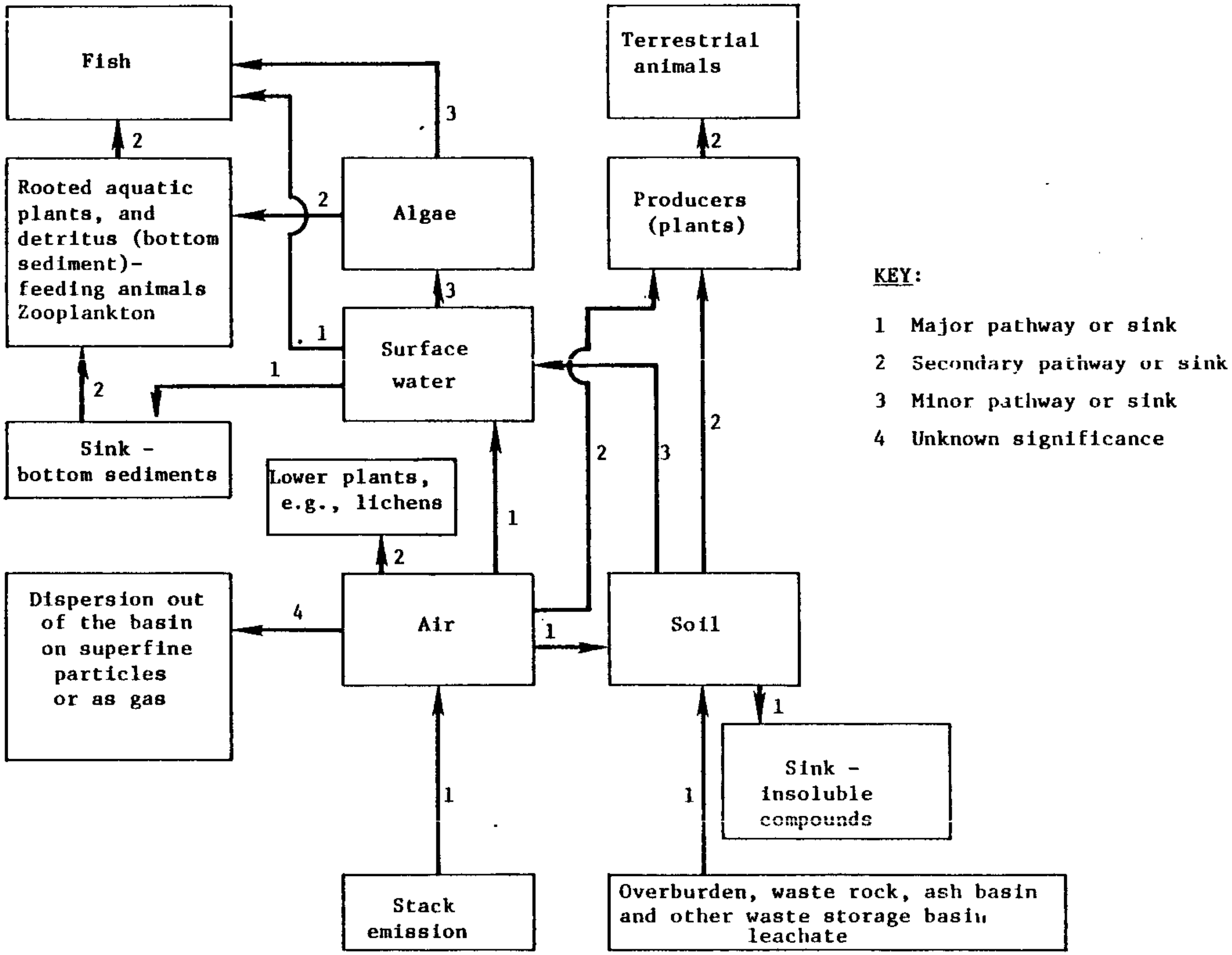


Figure F6-5. Potential pathways of Fluorine (F) movement through Hat Creek ecosystem components

F will enter the plant boilers. Test burns of Hat Creek coal (Section F4.3) indicate that about 280 kg/day of F will be emitted from the stack. The chemical makeup (i.e., percentages of hydrofluoric acid, silicofluorides, and other gaseous or solid fluorine compounds) of this total fluorine emmision is not known. Studies at other power plants[193] indicate that about 8% of F input to the boilers passes electrostatic precipitators (99% particulate removal) and is emitted from the stack as either gaseous compounds or as compounds absorbed on fly ash particles. If 8% of the total F in coal is emitted from the stack at the Hat Creek power plant, fluorine emissions would be about 480 kg/day. Gaseous fluorine compounds emitted from the stack can be accumulated by vegetative species. Due to the reactivity of many gaseous fluorine compounds, reaction with airborne particulates is likely. Thus, as will likely occur with many trace elements, particulate F deposited on soils will be mostly unavailable for plant uptake.[197] The amount of F absorbed from soil by plants is usually not related to F content of the soil.[8] The primary F inactivation mechanism in soils is formation of insoluble calcium fluoride, especially in fairly alkaline soils. However, certain plants possess unique abilities for absorbing much greater quantities of an element, such as F, than other plants growing on the same soil.[207] Therefore, individual plant characteristics are likely more important in determining plant uptake of F than the F concentration in the soil. Lower plants, such as lichens, that do not have root systems can accumulate F that is deposited on their cell membranes from air pollution sources.[78] Airborne F compounds can also be absorbed by plant leaves and accumulated in plant chloroplasts.[82] Fluorine compounds diffuse easily across gut walls of animals and are readily incorporated into growing bones. Most of the F that is not incorporated into hard body tissue is excreted by animals. The insolubility of calcium fluoride greatly limits the amount of soluble F existing in hard waters. Therefore, F entering surface waters will likely precipitate and subsequently become incorporated into biotic tissue of organisms that obtain nutrition from bottom sediments.

In summary, the most significant source of flourine from the proposed project will be gaseous emissions from the stack. Gaseous fluorine compounds are reactive and will undergo chemical reactions with airborne particulates. Some of the gaseous fluorine will be absorbed by vegetation, but much of the fluorine will be absorbed by soil and water, primarily in the form of calcium fluoride.

(f) Lead (Pb)

Since Pb concentrations in emitted fly ash are enriched in comparison to both bottom and precipitator ash (Section F4.3), some Pb, estimated to be about 4 kg/day (Table F4-13), will be emitted from the stack. As with Cu, Pb is highly adsorbed by soils and is not easily uptaken by plants or leached from soils. The limited distribution of Pb is depicted by schematic flows in Figure F6-6. Any Pb absorbed by plants from soils remains mostly in plant roots, and is thus unavailable to grazing animals. However, plant leaves can adsorb Pb from atmospheric aerosols.[88] Similar atmospheric uptake of Pb is also observed for lower plants like mosses and lichens. In addition to insolubility of many Pb compounds and immobilization in soils, another factor limiting biotic transport of Pb is its inability to be methylated.[199] Lead ingested by animals is not readily transported across gut walls, and only a small fraction of the Pb taken in by animals is stored in bones. Any Pb reaching alkaline surface waters in the Hat Creek area will exist almost entirely in colloidal or precipitated forms. This bound Pb could be slowly incorporated into organisms that utilize bottom sediments for nutrition sources. Once Pb has been incorporated into various organo-lead compounds or complexes, its mobility through the food chain is likely increased.

In summary, Pb distribution will likely be limited due to the insolubility of Pb compounds. However, vegetation can accumulate atmospheric Pb compounds, thus, increasing the potential mobility of Pb through the food chain.

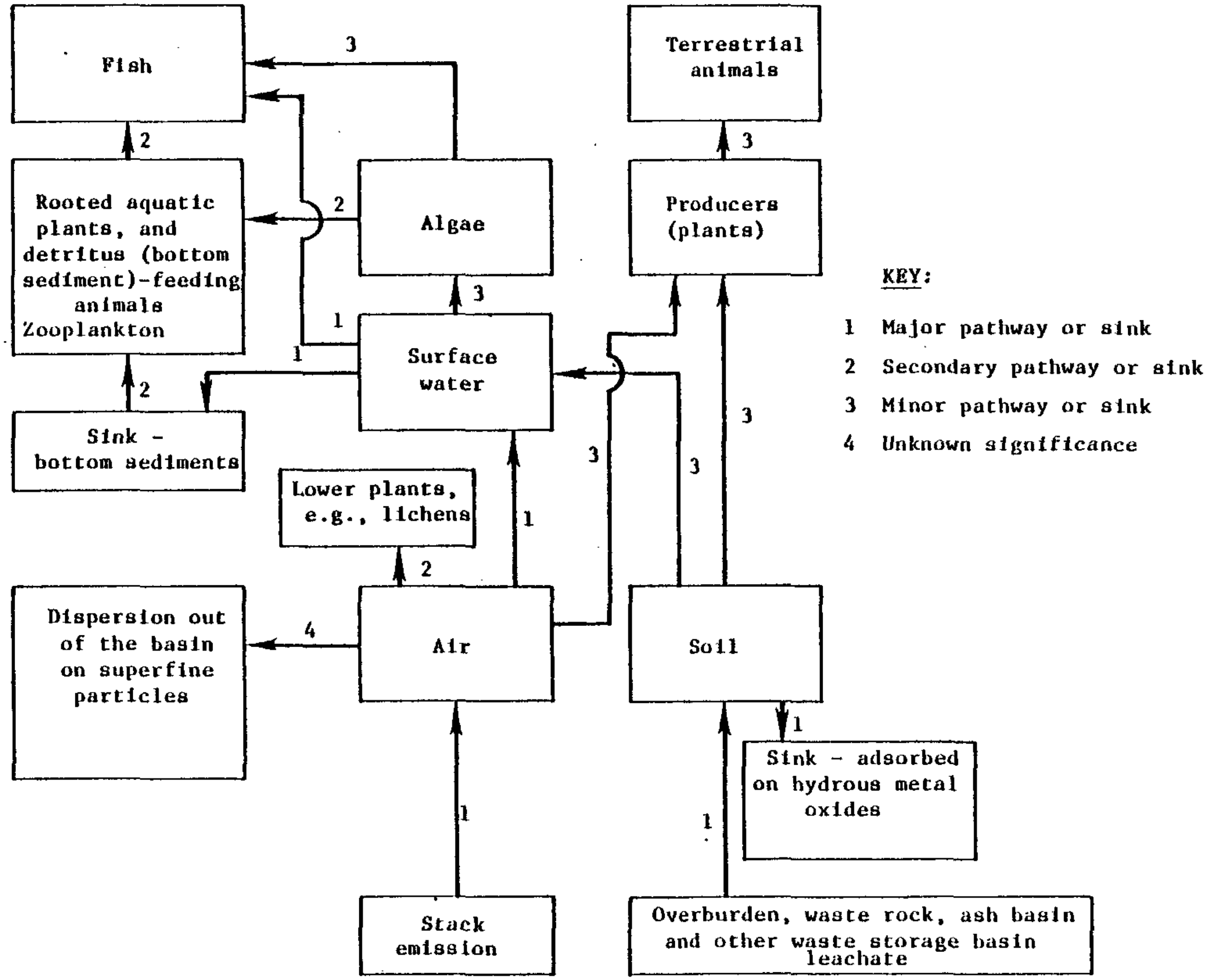


Figure F6-6. Potential pathways of Lead (Pb) movement through Hat Creek ecosystem components

(g) Mercury (Hg)

The principal source of Hg from mining and power plant activities in the Hat Creek area will be stack gas emission as only very low concentrations (0.001 to 0.01 mg/kg) of Hg exist in leachate from coal, overburden or waste rock (Section F4.1). It is estimated that Hg emissions from the power plant will be about 7 kg/day (Table F4-13). While in the gas phase, Hg likely undergoes many reactions with other trace organic and inorganic compounds in the stack emission. Eventually, these Hg compounds are adsorbed onto air particulates and are deposited on land and water environments. It is also likely that some gaseous Hg is adsorbed directly onto terrestrial organic matter and clays. Once deposited on land and water, Hg compounds undergo many reactions that contribute to both the wide distribution and bioaccumulation of Hg in the environment. Figure F6-7 summarizes the wide distribution and bioaccumulation potential of Hg in the Hat Creek environment subsequent to power plant start-up. Microorganisms can interconvert various inorganic forms of Hg. Aerobic bacteria can solubilize mercuric sulfide, a very insoluble compound, by oxidizing the sulfide to sulfate. Bacteria can also convert ionic mercury and methylmercury to metallic mercury, a conversion that can be regarded as a detoxification mechanism because elemental Hg can be vaporized back to the atmosphere.

The mercuric ion (Hg^{+2}) appears to be the most important and prevalent form of ionic Hg in the environment. Mercuric ion is usually required before the biological mercury methylation reaction will proceed.[118] At low Hg contamination levels, dimethylmercury is apparently the ultimate product of the methylation process, whereas monomethylmercury is primarily produced if large amounts of Hg are entering a particular environment. Alkaline environments appear to favor the formation of dimethylmercury, a volatile compound that can escape from the system by evaporation. However, acid systems favor the formation of monomethylmercury, which is less volatile than dimethylmercury and therefore more available for biotic uptake.[118]

Bohn[197] reports that Hg deposited on soils in typical industrial and urban areas is immobilized and only small proportions of the soil-absorbed

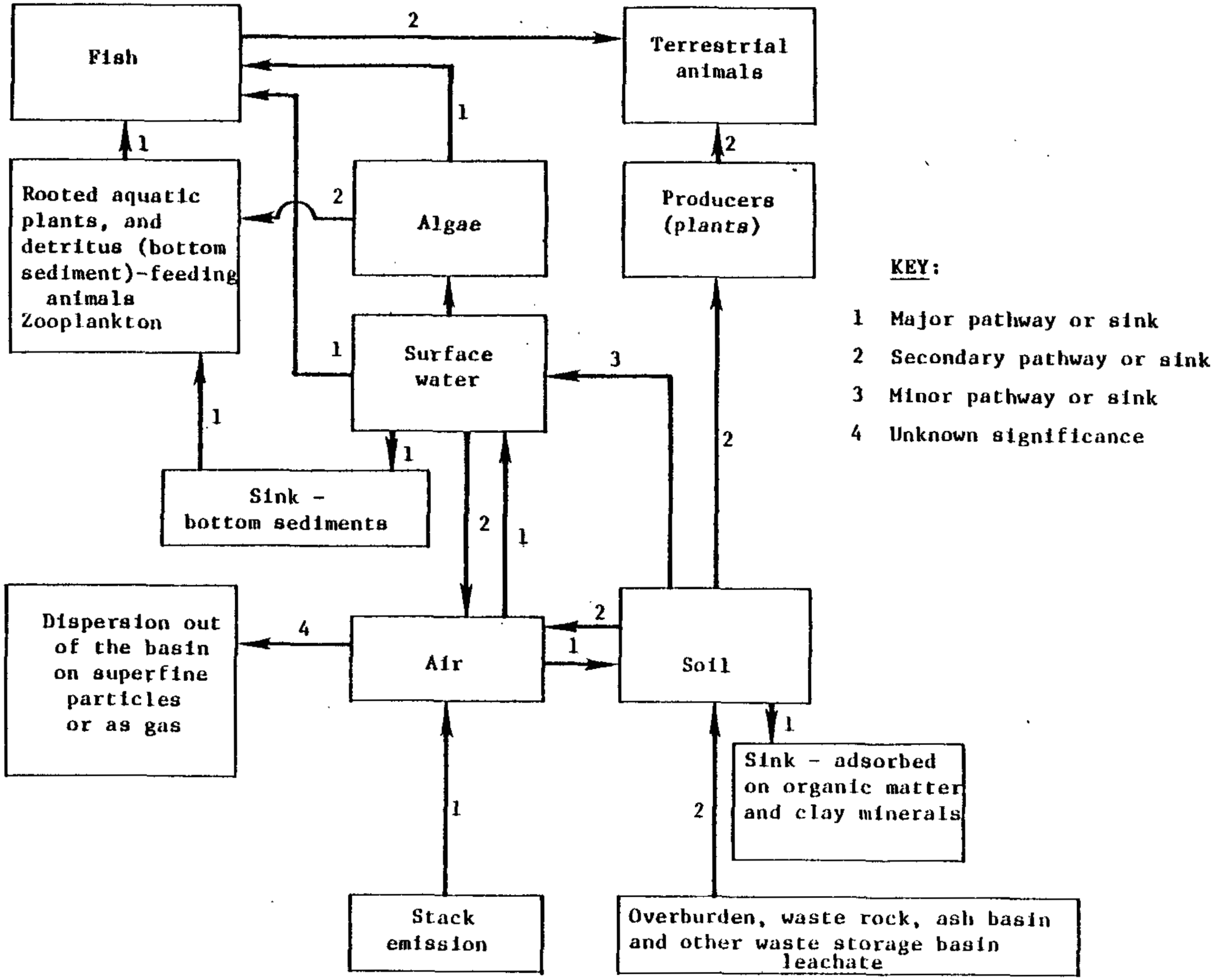


Figure F6-7. Potential pathways of Mercury (Hg) movement through Hat Creek ecosystem components

Hg is absorbed by plants. Organic matter, especially materials containing organic sulfur, strongly absorb ionic Hg.[208] Clay and sand have a lower Hg adsorptivity than organic matter. Methylmercury usually has lower attraction than ionic Hg to soil and sediment adsorbents. Even though adsorption mechanisms are effective in immobilizing both inorganic and organic Hg in soils, certain plants such as barley, oats, and rice can absorb Hg from aerial portions of the plant.[118] However, information on Hg uptake by terrestrial plants and their subsequent contribution to Hg burdens in consumer animals is not as well documented as is Hg transfer in aquatic systems.

Mercury and its compounds have an affinity for thiol (sulfur containing) groups that are found in biological protein structures. Since organic mercurials (e.g., monomethylmercury) are strongly complexed by these proteins, bioaccumulation of Hg is a widespread phenomenon. The high concentration of Hg in some animals (e.g., fish and fish-eating birds) is, in part, due to the fact that these animals are at the end of a food chain where each step of the chain significantly accumulates Hg. For example, certain benthic macroinvertebrates may accumulate Hg from the stream sediment they ingest. A certain species of fish may then feed almost exclusively on these macroinvertebrates, and thus will intake abnormally large amounts of organic Hg just because of specialized feeding habits. Animals do have mechanisms for excreting Hg from their systems, but organic Hg compounds are degraded only slowly by animals. For example, the half-life of various organic Hg compounds in trout varies from four months to one year.[201]

In summary, the Hg released to the environment by activities of the Hat Creek project will be distributed widely through many environmental components. Distant transport outside the site area may be important due to the volatile nature of elemental Hg and many of its compounds. Much of the Hg deposited near the site will likely be adsorbed by soils or stream sediment. However, a portion of the Hg released to the environment will likely undergo various biochemical transformations that will increase the biotic distribution of Hg. The basic characteristic (pH of 7 or higher) of surface waters in the Hat Creek drainage should limit the amount of methylmercury available for biotic uptake by aquatic organisms. However, any methylation of Hg in streams may be of importance, since predator fish species, such as locally existing salmon and trout, apparently have high potentials for accumulating Hg.[118]

(h) Vanadium (V)

Vanadium compounds are widely dispersed in nature and usually do not accumulate in particular ores. Therefore, V is considered a rare element even though its total content in the earth's crust is likely higher than that of copper. The most common forms of V in nature are vanadium pentoxide (V_2O_5) and associated salts (vanadates) of metavanadic acid (HVO_3). Vanadium compounds are soluble in alkaline media and, therefore, available to plants growing in basic soils. Many plants, including grazing crops such as clover and alfalfa, may accumulate any V deposited on basic soils in the Hat Creek area. Any V ingested by animals is readily absorbed across the gut wall and stored for short periods in the liver.[4]

Vanadium salts can be carried to local streams in surface runoff. Many V salts are water soluble, especially in basic waters. Soluble vanadate salts can be utilized by algae and subsequent transfer of V along the aquatic food chain may occur. For example, Hutchinson[200] reports that several species of rooted aquatic plants accumulate V. As with many other rare elements, V is adsorbed on hydrous metal oxides,[209] a process that is likely very important for reducing the availability of V and other trace elements to biological organisms.

Vanadium liberated by mining and power generating activities in the Hat Creek area will be associated with precipitated fly ash and with stack emissions estimated to be about 16 kg/day (Table F4-13). Although moderately high concentrations (about 50 to 400 ppm) of V were observed in coal and soil (Table F4-9 and F5-25) only very low amounts of leachable V were observed in coal, overburden and waste rock samples (Table F4-1). The relatively mobile characteristics of V in alkaline media is depicted in Figure F6-8. A portion (about 1-4 mg/kg) of the V associated with precipitated fly and bottom ash can be leached from the ash (Table F4-1),

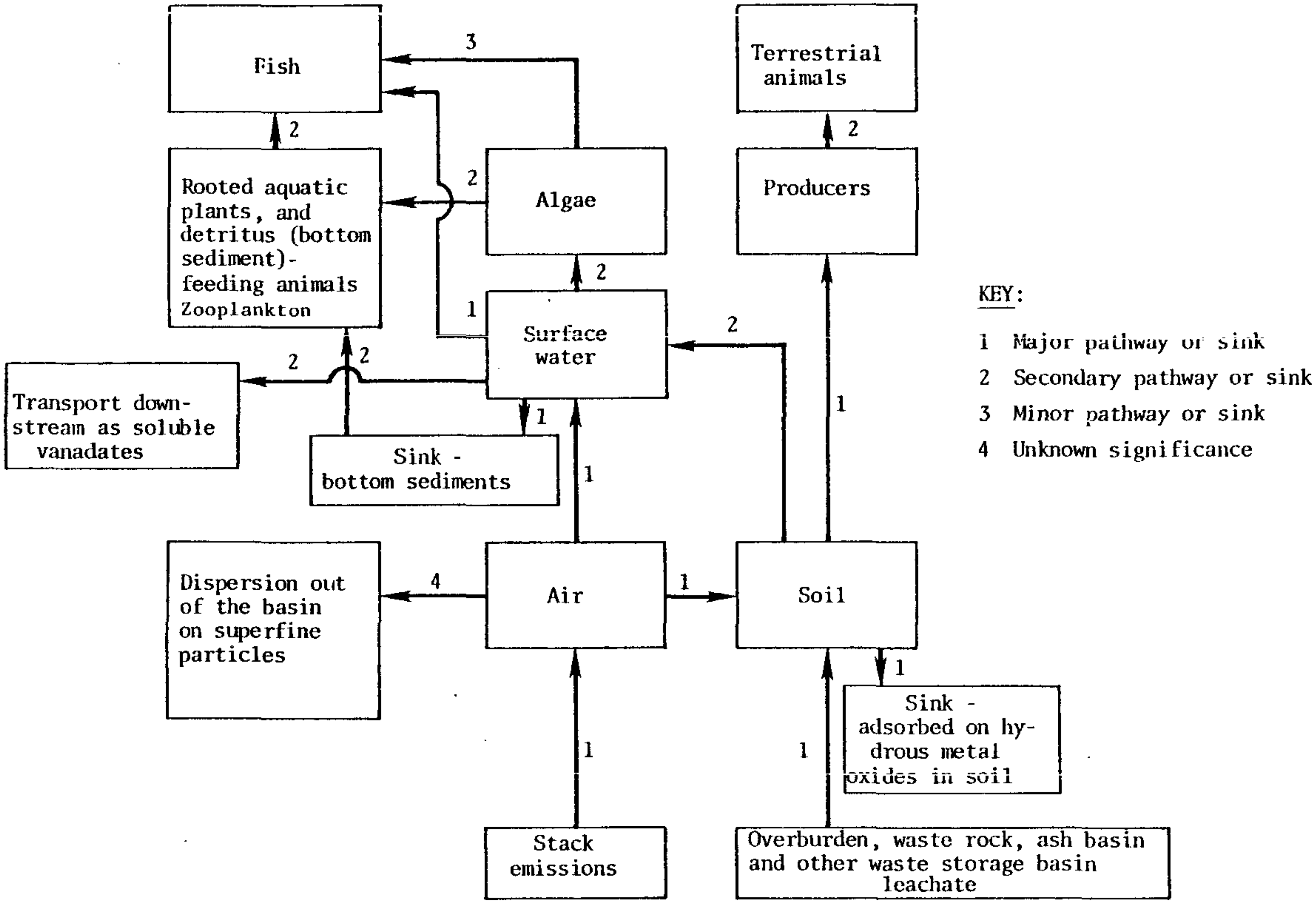


Figure F6-8. Potential pathways of Vanadium (V) movement through Hat Creek ecosystem components indicating that a potential pathway exists for migration of V compounds from ash storage basins if seepage and drainage are not carefully controlled. Any V associated with fine fly ash particles emitted from the power plant will be deposited on terrestrial and aquatic environments. Due to the alkaline characteristic of soils and waters in the Hat Creek area, a portion of this V will exist in a water soluble form available for biotic uptake. An unknown, but likely major, portion of the V deposited on local soils and waters will be absorbed on clay minerals and thus excluded from incorporation into biotic systems.

In summary, the general solubility of V compounds in alkaline media indicates that V will be widely distributed in Hat Creek environs. Some V will likely be accumulated by vegetation, but accumulation in animals is not expected.

(i) Zinc (Zn)

Zinc, as predicted for such elements as Pb, Cd and Cu, should also be relatively immobile in basic soils. However, salt extraction tests on coal, overburden and waste rock samples from Hat Creek valley indicated that about 10 mg Zn could be leached per kg of materials. Therfore, Zn may be relatively mobile trace element in the Hat Creek area. The wide distribution and bioaccumulation potential for Zn in the Hat Creek area subsequent to project startup is summarized in Figure F6-9. Many plants, ranging from lichens to leaf-bearing crops, have a high affinity for Zn and accumulate the element in concentrations much higher than those of other trace elements.[4,8,204] Zinc is an essential element to plants and their ability to accumulate Zn varies widely among species. Climatic conditions, soil moisture and light are also important environmental factors influening Zn uptake by plants.[207] Zinc is also required by animals but is only slightly absorbed across gut walls.[4] Many cells and enzymes require Zn for proper function, and the liver, brain and bones are accumulators of Zn.

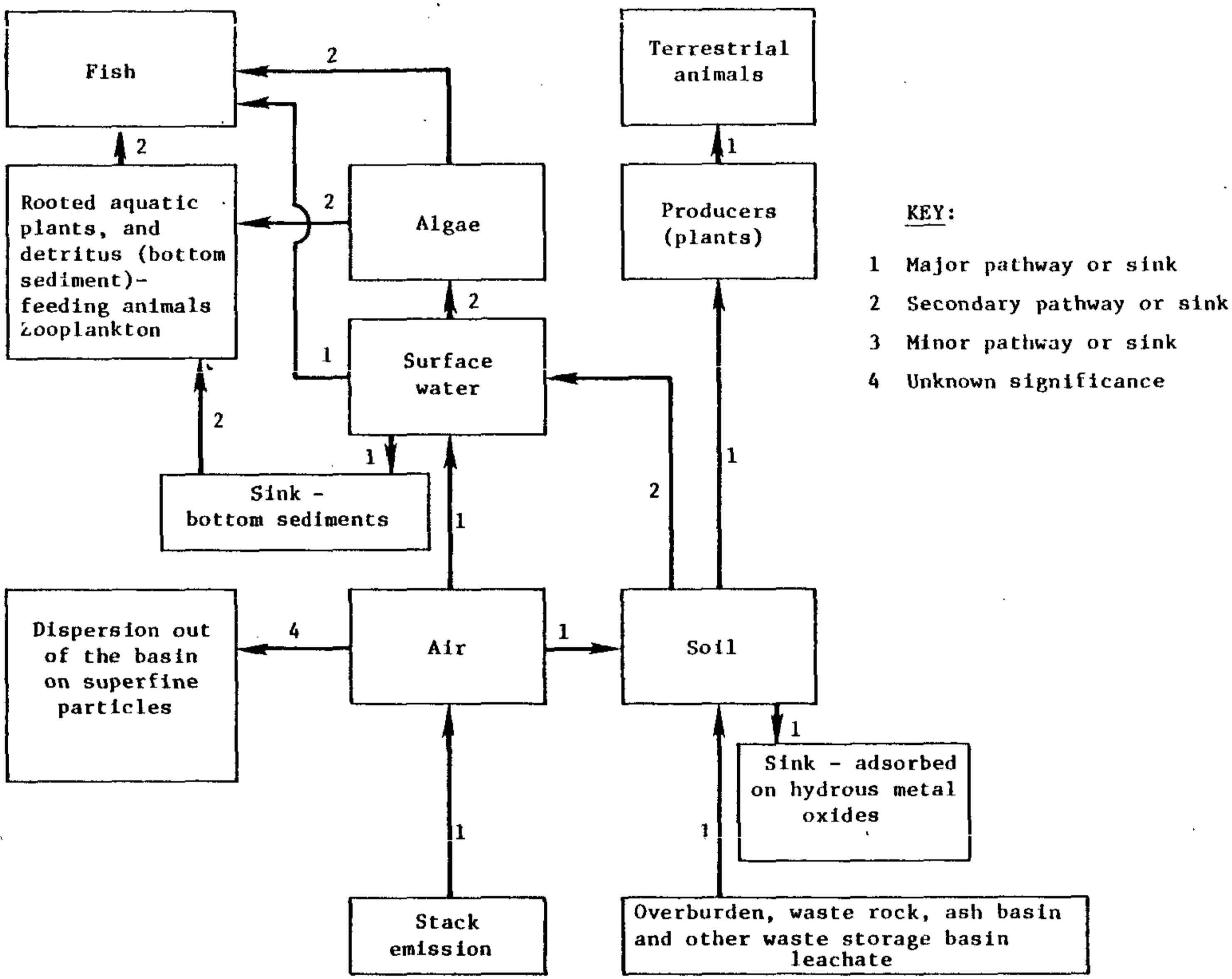


Figure F6-9. Potential pathways of Zinc (Zn) movement through Hat Creek ecosystem components

As with plants, many animals accumulate Zn in concentrations often comparable with those of Fe and usually much higher than those of other trace elements.[4,210] For example, Zn concentrations in some aquatic shellfish may be several thousand times greater than concentrations in the surrounding environment.[211] Apparently, a large portion of this Zn is derived from plankton on which the shellfish feed,[211] thus indicating that Zn is accumulated in each step of the food chain.

A major reservoir for Zn in soil and water is fine hydrous metal oxides that occur in clay minerals.[198] Adsorption of Zn on these oxides and precipitation of insoluble Zn compounds, such as zinc carbonate, in basic media are principal factors that reduce Zn mobility in the environment. Also, Zn cannot be methylated in the environment, a fact that will limit its potential mobility through biotic systems relative to elements such as As or Hg.[199]

Since a portion of the Zn liberated during coal combustion is adsorbed on fine fly ash particles that escape from the stack (Zn emissions from the stack may be about 13 kg/day; Table F4-13), Zn will be broadly deposited on land and water environments in the Hat Creek area. Although most of this Zn will likely be adsorbed on hydrous metal oxides in soil or stream sediment, the affinity of many organisms for Zn indicates that biotic systems will also be important accumulators of Zn. Zinc compounds contained in bottom and precipitated fly ash appear to be fairly water soluble as leaching tests indicated that 40 to 80 mg Zn could be extracted by water from 1 kg ash. However, ash storage basins will be designed and constructed to avoid migration of Zn from the basins into surrounding environments.[241]

F6.4 Summary

Several sources of trace elements exist at coal mines and coal-fired power generating plants. Principal sources of trace elements from the Hat Creek project will likely be overburden and waste rock piles, ash and blowdown storage basins and emissions of fly ash and gases from the stack. Secondary sources will include fugitive dust and cooling tower drift. The distribution of a trace element is dependent on both the nature of the source material and mobility of the particular element in air, soil and water media. For example, an element that is highly insoluble in basic media and is associated with precipitated fly ash or bottom ash will be narrowly distributed in the Hat Creek environment, whereas, an element that is soluble in basic media and is associated with airborne fly ash will be more widely distributed.

Due to interacting and changing environmental conditions, actual distribution, mobility and bioaccumulation of many elements cannot be clearly definable as either high or low. Only detailed studies could quantify elemental distribution after coal mining and power generating activities begin. However, empirical classification of trace elements into high or low distributional groups can be made based on existing information. The following classification is therefore useful as a qualitative indicator of which elements will likely be of greatest environmental concern in local ecosystems in the Hat Creek area:

1. Wide distribution/high mobility/moderate bioaccumulation potential: F.
2. Wide distribution/low mobility/high bioaccumulation potential: Cd, Cu, Pb, Zn.
3. Wide distribution/high mobility/high bioaccumulation potential: As, Cr, Hg, V.

F7.0 IMPACT ASSESSMENT

Assessment of potential impacts of trace elements emanating from Hat Creek project activities is a two-step process. Foremost and primary is an accurate determination, based on available technical design information and source data, of the potential contribution of mine and plant construction and operation activities to existing natural trace element levels in Hat Creek biota. For trace elements whose concentrations and mass balance are expected to be altered by the Hat Creek project, information on existing natural levels, tolerance levels, toxic concentrations and toxic effects is used to determine the potential for significant ecological impact. This information was provided in Section F5.0 for trace elements of major concern and is integrated here for those elements whose influx may affect the integrity of Hat Creek and vicinity ecosystems. The focus of this section then is to evaluate each project-associated trace element source in regard to its contribution to natural trace element burdens. Sources considered are leaching of overburden and waste rock piles, fugitive dust emission from coal mine operation, stack emissions, leaching of ash piles, and cooling tower drift.

F7.1 Coal Mine

(a) Coal, Overburden, and Waste Rock Leachates

Leaching of trace elements from piles of overburden, waste rock, and coal would be the principal mechanism by which trace elements could be released from storage piles to the surrounding environment. Predicted water soluble amounts of various elements in overburden, waste rock, and coal are given in Table F4-2. These predicted amounts were based on salt extraction tests performed on crushed samples, and likely represent maximum amounts of trace elements that can be experimentally extracted by deionized water. Therefore, amounts of elements listed in Table F4-2 represent the available pool of elements that could be leached from storage areas containing the total amount of material placed in them during a 35 year operating period. Several tons of water soluble trace elements will exist in these storage areas. Of special environmental concern are As (about 1200 metric tons of soluble material), B (about 2100 metric tons of soluble material), Hg (about 9 metric tons of soluble material), and Zn (about 12,000 metric tons of soluble material). Arsenic and B are relatively mobile in alkaline soil and water environments such as exist in the Hat Creek area. However, current design plans indicate that trace elements will be retained in or near storage piles or removed from pile runoff or seepage by treatment processes.[241]

(b) Fugitive Dust

Fugitive dust resulting from coal extraction and transport activities will be comprised of natural soil, overburden and waste rock materials. Trace element concentrations in these materials often vary because of local differences in mineralogy and erosional history. Surface and near surface deposits, which have long been exposed to weathering, may have a much lower content of potentially mobile trace elements than deeper overburden and waste rock. As these latter materials are exposed to weathering, certain trace elements may be mobilized into other sectors of the ecosystem. Table F4-2 presented concentrations of water-soluble trace elements in waste rock and overburden material. Comparison of these results to total levels of trace elements in Hat Creek soils (Section F5.0) shows that soils contain much higher trace element concentrations. Given the limited local distribution of fugitive dust emission and the generally low concentration of water-soluble trace elements in dust as compared to natural levels in Hat Creek soils, it is anticipated that fugitive dust emission will not significantly alter existing trace element balances or accumulation in Hat Creek receptors.

F7.2 Power Plant

(a) Stack Emissions

Certain trace elements that are sufficiently volatilized during coal combustion will exit the stack either in the gaseous phase or recondensed on the surface of fine fly ash particulates. As discussed in Sections F5.0 and F6.0, trace elements of most environmental concern that are also likely to be enriched in fly ash or gaseous emissions from the proposed Hat Creek power plant are As, Cd, Cr, Cu, F, Pb, Hg, V and Zn. These elements will ultimately be deposited on the terrestrial and/or aquatic environment, with potential impact on the natural trace element balance in Hat Creek biological receptors.

Various project design alternates were considered in air quality modeling and these are fully discussed in ERT's main report. Also discussed in the main report are uncertainties involved with model results. Results of air quality modeling of stack effluents provide a basis for predicting concentrations of selected trace elements emanating from the proposed power plant that will intercept Hat Creek ground and water surfaces. Model calculations were performed in two parts. A steady-state diffusion model, calibrated to the atmosphere of the Hat Creek valley using local meteorological data for 1975, assessed the potential effects on air quality for a radial distance of 25 km from the stack (see the ERT main report - Air Quality and Climatic Effects of the Proposed Hat Creek Project and Appendix B - Modeling Methodology for details of air quality modeling). Although no chemistry was incorporated in the local model, predicted ambient air concentrations of trace elements can be calculated by dividing trace element emission rates by SO_2 emission rates. The resulting ratios are reported in Table F7-1 and calculated air concentrations of trace elements are listed in Table F7-2. Assuming a trace element deposition velocity of 0.1 cm/sec, deposition flux ($\mu g/m^2/sec$) equals the product of trace element ambient concentration (SO_2 ambient concentration x ratio) and 0.1 cm/sec (deposition velocity).[244] Assuming that trace element interceptions at soil surfaces (deposition flux) penetrate no deeper than 5 cm and remain immobile, a basis is provided for predicting average annual increases in soil trace element levels that could result from plant operation (Table F7-2).

Annual average local SO_2 concentrations are shown in Figure F7-1 with coded isopleths replacing numerical concentrations. Coded isopleths indicate areas predicted to have certain air concentrations of trace elements. Concentrations and element concentration increases in soils associated with

Table F7-1

Ratio of selected trace element emission to SO_2 emission

Trace element	Projected stack emission rate (kg/day)	Element to SO_2 ratio
Arsenic	17.2	5.30×10^{-5}
Cadmium	0.35	1.08×10^{-6}
Chromium	5.20	1.60×10^{-5}
Copper	5.93	1.83×10^{-5}
Fluorine	281	8.65×10^{-4}
Lead	4.36	1.34×10^{-5}
Mercury	7.07	2.18×10^{-5}
Vanadium	16.1	4.96×10^{-5}
Zinc	12.9	3.97×10^{-5}

NOTE: Uncontrolled SO_2 emission estimated to be 324,768 kg/day burning 0.45% sulfur coal at coal-firing rate of 42,600 metric tons/day (see ERT's main report). Trace element emissions listed in Table F4-13. Highest emission projected by using either CCRL or Battle River test data was used (Table F4-13); thus, worst-case conditions (highest emissions) based on test data projections were used for impact assessment.

Table F7-2

Annual average air concentrations, deposition flux and soil concentration increases for selected trace elements within different zones near the proposed Hat Creek power plant

Trace element	Isopleth Code*	Ambient SO_2 level ($\mu g/m^3$)**	Ambient trace element level ($\mu g/m^3$)***	Deposition flux ($\mu g/m^2/yr$)†	Projected soil concentration increase (mg/kg/yr)††
Arsenic (As)	A	5	3 X 10^{-4}	9.5	1.4 X 10^{-4}
	B	3	2 X 10^{-4}	6.3	9.0 X 10^{-5}
	C	1	6 X 10^{-5}	1.9	2.7 X 10^{-5}
	D	0.1	6 X 10^{-6}	0.2	2.9 X 10^{-6}
Cadmium (Cd)	A	5	5 X 10^{-6}	0.16	2.3 X 10^{-6}
	B	3	3 X 10^{-6}	0.09	1.3 X 10^{-6}
	C	1	1 X 10^{-6}	0.03	4.3 X 10^{-7}
	D	0.1	1 X 10^{-7}	0.003	4.3 X 10^{-8}
Chromium (Cr)	A	5	8 X 10^{-5}	2.5	3.5 X 10^{-5}
	B	3	6 X 10^{-5}	1.9	2.7 X 10^{-5}
	C	1	2 X 10^{-5}	0.6	8.6 X 10^{-6}
	D	0.1	2 X 10^{-6}	0.06	8.6 X 10^{-7}
Copper (Cu)	A	5	9 X 10^{-5}	2.8	4.0 X 10^{-5}
	B	3	5 X 10^{-5}	1.6	2.3 X 10^{-5}
	C	1	2 X 10^{-5}	0.6	8.6 X 10^{-6}
	D	0.1	2 X 10^{-6}	0.06	8.6 X 10^{-7}

Table F7-2 (Continued)

Trace element	Isopleth Code*	Ambient SO_2 level (μg/m³)**	Ambient trace element level (μg/m³)***	Deposition flux (μg/m²/yr)†	Projected soil concentration increase (mg/kg/yr)††
Fluorine (F)	A	5	4×10^{-3}	126	1.8×10^{-3}
	B	3	3×10^{-3}	95	1.4×10^{-3}
	C	1	9×10^{-4}	28	4.0×10^{-4}
	D	0.1	9×10^{-5}	2.8	4.0×10^{-5}
Lead (Pb)	A	5	7×10^{-5}	2.2	3.1×10^{-5}
	B	3	4×10^{-5}	1.3	1.9×10^{-5}
	C	1	1×10^{-5}	0.3	4.3×10^{-6}
	D	0.1	1×10^{-6}	0.03	4.3×10^{-7}
Mercury (Hg)	A	5	1×10^{-4}	3.2	4.6×10^{-5}
	B	3	7×10^{-5}	2.2	3.1×10^{-5}
	C	1	2×10^{-5}	0.6	8.6×10^{-6}
	D	0.1	2×10^{-6}	0.06	8.6×10^{-7}
Vanadium (V)	A	5	2×10^{-4}	6.3	9.0×10^{-5}
	B	3	1×10^{-4}	3.2	4.6×10^{-5}
	C	1	5×10^{-5}	1.6	2.3×10^{-5}
	D	0.1	5×10^{-6}	0.2	2.9×10^{-6}

Table F7-2 (Continued)

Trace element	Isopleth Code*	SO_2 Ambient level ($\mu g/m^3$)**	Ambient trace element level ($\mu g/m^3$)***	Deposition flux ($\mu g/m^2/yr$)†	Projected soil concentration increase (mg/kg/yr)††
Zinc (Zn)	A	5	2×10^{-4}	6.3	9.0×10^{-5}
	B	3	1×10^{-4}	3.2	4.6×10^{-5}
	C	1	4×10^{-5}	1.2	1.7×10^{-5}
	D	0.1	4×10^{-6}	0.1	1.4×10^{-6}

* See Figure F7-1 for corresponding isopleths.

** SO_2 concentration (annual average) with 1200 ft. stack and no SO_2 removal (see the ERT main report for details of model).

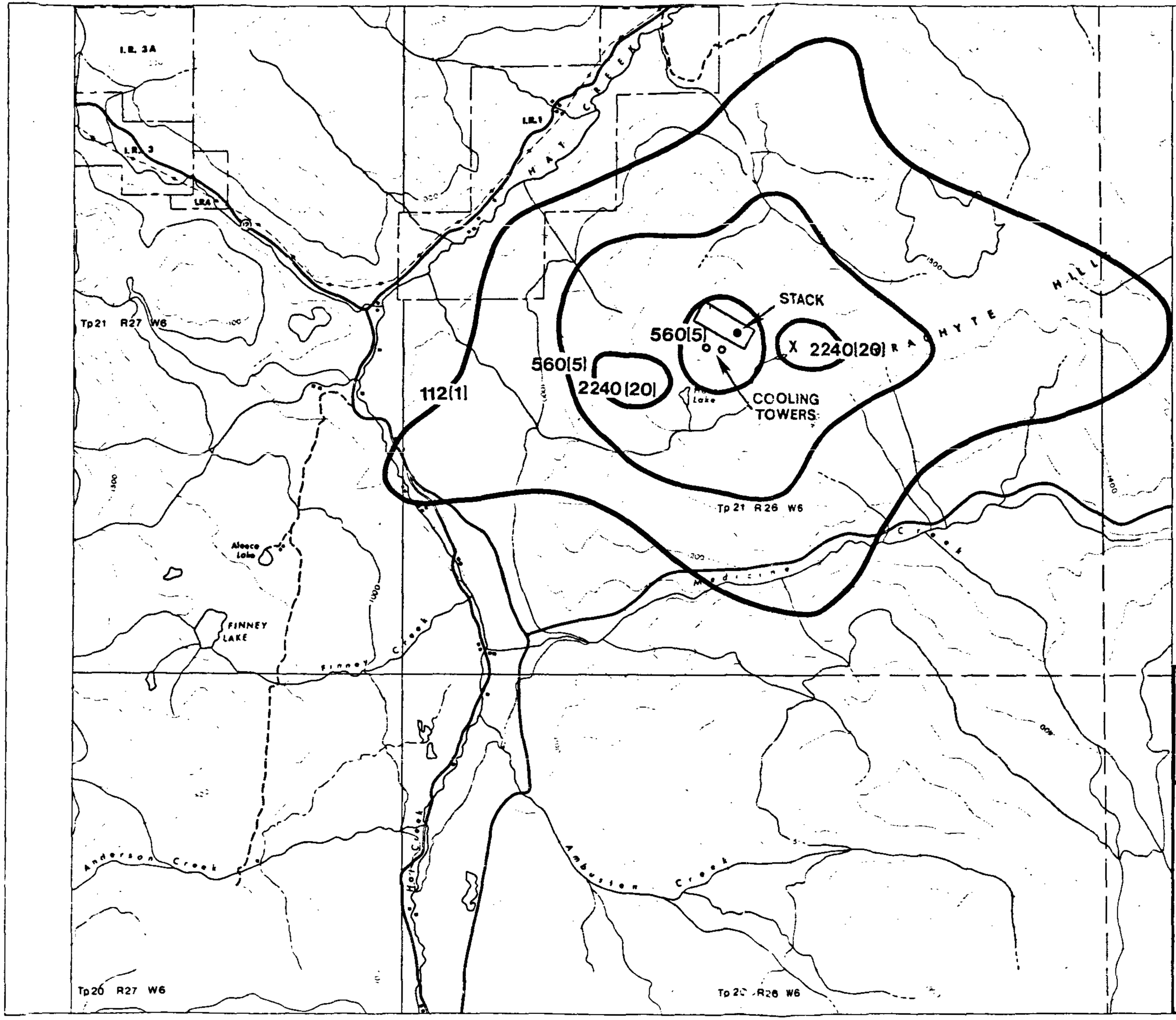
*** Trace element concentration (annual average) = SO_2 level X element to SO_2 emission ratio (Table F7-1).

† Deposition flux ($\mu g/m^2/yr$) = ambient trace element level X 3.15×10^4 m/yr (deposition velocity, see text).

†† Assumes element mixes with top 5 cm of soil and soil bulk density = 1.4 g/cc.

Then, soil concentration increase per year = depositional flux X 1 m^2 ÷ (0.05 m^3 X 10^6 cc/m^3 X 1.4 g/cc) = $\mu g/7 \times 10^4$ g = $mg/7 \times 10^4$ kg. Therefore, soil increase (mg/kg/yr) = deposition flux ÷ 7×10^4.

Calculation based on power plant operating at full capacity for 365 days/year (hypothetical worst-case for trace element impact assessment).



X = maximum = 4700 kg/km^2/year (42 lb/acre/year)

SCALE - 1:50,000

0 Kilometres 1 2 3

CONTOUR INTERVAL - 100 METRES

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Figure F7-2. Predicted Annual Salt Deposition in kg/km^2/year (lb/acre/year) Due to Drift from Proposed (Two) Natural Draft Cooling Towers these isopleths are presented in Table F7-2. Although trace element distributions are not likely to correspond exactly to the SO_2 distribution, the results reported in Figure F7-1 and Table F7-2 nevertheless provide an estimate of projected average annual ground level concentrations for trace elements of concern. Trace element distribution as predicted by the model indicate that depositional amounts of trace elements on local ecosystems will be low. For example, the model predicts that fluorine, the trace element having the highest deposition flux, would only be enriched in soil in the highest depositional zones by about 0.002 mg/kg/yr (about 1 mg/kg every 500 years).

To further investigate levels of trace elements that might be deposited on local ecosystems, a calculation was made that assumes that all trace elements in stack emissions would be evenly deposited and retained within a 25 km radius of the stack. Such an assumption likely projects worst case increases in soil concentration of selected trace elements. Concentrations generated by this model are listed in Table F7-3 and represent hypothetical results that would occur if no long range dispersion of stack emission occurred and all trace elements in stack emissions were deposited evenly within a 25 km radial area around the stack. Additionally, it was assumed that these conditions would exist continually for one year under full operating capacity (42,600 metric tons/day coal firing rate). Under these conditions (which are not likely to occur in the project environment even under the worst meteorological conditions, in the case of extreme washout from heavy rain or snowfall, or under maximum annual average load factors), a response in trace element levels in soil would not be detectable for most elements. However, a 0.7 mg/kg annual increase in soil fluorine content might be measurable. Plants normally accumulate only small amounts of fluorine from soil and there is little relationship between the concentration of fluorine in the soil and in the plant.[237] Therefore, plants in the Hat Creek area would not likely accumulate fluorine from soils in levels that would be detrimental to the plant. As discussed in Section F5.0, fluorine levels in grass samples collected from the study area in 1976 and 1977 varied from about 20 to 1500 mg/kg, indicating that fluorine accumulation in plants found in the Hat Creek environs already varies widely.

Table F7-3

Projected soil concentration increases of selected trace elements assuming all elements are evenly deposited within a 25 km radius of the stack

Element	Projected stack emission rate (kg/day)*	Projected stack emission rate (kg/yr)**	Projected soil concentration increase (mg/kg/yr)***
Arsenic (As)	17.2	6,278	0.05
Cadmium (Cd)	0.35	128	0.001
Chromium (Cr)	5.20	1,898	0.01
Copper (Cu)	5.93	2,164	0.02
Fluorine (F)	281	102,565	0.7
Lead (Pb)	4.36	1,591	0.01
Mercury (Hg)	7.07	2,581	0.02
Vanadium (V)	16.1	5,877	0.04
Zinc (Zn)	12.9	4,709	0.03

● Highest emission projected by using either CCRL or Battle River test data was used (Table F4-13); thus, worst-case conditions (highest emissions) based on test data projections were used for impact assessment.

** Assumes plant operating at full capacity (42,600 metric tons/day coal firing rate) for 365 days/year (hypothetical worst-case for trace element impact assessment).

*** Assumes that all deposited elements will remain in residence in top 5 cm of soil and that neither uptake by vegetation nor erosion of soil to watershed drainages will occur. Assume soil bulk density = 1.4 g/cc. Then weight of soil in a cylinder with 25 km radius and 5 cm height = $(25 \times 10^3 \text{m})^2 \times 0.05 \text{ m} \times \pi \times 1.4 \text{ g/cc} \times 10^6 \text{ cc/m}^3 = 137.4 \times 10^{12} \text{ g} = 137.4 \times 10^9 \text{ kg}$.

Airborne fluorine compounds can be detrimental to susceptible vegetation. The National Academy of Science reported that a 30-day average air concentration of gaseous fluoride of about 0.5 $\mu g/m^3$ may be the threshold for causing foliar damage to susceptible vegetation.[222] Doze-response relationships for different plants indicate that foliar injury to susceptible vegetation occur at fluorine levels of 5 to 10 $\mu g/m^3$ for one-day exposures.[238] In another study, foliar damage was observed when susceptible plants were exposed to 5.5 $\mu g/m^2$ fluorine for 40 hours.[239] Maximum 24-hour ground level fluorine concentration predicted within 25 km of the Hat Creek power plant would be about 0.4 $\mu g/m^3$ (Table 5-12 in the ERT main report). Such short-term (24-hour maximum) levels are less than values reported to cause damage to susceptible vegetation.

In addition to non-radioactive trace elements, coal also contains small quantities of uranium isotopes, thorium, and their daughter products that are released during coal combustion. A recent predictive model study[233] can be used to calculate maximum human doses from both inhalation and ingestion pathways near a 200-MW (e) coal-fired power plant burning coal containing 1 mg/kg uranium and 2 mg/kg thorium and with 99.7% precipitator efficiency (Table F7-4). Predicted doses are all less than guideline values for protection of human health.[234] Since uranium and thorium content in coal (Table F4-9), design particulate collection efficiency, and design size of the Hat Creek power plant[243] are very similar to conditions assumed in this predictive model, radioactive dose commitments near the Hat Creek project are expected to be similar to those calculated by the model (i.e., less than U.S. guideline values for protection of human health). However, because environmental effects of long-term (35 years) exposure of ecosystem components to low level radiation that might exist near coal-fired power plants are largely undocumented, any radiological impacts to ecosystem components near the proposed Hat Creek power plant cannot be estimated.

(b) Ash Basin

Except for volatile trace elements such as Hg, the greatest amounts of trace elements in coal will be contained in bottom and collected fly ash.

Table F7-4

Maximum individual dose commitments (man rem per year) from the airborne releases of model 2000-MW(e) power plants

Organ	Predicted dose*	Guideline**
Whole body	1.1	5
Bone	10.9	15
Lungs	1.1	15
Thyroid	1.1	15
Kidneys	2.0	15
Liver	1.4	15
Spleen	1.6	15

* Predicted values for 2000-MW(e) power plant with 99.7% removal of fly ash.[233]

** Guidelines from U.S. Code of Federal Regulations, 10 CFR 50.[234]

The water soluble amounts of trace elements estimated to be contained in collected ash for a 35 year plant operating period are listed in Table F4-2. Weights of water soluble elements in the ash basin or coal pile are projected to be mostly less than combined weights of water soluble elements in waste rock and overburden piles. Current design plans indicate that trace elements will be retained in or near storage basins or removed from basin seepage by treatment processes.[241]

(c) Cooling Tower Drift

A secondary and localized source of trace elements associated with power plant operation will be cooling tower drift. It is predicted that Thompson River water, the source of cooling water, will be concentrated by a factor of 14 as it is recycled through the cooling system.[242] A small portion of the concentrated circulating water (about 0.008%) will be carried to areas near the cooling tower as winds disperse some of the water away from the tower. Table F4-3 presented the predicted amount (kg/yr) of selected trace elements that will be contained in cooling tower drift. Information in Table F4-3 and the predicted salt deposition due to drift from various cooling tower designs provides the basis for a model that predicts soil concentration increases (mg/kg) of trace elements in various salt depositional zones. The model makes the same assumption concerning the fate of elements in the soil as described in Section F7.2(a). The ratio of trace element concentrations to TDS (salt) concentration in drift is used to determine trace element deposition rates in various depositional zones (the model assumes trace elements have similar deposition as TDS) that would occur for two natural draft towers (preferred cooling tower design[243]). Projected increases in soil concentrations of trace elements in various salt deposition zones for two natural draft cooling towers are presented in Table F7-5. Areal extension of these depositional zones are presented on Figure F7-2. Salt deposition associated with other cooling tower designs are discussed in Appendix D, Assessment of Atmospheric Effects and Drift Deposition Due to Alternate Cooling Tower Designs.

For two natural draft cooling towers, maximum salt deposition (4,700 $kg/km^2/yr$) is predicted to occur at a point about one kilometer east from the

Table F7-5

Projected annual increase (mg/kg) of selected trace elements in soil due to drift from two natural draft cooling towers

Element	Predicted amount in drift (kg/yr)	Salt depositional zones ($kg/km^2/yr$)*			
		4,700	2,240	560	112
Arsenic (As)	71	0.03	0.01	0.004	0.0007
Cadmium (Cd)	7.1	0.003	0.001	0.004	0.00007
Chromium (Cr)	2.9	0.001	0.0005	0.0001	0.00002
Copper (Cu)	14	0.006	0.003	0.0007	0.0001
Fluorine (F)	142	0.06	0.03	0.007	0.001
Lead (Pb)	71	0.03	0.01	0.004	0.0007
Mercury (Hg)	1.4	0.0006	0.0003	0.00007	0100001
Vanadium (V)	9	0.004	0.002	0.0005	0.00009
Zinc (Zn)	44	0.02	0.009	0.002	0.0005

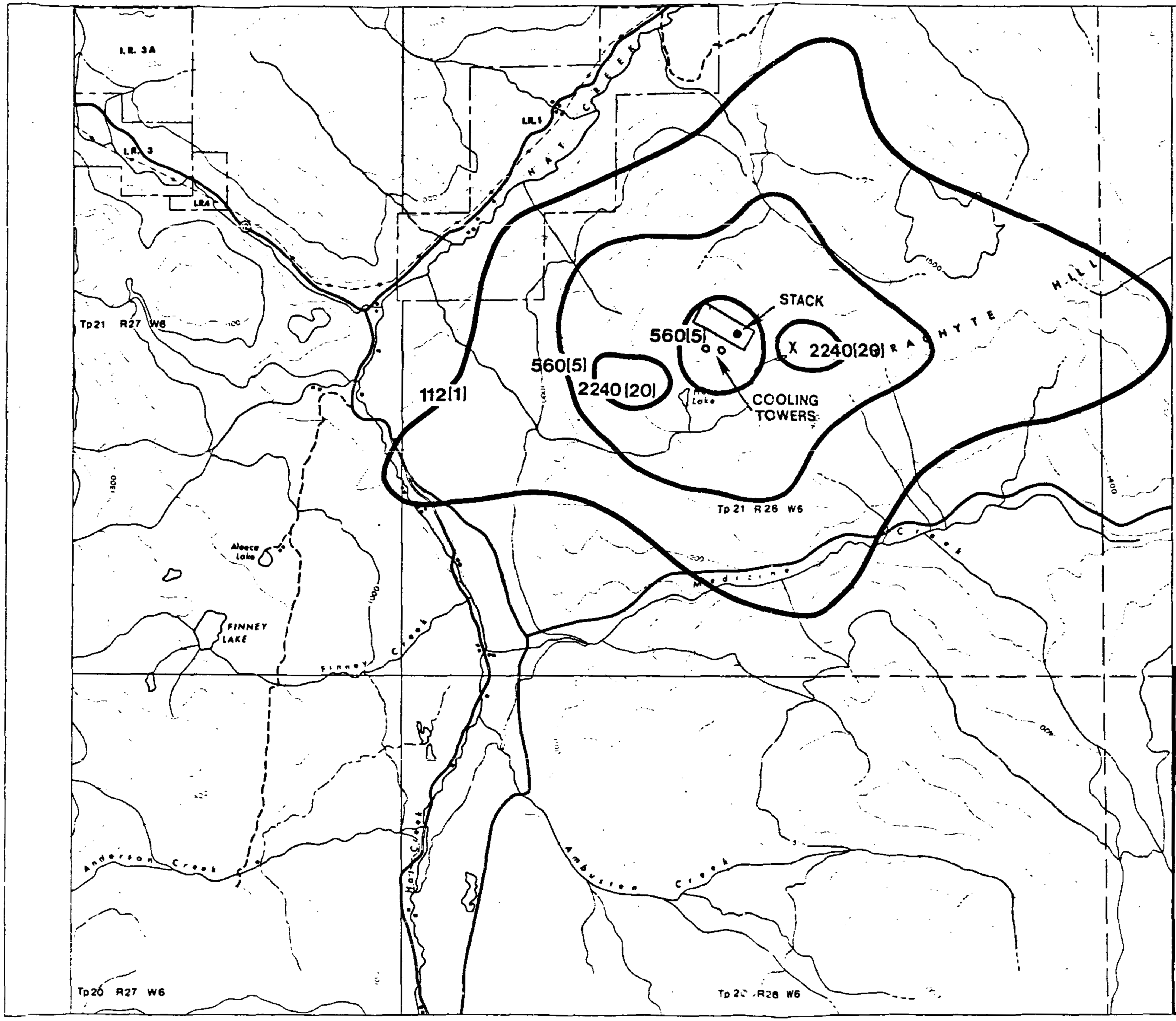
* See Figure F7-2 for areal extension of these depositional zones.

Trace element deposition flux ($kg/km^2/yr$) = salt deposition rate X element to salt concentration ratio in drift (see Table F4-3).

Assumes that all deposited elements will remain in residence in top 5 cm of soil and that neither uptake by vegetation nor erosion of soil to watershed drainages will occur. Assume soil bulk density = 1.4 g/cc.

Then, soil concentration increase per year = depositional flux X 1 $km^2 \div (0.05 \times 10^6\ m^3 \times 1.4\ g/cc \times 10^6\ cc/m^3)$ = kg/70 X 10^6 kg = mg/70 kg. Therefore, soil increase (mg/kg/yr) = deposition flux ÷ 70.

Calculation based on cooling towers operating at design capacity for 365 days/year (hypothetical worst-case for trace element impact assessment).



X = maximum = 4700 kg/km^2/year
(42 lb/acre/year)

SCALE - 1:50,000
0 Kilometres 1 2 3
CONTOUR INTERVAL - 100 METRES

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Figure F7-2. Predicted Annual Salt Deposition in kg/km^2/year (lb/acre/year) Due to Drift from Proposed (Two) Natural Draft Cooling Towers

towers (Figure F7-2). Even at this point of maximum salt deposition, trace element increase in soil is predicted to be no greater than 0.06 mg/kg/yr for any one trace element. Increases in the 2,240 kg/km^2/yr salt deposition zones (Figure F7-2) would be 0.03 mg/kg/yr or less for any one trace element. Maximum increase (0.06 mg/kg/yr) is predicted for fluorine. Based on existing levels of fluorine in soils (about 200 mg/kg; see Section F5.0) from the Hat Creek region, cooling tower drift would cause a 0.03% annual increase in existing soil fluorine levels at the point of maximum salt deposition. Such small increases would not be detectable and effects to ecosystem components caused by trace elements in cooling tower drift are not anticipated. As mentioned previously, the area of maximum salt deposition for two natural draft cooling towers is about one kilometer east from the towers. This area is within isopleth code D (see Figure F7-1 and Table F7-2), a zone around the power plant where trace element deposition from stack emissions is projected to be very low. For example, in this zone, increases in soil fluorine levels due to deposition of stack emissions are projected to be 0.00004 mg/kg/yr. Therefore, cumulative effects due to trace element deposition from cooling towers and stack emissions are not anticipated.

F8.0 MITIGATION

As discussed in Section F7.0, release of trace elements from coal mining and electric power generating activities of the Hat Creek project is not expected to be detrimental to terrestrial or aquatic ecosystems. Since no detrimental impacts are predicted, the implementation of current design and operating specifications for the mine and power plant should adequately mitigate any environmental impact that might be caused by trace elements. Proper design and construction of overburden, waste rock, and ash storage piles will prevent migration of trace elements from these piles to ground or surface waters.[241] Pollution control devices installed at the power plant should remove most of the fly ash particulates (99.7%) released during coal combustion.[243] Gaseous and particulate trace elements that pass through the pollution control devices and that are emitted from the gas stack were determined to exist in amounts that will not be detrimental to ecosystem components.

Cooling towers, by virtue of the relatively low concentration of trace elements in cooling water make-up that will be taken from the Thompson River and the extremely limited distribution of salt drift, will not be a significant source of trace elements to terrestrial and aquatic ecosystems.

F9.0 MONITORING PROGRAM

It was established in Section F7.0 that, barring any accidents or natural catastrophes, provided available technical information was reasonably accurate, minimal, if any, environmental impact of trace elements emanating from mine or plant construction activities or operations is anticipated. However, given the wide distribution, high mobility and high bioaccumulation and toxicity potentials of some trace elements in Hat Creek source materials and the uncertainties of the trace element dispersion model, a sampling program is proposed to monitor and verify predictions of no significant impact. Such a program would be designed to increase scientific confidence in our understanding of trace element impacts and would provide quantitative, statistically valid data for evaluating any impacts associated with the Hat Creek Project. To ensure that trace element influx from project activities are indeed minimized by technical design features, source as well as receptor materials are proposed for monitoring.

F9.1 Source Monitoring

The sources of trace elements associated with the Hat Creek Project are leachates from coal storage, waste overburden, waste rock,...and ash disposal piles, fugitive dust emissions, stack emissions and cooling tower drift. Of these, stack emissions are of primary concern because trace elements in stack emission are widely distributed and the most insidious trace elements in coal are frequently concentrated in fly ash (Section F9.2). Accordingly, the source monitoring program will focus on ascertaining the kinds and amounts of trace elements potentially entering Hat Creek ecosystems via stack emissions. The receptor monitoring program design (Section F9.2) incorporates features for assessing effects of other sources on existing Hat Creek trace element burdens.

Specialized sampling and analytical techniques are required to determine the environmentally important characteristics of atmospheric emissions generated by coal combustion. In addition, several criteria are necessarily imposed on any proposed stack emission sampling technique. These include:

1. Sampling must completely capture both particulate and gaseous emissions.

2. Volatiles (e.g., Hg, As, and F) must be sampled by special absorbers.
3. Samples must not be contaminated by collection or analysis techniques.
4. Trace elements of concern should be quantified as a function of particle size since the environmental effects of these emissions are a function of particle size; i.e., the most toxic of trace elements are frequently emitted as a vapor or condensed into submicron particles.

Meeting the last criterion is especially challenging since the sample must be fractionated by size yet enough material must be available in each size category for subsequent analysis.

The recent interest in trace elements from coal-fired generating stations has promoted advances in the technology for sizing and characterizing the size fractions of stack emissions. A high volume sampling train which separates particulate matter into size classes by a series of cyclones and a back-up filter and captures volatiles (such as Hg vapor) in specific absorbing solutions has been recently developed for *in situ* stack sampling of trace elements. It is recommended that selected trace element quantification of stack emissions be conducted semiannually during the first 5 years of plant operation to provide an adequate data base for monitoring trace elements in stack emissions. Sampling intensity could be reevaluated after 5 years and adjusted to a level commensurate with the potential hazard associated with trace elements in stack emissions.

F9.2 Receptor Monitoring

The specific questions to be addressed by a receptor monitoring program design are:

1. Does the concentration of a specific trace element in a specific receptor at a specific site show a response (i.e., increase) after plant operation commences, and if so
2. Is that response due to trace element influx from project activities?

The first question can be addressed by comparing operational trace element data with pre-operational baseline data. A statistically significant difference in these data would indicate a response but would not identify the source of the response; that is, is the response due to natural variation or plant and mine activities? The use of control sites outside the projected zone of influence should allow the identification of natural variation contributions to observed responses and thus permit the identification of man-induced impacts. The question then becomes: is the difference between trace element levels at the control and monitoring sites after plant operation greater than the differences between control and monitoring sites before plant operation? Note that the question considers that natural differences may exist between primary (potentially impacted) and control sites but assumes that environmental factors affecting natural trace element considerations at both sites are the same. Thus, a change in the difference between trace element concentrations at primary and control sites (i.e., levels of selected trace elements increase at a greater rate at the primary site than in the control site) would indicate a project-related response. To rephrase the question as a null hypothesis that is amenable and appropriate to statistical testing techniques:

> H_0: There is no difference between concentrations of a specific trace element at a specific primary and control site before and during Hat Creek facility construction and operation activities.

The statistical model used to test this hypothesis is known as the two-factor analysis of variance design model.[212] This model permits the comparison of data between two different types of sites (control and primary) and obtained at two different times (before and during operation). Experimental design considerations for collecting data applicable to the stated hypothesis, appropriate to the two-factor design model and commensurate with the needs of the Hat Creek project, include number and location of sampling locations, receptors samples at each location, trace elements analyzed in each receptor and sampling intensity.

(a) Number and Location of Sampling Stations

Terrestrial sampling locations are selected to monitor trace elements emanating from the major potential trace element sources of the Hat Creek project. These major sources are 1) leachates from coal, overburden and waste rock storage and bottom ash piles; 2) fugitive dust emissions; 3) cooling tower drift; and 4) stack emissions. Provided adequate samples can be obtained at each selected site, testing of the hypothesis does not require a large number of sampling sites; that is, comparisons need only be made between a primary site and a control site. Accordingly, it is proposed that primary sites be established in areas of highest projected impact of each of the above sources (e.g., for stack emission, a primary site would be established in an area receiving the highest yearly depositional flux of trace elements). Two control sites located outside of the zone of influence would be sufficient to identify existing natural variation. Existing terrestrial sites 4 (Cornwall Mountain) and 5 (Ashcroft) would be used to monitor stack emissions and to serve as a control, respectively (Figure F3-1). Location of site 2 (Lower Hat Creek) may be amenable to monitoring both fugitive dust and stack emissions. An additional site would be established near the mine and disposal sites to monitor leachates and fugitive dust and another control site would be located outside the primary zone of project influence.

The major potential source of trace elements to aquatic systems in the area (i.e., streams and rivers) will be leachate from material storage and disposal piles. Accordingly, establishment of a sampling station on Hat Creek below where any leachate would enter the stream would be sufficient to ascertain the extent of trace element impact from these sources. A station on Hat Creek above storage and disposal piles would serve as a control. Anticipation of this monitoring program objective was a primary criterion for locating existing aquatic sampling stations on Hat Creek and these would be used during monitoring activities (Figure F3-1).

(b) Receptors Sampled at Each Site

Important considerations in selecting receptors to be studied within a rigorous monitoring program design are their amenability to sampling and ability to provide statistically sound data (i.e., low within-site variability). Amenability to sampling constraints include availability of receptors at all sites and ease of sample collection and preparation. These criteria generally preclude highly mobile animals from such a sampling program. Moreover, animals are exposed to trace elements via a number of routes (e.g., ingestion, inhalation and absorption) and frequently from a number of sources. This results in a naturally high variation of trace elements; variation that is difficult to quantify. By focusing monitoring efforts on vegetation and major abiotic receptors such as water, soil and stream sediment, a sufficient data base can be obtained to evaluate effects of mining and power plant activities in the Hat Creek area. Furthermore, since the primary intake of trace elements by animals is via the food chain (initiating, of course, with producers), trace element investigations on vegetation will provide a basis for postulating impacts to animals. Accordingly, the following receptors that were sampled in the initial baseline program are proposed for use in monitoring program:

Terrestrial:	Aquatic:
Soil	Water
Grass (bunchgrass)	Stream sediment
Shrub (*Salix* sp.)	
Lichens	

Lichens would not be sampled at the leachate impact site since they do not have a soil-based root system and would be exposed to trace elements primarily via absorption on foliar surfaces.

(c) Trace Elements Analyzed in Each Receptor

Several trace elements have been identified in previous sections as being of concern because of their relatively high concentration in source materials, wide distribution, high mobility, and high bioaccumulation and toxic potential in Hat Creek ecosystems. These elements provide the logical focus for a monitoring program and include:

Arsenic
Cadmium
Copper
Fluorine
Lead
Mercury

Vanadium
Zinc

Monitoring of other trace elements, especially during early phases of project operation, would provide added detail to the monitoring program. Recommended additional trace elements for monitoring include boron (water soluble element that can reach relatively high concentrations in ash basins), selenium (historically, this element has received much attention at fossil fuel power plants), and tin (abnormally high values were measured in Hat Creek soils, vegetation, and animals, see Section F5.1.)

It is anticipated that any contribution to natural trace element loads in the Hat Creek area from project activities will be first reflected in and perhaps limited to an increase in levels of the above elements. Accordingly, focusing monitoring efforts on these few, select elements can provide an efficient program for evaluating the effect of the Hat Creek project on trace elements in the Hat Creek environment.

(d) Sampling Intensity

The primary criterion in determining sampling intensity is the number of samples required to identify a response for a particular trace element in a specific receptor with a desired amount of confidence. There are three aspects of addressing this criterion that merit attention: 1) what increase in trace element concentrations in receptors due to the Hat Creek project is it important to detect; 2) how important is it to avoid saying that an increase has occurred when it actually has not (statistical Type I error); 3) how important is it to avoid saying that an increase has not occurred when it actually has (statistical Type II error). Given the potential toxicity of trace elements and the degree of public concern over trace elements, minimizing Type II error is of special concern.

Determining a desired detection limit for a concentration of a given trace element should logically derive from an evaluation of natural trace element levels and determination of potential tolerance and toxic concentrations for receptors of a given trace element. While information on natural trace element levels is available, site-specific data on tolerance and toxic concentrations are not. Accordingly, identification of detection limits for different trace elements and receptors is a subjective determination based on available literature. Table F9-1 summarizes the sample size needed to detect specified responses (50 to 200% of baseline levels) of different receptors for some of the trace elements of concern. Sample sizes were determined by testing interactions in the two factor analysis of variance model.[212] Calculation of these sample sizes utilizes estimates of existing within-site variability as determined from the October 1976 data. For all detection limits, Type I error ($\alpha = 0.05$) and Type II error ($\beta = 0.05$) are minimized.

Sample sizes for most receptors are quite large even to statistically detect concentration changes as large as 50%. However, these sample size determinations may not be highly reliable since the estimation of within-site variability was based on a sample size of only three replicates. Since an adequate sample size is germane to accurate hypothesis testing, it is recommended that a one-time sampling program be conducted during which 10 replicate samples of each receptor are collected at each of the primary and control monitoring sites and concentrations of the aforementioned trace elements are estimated. Commensurate with this sampling program, an information search would be conducted to determine desired detection limits for each trace element in each receptor. This information search will utilize published information and interviews with knowledgeable researchers. The results of the sampling program and literature search would dictate sample sizes applicable to testing the stated hypothesis and appropriate to the needs of the Hat Creek Project.

Subsequent to establishment of reliable sample sizes and desired detection limits, a two-year pre-operational monitoring program is suggested with sampling to be conducted semi-annually, most likely during spring and fall. Sampling during each season is precluded by wintertime conditions (burial of sites under snow, icing of streams, inaccessibility of some sampling locations, etc.). Commencing with project construction activities, an operational monitoring program requiring spring and fall sampling each year would be recommended to provide data for comparison with preoperational conditions. Sampling intensity could be modified during early stages of

Table F9-1

Sample sizes required to detect specified responses (50, 100 and 200% of baseline levels) of different receptors for several of the trace elements of concern

Element/Receptor	Baseline (October 1976) Levels Mean*	Std. Dev.	Sample Sizes For Various Detection Levels** 50%	100%	200%
Arsenic (As)					
Water	0.002	0.001	13	5	3
Stream sediment	6.50	3.70	18	6	3
Soil	4.87	2.37	14	5	2
Shrub	0.60	0.43	28	8	4
Grass	0.66	0.86	90	24	7
Lichen	1.01	0.67	24	8	3
Small mammal	1.85	2.29	81	21	7
Chromium (Cr)					
Water	0.01	0.008	20	6	3
Stream sediment	285.75	295.20	57	15	5
Soil	247.07	228.83	46	13	5
Shrub	4.40	4.85	65	17	6
Grass	4.69	2.61	18	6	3
Lichen	7.73	4.10	16	6	3
Small mammal	3.60	1.93	16	6	3

Table F9-1

(Continued)

Element/Receptor	Baseline (October 1976) Levels		Sample Sizes For Various Detection Levels**		
	Mean*	Std. Dev.	50%	100%	200%
Mercury (Hg)					
Water	0.0001	0.00006	15	5	3
Stream sediment	0.14	0.02	3	2	2
Soil	0.09	0.03	7	3	2
Shrub	0.07	0.02	4	2	2
Grass	0.14	0.06	13	5	2
Lichen	0.47	0.16	8	3	2
Small mammal	0.03	0.01	17	6	3
Vanadium (V)					
Water	0.002	0.0003	3	2	2
Stream sediment	154.00	139.15	44	12	5
Soil	297.60	218.25	29	9	4
Shrub	0.30	0.22	29	9	4
Grass	0.75	0.74	52	14	5
Lichen	3.47	1.90	17	6	3
Small mammal	0.25	0.08	7	3	2

Table F9-1

(Continued)

Element/Receptor	Baseline (October 1976) Levels Mean*	Std. Dev.	Sample Sizes For Various Detection Levels** 50%	100%	200%
Zinc (Zn)					
Water	0.02	0.03	70	19	6
Stream sediment	72.17	35.24	14	5	3
Soil	147.13	119.77	36	11	4
Shrub	221.80	72.13	7	3	2
Grass	22.07	7.81	8	3	2
Lichen	47.27	44.74	48	13	5
Small mammal	124.67	97.42	33	10	4

* Over all sites.

** Detection levels are described as a percentage of the baseline mean; e.g., if the baseline mean was 72 ppm, a 100% detection level would be 144 ppm.

the monitoring program. Results should determine if the Hat Creek Project is having any effect on trace element levels in Hat Creek ecosystems.

(e) Sample Collection, Preparation and Analysis

Sample collection and preparation should utilize the methodologies outlined in Section F3.0. Sample analyses would be performed using atomic absorption techniques (also defined in Section F3.0).

F9.3 Other Recommended Studies

Interpretation of trace element monitoring data can be complicated by existing natural stress conditions on Hat Creek biota. Not only can natural stress result in receptors being more susceptible to trace element injury, it can also cause symptoms that can be wrongly attributed to trace elements from project activities. Moreover, effects of plant operation, such as SO_2 emissions, can stress Hat Creek ecosystems and potentially reduce certain receptors' resistence to trace element accumulation and damage.[240] Vegetation stress analyses provide a useful tool for evaluating a myriad of potential ecological impacts from coal-fired power plant operation and present an additional means for identifying the cause of any response in Hat Creek trace element burdens. Comparison of stress before and after operation of the power plant could support or help repudiate various damage claims which are attributed to power plant activities.

Color infrared imagery (CIR) of habitats within the projected primary zone of influence of the Hat Creek Project would provide the most obvious interpretable indications of vegetation stress. Healthy vegetation shows as red (the mesophyll layers of a broad leaf reflect near-infrared wavelengths), while stressed vegetation gives a brown to steely blue image. Evaluation of vegetation conditions from the aerial photographs (CIR) could be correlated with air quality data by superimposing air quality isopleths on CIR imagery. Areas in which vegetation stress or damage corresponded to areas receiving potentially maximum levels of pollutants (i.e., SO_2, trace elements) could then be identified.

F10.0 GLOSSARY

Additive Toxicity - the total toxicity of a mixture; equal to the sum of the individual toxicities.

Albumin - simple, heat-coagulable, water-soluble proteins that occur in blood plasma or serum, muscle, egg whites, milk and other plant and animal tissues and fluids.

Anoxia - a condition of subnormal blood oxygenation resulting in permanent damage.

Antagonism - a decrease in the toxicity of one element due to interaction with another element.

Antihelminthic - any drug used to worm animals.

Antimetabolite - a substance that replaces or inhibits the utilization of a metabolite.

ATP - adenosine triphosphate; a chemical species present in cellular systems that supplies energy for many biochemical cellular processes by undergoing enzymatic hydrolysis to ADP or free P groups.

Atrophy - a decrease in size of a body part or tissue.

Auxins - an organic substance capable in low concentrations of promoting elongation of plant shoots and controlling other specific growth effects.

Bioaccumulation - the ability of an organism to concentrate elements present in the environment throughout its lifetime.

Bioconcentration - the ability of an organism or population of organisms of the same trophic level to concentrate a substance from an aquatic system.

Biomagnification - a term used when a substance is found to exist in successively greater quantities at higher trophic levels in ecosystem food chains.

Blood Barrier Gap - the single cell barrier between internal blood circulation and external air circulation in the respiratory tract of an organism.

Bone Marrow Hyperplasia - a proliferation in the cell types making up bone marrow.

Catarrh - inflammation of a mucous membrane especially in the upper respiratory tract.

Chlorosis - a diseased condition of plants marked by yellowing or blanching.

Cirrhosis - fibrosis of the liver with hardening caused by excessive formation of connective tissue followed by contraction.

Concentration Factor - the ratio of the concentration of a material in a biological species to the concentration of the material in water or in the preceeding link of the food chain.

Conjunctivitis - inflammation of the mucous membrane that is associated with the eye.

Corticosteroid - any of various adrenal-cortex steroids.

Cutaneous - of, relating to, or affecting the skin.

Cytochrome Oxidase - an iron-porphyrin enzyme important in cell respiration because of its ability to catalyze the oxidation of reduced cytochrome C in the presence of oxygen.

Dyspnea - difficult or labored breathing.

Ecchymotic hemorrhage - the escape of blood into the tissues from a ruptured blood vessel.

Emphysematose foeti - a fetus delivered dead of emphysema.

Endemic - disease restricted to a locality or region.

Epigenetic - those elements introduced into the coal seams during the coalification process.

Epithelium - the membranous cellular tissue covering a free surface or lining a tubal cavity of an animal to enclose and protect the underlying organs.

Erythrocyte - the red blood cell.

Gill Lamellae - the respiratory organ in fish.

Half Retention Time - the time it takes for half of the absorbed element to be eliminated from the organism.

Hematocrit - the ratio of volume of packed red blood cells to volume of whole blood.

Hematopoetic system - responsible for the formation of blood cells in the living body.

Hemoglobin - an iron containing, conjugated protein, respiratory pigment occurring in the red blood cells of vertebrates.

Hemolysis - the disintegration of red blood cells with liberation of hemoglobin.

Hepatic - in association with the liver.

Hyperglycemia - abnormal increase of blood sugar.

Hypertonic - having a higher osmotic pressure than the surrounding medium causing the net movement of solvents out of the membrane.

Hypertrophic Heart Ventricles - cell proliferation in the area of the heart ventricle.

Hypocardia - a disease characterized by a reduction in heart rate.

Hypoglycemia - abnormal decrease of blood sugar.

Immunobiologic Response - antibodies and other defensive cells responding to antigen challenge.

Interlamellar Space - the space between the thin plates composing the gills of a fish.

Intraperitoneal Injection - an injection into the smooth, transparent, serous membrane that lines the abdominal cavity.

Lateral Line - a mechano-chemico receptor system in fish that aids in navigation, communication, and peripheral awareness.

Lethal Concentration - that concentration of an element that will kill an organism.

LC_{50} - the concentration of a toxin required to kill 50% of a test population.

LD_{50} - the dosage of a toxin required to kill 50% of the test organisms.

Leucocyte - any of the white nucleated cells that occur in the blood that serve a protective function.

Lignification - in molecule biosynthesis, the assumption of a specified configuration.

Lymphoma - a tumor of lymphoid tissue.

MATC - maximum acceptable toxicant concentration (the level of no chronic effect).

Meristem - a formative plant tissue made up of small cells capable of dividing indefinitely and giving rise to similar cells or to cells that can differentiate into definitive tissues and organs.

Median Tolerance Limit - the average dosage of a toxin that an organism can tolerate without toxic effects.

Microcytic Hypochronic Anemia - a disease of the blood characterized by small lightly colored red blood cells which are few in number.

µg/l - micrograms per liter - equivalent to ppb (parts per billion).

mg/l - milligrams per liter - equivalent to ppm (parts per million).

Mitochondria - a round or oval cellular organelle that is found outside the nucleus of a cell and which produces energy for the cell through cellular respiration.

Natality - birth rate.

Necrosis - localized death of living tissue.

Neoplasm - a new growth of tissue serving no physiologic function.

Nephrosis - the death of living kidney tissue.

Organelles - a specialized cellular part (as a mitochondrion) that is analogous to an organ.

Osmoregulation - the regulation of the pressure produced by the diffusion through a semipermeable membrane of solvents from a solute to a solution depending on molar concentration and absolute temperature.

Osteomalasia - a disease characterized by softening of the bones in the adult and equivalent to rickets in the immature.

Osteopetrosis - a disease of the bone characterized by exceptional hardening of the bone tissue.

Pectin - a water-soluble substance which binds adjacent cell walls in plants.

Petechial Hemorrhage - a minute hemorrhagic spot appearing in the skin or mucous membrane.

Phagocytosis - the engulfing and destruction of particulate matter by leucocytes in the blood and surrounding tissue.

Plasma Cortisol - the concentration of corticosteroids (e.g., adrenalin) in the blood plasma.

Polycythemia - a condition marked by an abnormal increase in the number of circulating red blood cells.

Reticulocytosis - a reduction in the number and type of reticulocytes (a white blood cell) circulating in the blood.

Reticuloendothelial System - a diffuse system of cells that comprises all of the phagocytic cells of the body except the circulating leucocytes.

Small Lymphocytes - a type of white blood cell.

Stomata - small openings in the surface of leaves that allow gaseous exchange of O_2 and CO_2.

Stomatal Resistence - the aperture of the stomata opening to allow more or less transpiration in a plant surface.

Synergism - an increase in the toxicity of a mixture of elements such that it is greater than the sum of the individual toxicities.

Syngenetic - coal minerals which are associated with the origin from the original plant material.

Teratogenic - tending to cause developmental malformations and monstrosities.

Testicular Hypoplasia - a cell decrease (in size or number) in the testes.

TD_{50} - a toxic dose which affects 50% of the organisms tested.

TD_{lo} - the lowest published toxic dose of an element to an organism.

TLM - median tolerance limit.

Toxic Concentration - that concentration of an element which has adverse effects upon an organism.

Trace Element Symbols -

Al - aluminum
Sb - antimony
As - arsenic
Ba - barium
Be - beryllium
Bi - bismuth
B - boron
Br - bromine
Cd - cadmium
Ca - calcium
C - carbon
Ce - cerium
Cs - cesium
Cl - chlorine
Cr - chromium
Co - cobalt
Cu - copper
Dy - dysprosium
Er - erbium
F - fluorine
Gd - gadolinium
Ga - gallium
Ge - germanium
Au - gold
Hf - hafnium
Ho - holmium
H - hydrogen
In - indium
I - iodine
Ir - iridium
Fe - iron
La - Lanthanum
Pb - lead
Li - lithium
Mg - magnesium
Hg - mercury
Mo - molybdenum
Nd - neodymium
Ni - nickel
Nb - niobium
N - nitrogen
Os - osmium
O- oxygen
Pd - palladium
P - phosphorus
Pt - platinum
K - potassium
Pr - praseodymium
Ra - radium
Rn - radon
Re - rhenium
Rh - rhodium
Rb - rubidium
Sm - samarium
Sc - scandium
Se - selenium
Si - silicon
Ag - silver
Na - sodium
Sr - strontium
S - sulfur
Ta - tantalum
Te - tellurium
Tb - terbium
Tl - thallium
Th - thorium
Tm - thulium
Sn - tin
Ti - titanium
W - tungsten
U - uranium
V - vanadium
Yb - ytterbium
Y - yttrium
Zn - zinc
Zr - zirconium

Tumorigenesis - production or the tendency towards production of tumors.

Wind Rose - the pattern of aerial distribution of elements emitted from a point source.

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ADDENDUM A

TRACE ELEMENT CONCENTRATION IN RECEPTORS
OCTOBER 1976

Table (A)-1

Trace element concentration (ug/ml) in water samples collected during January 1977

Element	Site 1		Site 2		Site 3		Site 4		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	0.0033	0.0120	0.1033	0.0549	0.2333	0.0802	0.0900	0.0551	0.1275	0.0313
Antimony (Sb)	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0013	> 0.0003	< 0.0013	> 0.0003	< 0.0013	> 0.0001
Arsenic (As)	0.0027	0.0007	< 0.0023	> 0.0007	< 0.0020	> 0.0006	< 0.0020	> 0.0006	< 0.0023	> 0.0003
Barium (Ba)	0.0400	0.0100	0.1333	0.0333	0.0567	0.0033	0.0600	0.0058	0.0725	0.0132
Beryllium (Be)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Bismuth (Bi)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Boron (B)	0.0037	0.0003	0.0060	0.0023	0.0033	0.0023	0.0050	0.0015	0.0045	0.0008
Bromine (Br)	0.0060	0.0017	0.0083	0.0012	0.0103	0.0048	0.0213	0.0144	0.0115	0.0037
Cadmium (Cd)	< 0.0013	> 0.0003	< 0.0013	> 0.0003	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0013	> 0.0001
Calcium (Ca)	> 10.0000	> 0.0000	> 10.0000	> 0.0000	> 10.0000	> 0.0000	> 10.0000	> 0.0000	> 10.0000	> 0.0000
Cerium (Ce)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0017	> 0.0003	< 0.0012	> 0.0001
Cesium (Cs)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Chlorine (Cl)	0.1667	0.0667	0.5000	0.2517	0.0533	0.0240	0.1567	0.0722	0.2192	0.0769
Chromium (Cr)	0.0167	0.0067	0.0200	0.0000	0.0097	0.0054	< 0.0067	> 0.0028	< 0.0133	> 0.0025
Cobalt (Co)	< 0.0013	> 0.0003	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0012	> 0.0001
Copper (Cu)	0.0057	0.0015	0.0083	0.0009	< 0.0037	> 0.0015	0.0070	0.0017	< 0.0052	> 0.0008
Dysprosium (Dy)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Erbium (Er)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Europium (Eu)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Fluorine (F)	0.0700	0.0053	1.0333	1.0929	0.1500	0.0755	0.1267	0.0371	0.5450	0.3240
Gadolinium (Gd)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Gallium (Ga)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Germanium (Ge)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Gold (Au)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001

Table (A)-1

Trace element concentration (ug/ml) in water samples (continued)

Element	Site 1 Mean	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Overall Mean	Overall Std err
Hafnium (Hf)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Holmium (Ho)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Iodine (I)	< 0.0020	> 0.0006	0.0023	0.0003	0.0017	0.0003	0.0027	0.0003	< 0.0022	> 0.0002
Iridium (Ir)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Iron (Fe)	0.1667	0.0333	0.0867	0.0133	0.2667	0.1202	0.0833	0.0088	0.1508	0.0350
Lanthanum (La)	< 0.0013	> 0.0003	< 0.0013	> 0.0003	0.0020	0.0000	< 0.0023	> 0.0007	< 0.0018	> 0.0002
Lead (Pb)	< 0.0500	> 0.0000	< 0.0500	> 0.0000	< 0.0500	> 0.0000	< 0.0500	> 0.0000	< 0.0500	> 0.0000
Lithium (Li)	< 0.0013	> 0.0003	0.0020	0.0006	< 0.0010	> 0.0000	< 0.0020	> 0.0006	< 0.0016	> 0.0002
Lutetium (Lu)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Magnesium (Mg)	> 10.0000	> 0.0000	> 10.0000	> 0.0000	> 10.0000	> 0.0000	> 10.0000	> 0.0000	> 10.0000	> 0.0000
Manganese (Mn)	0.0267	0.0120	0.0083	0.0009	0.0080	0.0020	0.0037	0.0012	0.0117	0.0037
Mercury (Hg)	< 0.0001	> 0.0000	0.0002	0.0001	< 0.0001	> 0.0000	< 0.0001	> 0.0000	< 0.0001	> 0.0000
Molybdenum (Mo)	0.0067	0.0017	0.0087	0.0013	0.0267	0.0167	0.0133	0.0033	0.0138	0.0043
Neodymium (Nd)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Nickel (Ni)	0.0023	0.0003	< 0.0020	> 0.0006	0.0053	0.0013	0.0043	0.0003	< 0.0035	> 0.0005
Niobium (Nb)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Osmium (Os)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Palladium (Pd)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Phosphorus (P)	0.1133	0.0437	0.0267	0.0033	0.1667	0.0333	0.4667	0.2667	0.1933	0.0766
Platinum (Pt)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Potassium (K)	> 5.0000	> 1.0000	> 8.0000	> 1.0000	> 6.0000	> 2.6458	> 8.0000	> 2.0000	> 6.7500	> 0.8627
Praesodymium (Pr)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Rhenium (Re)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Rhodium (Rh)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Rubidium (Rb)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0017	> 0.0007	< 0.0023	> 0.0009	< 0.0015	> 0.0003

Table (A)-1
Trace element concentration (ug/ml) in water samples (continued)

Element	Site 1 Mean	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Overall Mean	Overall Std err
Ruthenium (Ru)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Samarium (Sm)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Scandium (Sc)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Selenium (Se)	< 0.0027	> 0.0003	< 0.0020	> 0.0000	< 0.0023	> 0.0003	< 0.0023	> 0.0007	< 0.0023	> 0.0002
Silicon (Si)	5.0000	1.1547	> 7.0000	> 3.0000	6.3333	0.8819	> 6.6667	> 2.0276	> 6.2500	> 0.8627
Silver (Ag)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Sodium (Na)	> 1.6667	> 0.6667	> 1.6667	> 0.3333	> 2.3333	> 0.3333	> 2.3333	> 0.6667	> 2.0000	> 0.2462
Strontium (Sr)	0.2333	0.0333	0.2667	0.0667	0.1333	0.0333	0.2667	0.0667	0.2250	0.0279
Sulfur (S)	> 4.3333	> 1.3333	> 4.3333	> 0.8819	> 5.0000	> 1.0000	> 5.6667	> 1.8559	> 4.8333	> 0.5882
Tantalum (Ta)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Tellurium (Te)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Terbium (Tb)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Thallium (Tl)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Thorium (Th)	< 0.0060	> 0.0020	< 0.0060	> 0.0010	< 0.0070	> 0.0015	< 0.0070	> 0.0030	< 0.0065	> 0.0009
Thulium (Tm)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Tin (Sn)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Titanium (Ti)	< 0.0087	> 0.0058	0.0167	0.0033	0.0233	0.0033	0.0160	0.0070	< 0.0162	> 0.0027
Tungsten (W)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0027	> 0.0012	< 0.0014	> 0.0003
Uranium (U)	< 0.0047	> 0.0017	< 0.0047	> 0.0007	< 0.0057	> 0.0012	< 0.0063	> 0.0022	< 0.0055	> 0.0007
Vanadium (V)	0.0020	0.0000	< 0.0010	> 0.0000	0.0023	0.0003	< 0.0020	> 0.0000	< 0.0018	> 0.0002
Ytterbium (Yb)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Yttrium (Y)	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0010	> 0.0000	< 0.0013	> 0.0003	< 0.0011	> 0.0001
Zinc (Zn)	0.0123	0.0039	0.0130	0.0035	0.0467	0.0267	0.0170	0.0115	0.0225	0.0076
Zirconium (Zr)	< 0.0020	> 0.0006	0.0017	0.0007	0.0027	0.0003	0.0023	0.0003	< 0.0022	> 0.0002

Table (A)-2

Trace element concentration (ppm) in stream sediment samples collected during October 1976

	Site 1		Site 2		Site 3		Site 4		Overall	
Element	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Antimony (Sb)	1.33	0.33	0.53	0.03	0.97	0.03	< 1.57	> 0.72	< 1.10	> 0.21
Arsenic (As)	10.00	3.79	6.33	0.33	5.00	1.53	4.67	1.20	6.50	1.11
Barium (Ba)	> 900.00	> 100.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 975.00	> 25.00
Beryllium (Be)	< 0.47	> 0.27	0.10	0.00	0.10	0.00	0.27	0.17	< 0.23	> 0.08
Bismuth (Bi)	< 0.27	> 0.03	< 0.20	> 0.00	< 0.50	> 0.21	< 0.30	> 0.10	< 0.32	> 0.06
Boron (B)	8.33	3.18	1.67	0.67	3.00	1.00	6.67	3.18	4.92	1.28
Bromine (Br)	4.00	1.53	5.00	0.00	2.33	0.88	2.00	0.58	3.33	0.54
Cadmium (Cd)	< 0.37	> 0.15	< 0.23	> 0.03	< 0.43	> 0.09	< 0.47	> 0.22	< 0.38	> 0.07
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	24.00	10.02	32.00	2.89	35.00	8.89	22.33	0.88	28.33	3.34
Cesium (Cs)	2.00	0.00	2.33	0.88	1.67	0.33	1.63	0.37	1.91	0.23
Chlorine (Cl)	28.00	8.72	17.33	5.93	40.67	5.81	48.33	15.38	33.58	5.49
Chromium (Cr)	61.67	18.56	261.33	180.06	293.33	158.99	> 526.67	> 241.13	> 285.75	> 86.07
Cobalt (Co)	8.33	2.91	6.00	1.00	14.33	3.84	22.00	4.04	12.67	2.31
Copper (Cu)	26.67	3.71	25.33	9.49	49.00	16.50	33.67	7.54	33.67	5.26
Dysprosium (Dy)	< 1.30	> 0.85	1.67	0.33	3.67	0.88	< 1.33	> 0.83	< 1.99	> 0.44
Erbium (Er)	< 0.47	> 0.22	0.50	0.06	1.13	0.43	< 0.60	> 0.21	< 0.60	> 0.14
Europium (Eu)	0.63	0.19	0.60	0.15	0.83	0.17	0.73	0.22	0.70	0.08
Fluorine (F)	202.00	83.17	72.33	26.67	156.67	17.64	> 347.00	> 326.50	> 194.50	> 78.15
Gadolinium (Gd)	1.93	1.03	1.67	0.33	2.33	0.67	1.47	0.53	1.85	0.31
Gallium (Ga)	18.67	3.28	13.67	3.71	29.33	4.84	27.33	4.91	22.25	2.64
Germanium (Ge)	1.13	0.47	0.37	0.12	0.73	0.13	0.70	0.06	0.73	0.14
Gold (Au)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03

Table (A)-2

Trace element concentration (ppm) in stream sediment samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Hafnium (Hf)	< 0.40	> 0.06	< 0.20	> 0.00	< 0.30	> 0.06	< 0.57	> 0.23	< 0.37	> 0.07
Holmium (Ho)	< 0.87	> 0.57	0.87	0.07	1.67	0.67	< 0.57	> 0.18	< 0.99	> 0.23
Iodine (I)	1.93	1.03	1.67	0.33	0.87	0.07	< 8.63	> 8.18	< 3.28	> 2.00
Iridium (Ir)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Iron (Fe)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Lanthanum (La)	17.00	4.51	37.33	6.01	41.67	8.45	14.00	2.08	27.50	4.41
Lead (Pb)	< 4.33	> 0.33	< 4.67	> 0.67	< 4.67	> 0.67	< 4.00	> 0.00	< 4.42	> 0.23
Lithium (Li)	37.33	31.38	2.60	1.25	4.00	1.53	3.67	2.19	11.90	8.05
Lutetium (Lu)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.33	> 0.07	< 0.30	> 0.10	< 0.28	> 0.04
Magnesium (Mg)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Manganese (Mn)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 533.33	> 237.86	> 856.67	> 143.33	> 847.50	> 82.51
Mercury (Hg)	0.16	0.02	0.14	0.01	0.13	0.02	0.11	0.00	0.14	0.01
Molybdenum (Mo)	1.83	1.09	1.17	0.44	1.33	0.33	2.23	0.96	1.64	0.36
Neodymium (Nd)	8.67	2.73	7.67	1.45	9.33	0.67	8.00	2.52	8.42	0.88
Nickel (Ni)	32.00	11.79	29.33	5.78	156.33	45.17	118.33	36.78	84.00	20.91
Niobium (Nb)	17.67	10.68	13.00	3.06	12.30	6.15	14.00	2.08	14.24	2.81
Osmium (Os)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Palladium (Pd)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Phosphorus (P)	> 1000.00	> 0.00	> 790.00	> 127.41	> 910.00	> 90.00	> 976.67	> 23.33	> 919.17	> 41.66
Platinum (Pt)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Potassium (K)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Praseodymium (Pr)	5.00	2.00	3.67	0.88	5.00	0.00	3.67	1.20	4.33	0.57
Rhenium (Re)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Rhodium (Rh)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Rubidium (Rb)	40.33	15.76	21.00	6.24	45.33	16.41	49.67	15.68	39.08	6.88

Table (A)-2

Trace element concentration (ppm) in stream sediment samples (continued)

Element	Site 1 Mean	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Overall Mean	Overall Std err
Ruthenium (Ru)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Samarium (Sm)	4.33	1.86	4.00	1.53	6.67	2.33	4.33	1.76	4.83	0.87
Scandium (Sc)	18.67	12.33	4.33	1.86	7.33	2.33	15.67	3.76	11.50	3.33
Selenium (Se)	2.83	1.30	< 1.13	> 0.47	1.67	0.67	2.53	1.30	< 2.04	> 0.47
Silicon (Si)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Silver (Ag)	4.33	2.33	< 1.80	> 1.60	3.00	0.58	< 7.97	> 7.52	< 4.28	> 1.05
Sodium (Na)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Strontium (Sr)	> 560.00	> 224.80	340.00	110.00	> 653.33	> 211.53	523.33	43.33	> 519.17	> 78.38
Sulfur (S)	176.67	73.11	99.00	6.66	86.67	40.07	> 486.67	> 265.85	> 212.25	> 76.95
Tantalum (Ta)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.33	> 0.09	< 0.28	> 0.03
Tellurium (Te)	< 0.27	> 0.09	< 0.23	> 0.03	< 0.30	> 0.06	< 0.37	> 0.09	< 0.29	> 0.03
Terbium (Tb)	0.53	0.23	0.40	0.06	0.77	0.19	0.53	0.22	0.56	0.09
Thallium (Tl)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Thorium (Th)	< 5.00	> 3.06	5.67	0.88	< 5.00	> 1.53	< 4.67	> 1.45	< 5.08	> 0.82
Thulium (Tm)	< 0.27	> 0.09	< 0.13	> 0.03	< 0.30	> 0.06	< 0.30	> 0.10	< 0.25	> 0.04
Tin (Sn)	> 561.67	> 264.83	49.67	22.81	> 646.67	> 191.95	111.67	89.34	> 342.42	> 107.72
Titanium (Ti)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Tungsten (W)	< 0.27	> 0.09	< 0.20	> 0.00	< 0.30	> 0.06	< 0.30	> 0.10	< 0.27	> 0.03
Uranium (U)	< 4.33	> 2.33	3.67	1.20	< 3.00	> 0.58	< 3.00	> 1.00	< 3.50	> 0.63
Vanadium (V)	56.33	11.72	184.00	113.00	189.00	106.60	186.67	39.30	154.00	38.25
Ytterbium (Yb)	< 0.37	> 0.03	< 0.20	> 0.00	< 0.87	> 0.57	< 0.30	> 0.10	< 0.43	> 0.15
Yttrium (Y)	26.33	14.62	19.00	6.11	11.67	3.18	28.67	5.61	21.42	4.16
Zinc (Zn)	42.33	4.06	36.33	4.67	92.00	16.77	118.00	36.56	72.17	13.47
Zirconium (Zr)	86.33	37.09	77.33	16.33	157.00	62.07	121.00	31.37	110.42	19.61

Table (A)-3

Trace element concentration (ppm) in fish samples collected during October 1976

Element	Site 1		Site 2		Site 3 *		Site 4		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	3.33	1.86	4.33	1.45			> 69.33	> 65.36	> 25.67	> 21.81
Antimony (Sb)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Arsenic (As)	< 0.43	> 0.03	< 0.53	> 0.09			< 0.33	> 0.07	< 0.43	> 0.04
Barium (Ba)	23.67	20.19	7.00	2.52			8.67	1.86	13.11	6.46
Beryllium (Be)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Bismuth (Bi)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Boron (B)	1.90	1.05	1.03	0.49			0.97	0.52	1.30	0.40
Bromine (Br)	24.00	5.69	16.67	1.20			22.67	10.49	21.11	3.64
Cadmium (Cd)	< 0.30	> 0.06	< 0.17	> 0.03			< 0.30	> 0.12	< 0.26	> 0.04
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00			> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	< 0.23	> 0.03	< 0.17	> 0.03			< 0.20	> 0.06	< 0.20	> 0.02
Cesium (Cs)	< 0.17	> 0.03	< 0.10	> 0.00			< 0.13	> 0.03	< 0.13	> 0.02
Chlorine (Cl)	> 963.33	> 36.67	> 1000.00	> 0.00			> 793.33	> 206.67	> 918.89	> 60.44
Chromium (Cr)	9.83	8.59	2.67	0.88			3.53	2.74	5.34	2.05
Cobalt (Co)	0.37	0.15	< 0.30	> 0.20			0.37	0.03	< 0.34	> 0.07
Copper (Cu)	4.67	0.88	4.33	0.67			4.00	1.00	4.33	0.44
Dysprosium (Dy)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Erbium (Er)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Europium (Eu)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Fluorine (F)	74.33	28.37	145.00	73.65			63.33	30.82	94.22	27.60
Gadolinium (Gd)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Gallium (Ga)	< 0.80	> 0.60	< 0.33	> 0.15			< 0.43	> 0.13	< 0.52	> 0.20
Germanium (Ge)	< 0.30	> 0.10	< 0.17	> 0.03			< 0.17	> 0.03	< 0.21	> 0.04
Gold (Au)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01

Table (A)-3

Trace element concentration (ppm) in fish samples (continued)

Element	Site 1 Mean	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 * Mean	Site 3 * Std err	Site 4 Mean	Site 4 Std err	Overall Mean	Overall Std err
Hafnium (Hf)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Holmium (Ho)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Iodine (I)	0.77	0.13	0.47	0.17			0.57	0.12	0.60	0.08
Iridium (Ir)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Iron (Fe)	36.33	10.60	45.67	13.48			70.00	14.36	50.67	0.19
Lanthanum (La)	< 0.47	> 0.03	< 0.17	> 0.03			< 0.27	> 0.12	< 0.30	> 0.06
Lead (Pb)	< 2.00	> 0.00	< 2.17	> 0.17			< 2.50	> 0.50	< 2.22	> 0.17
Lithium (Li)	< 0.10	> 0.00	< 0.10	> 0.00			< 0.13	> 0.03	< 0.11	> 0.01
Lutetium (Lu)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Magnesium (Mg)	> 1000.00	> 0.00	> 1000.00	> 0.00			> 1000.00	> 0.00	> 1000.00	> 0.00
Manganese (Mn)	13.67	6.89	27.33	10.33			11.67	4.41	17.56	6.30
Mercury (Hg)	< 0.08	> 0.04	0.06	0.02			< 0.02	> 0.00	< 0.05	> 0.01
Molybdenum (Mo)	4.00	0.58	4.67	0.33			4.00	1.15	4.22	0.40
Neodymium (Nd)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Nickel (Ni)	4.00	2.08	0.93	0.03			3.67	1.20	2.87	0.05
Niobium (Nb)	< 0.40	> 0.10	< 0.40	> 0.25			< 0.43	> 0.20	< 0.41	> 0.10
Osmium (Os)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Palladium (Pd)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Phosphorus (P)	> 1000.00	> 0.00	> 1000.00	> 0.00			> 1000.00	> 0.00	> 1000.00	> 0.00
Platinum (Pt)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Potassium (K)	> 940.00	> 60.00	> 1000.00	> 0.00			> 1000.00	> 0.00	> 980.00	> 20.00
Praesodymium (Pr)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Rhenium (Re)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Rhodium (Rh)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Rubidium (Rb)	7.67	3.18	6.00	0.58			4.67	1.20	6.11	1.09

Table (A)-3
Trace element concentration (ppm) in fish samples (continued)

Element	Site 1		Site 2		Site 3 *		Site 4		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Ruthenium (Ru)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Samarium (Sm)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Scandium (Sc)	< 0.13	> 0.03	< 0.10	> 0.00			< 0.10	> 0.00	< 0.11	> 0.01
Selenium (Se)	< 0.70	> 0.15	< 0.67	> 0.17			< 0.70	> 0.21	< 0.69	> 0.09
Silicon (Si)	102.00	33.13	48.33	8.01			165.33	60.24	105.22	26.17
Silver (Ag)	2.67	0.67	2.67	0.67			0.53	0.23	1.96	0.45
Sodium (Na)	> 533.33	> 39.30	> 496.67	> 32.83			> 426.67	> 83.33	> 485.56	> 32.28
Strontium (Sr)	98.67	80.00	22.00	4.93			28.67	7.69	49.78	26.48
Sulfur (S)	> 1000.00	> 0.00	> 1000.00	> 0.00			> 873.33	> 126.67	> 957.78	> 42.22
Tantalum (Ta)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Tellurium (Te)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.20	> 0.06	< 0.19	> 0.02
Terbium (Tb)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Thallium (Tl)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Thorium (Th)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Thulium (Tm)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Tin (Sn)	< 0.20	> 0.00	< 0.27	> 0.07			3.67	1.67	< 1.38	> 0.75
Titanium (Ti)	10.33	6.44	5.33	0.33			4.00	1.00	6.56	2.12
Tungsten (W)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Uranium (U)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Vanadium (V)	0.97	0.55	1.23	0.88			0.27	0.03	0.82	0.33
Ytterbium (Yb)	< 0.20	> 0.00	< 0.17	> 0.03			< 0.17	> 0.03	< 0.18	> 0.01
Yttrium (Y)	< 0.13	> 0.03	< 0.13	> 0.03			< 0.17	> 0.07	< 0.14	> 0.02
Zinc (Zn)	81.67	23.51	94.33	37.97			67.33	24.26	81.11	15.18
Zirconium (Zr)	0.67	0.18	< 0.60	> 0.21			< 0.47	> 0.09	< 0.58	> 0.09

* Fish samples not collected at Site 3.

Table (A)-4
Trace element concentration (ppm) in soil samples collected during October 1976

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Antimony (Sb)	< 0.53	> 0.23	< 1.40	> 0.60	< 0.27	> 0.03	< 0.27	> 0.03	< 0.40	> 0.15	< 0.57	> 0.16
Arsenic (As)	4.33	0.88	8.33	2.33	3.00	1.53	5.00	0.58	3.67	0.67	4.87	0.72
Barium (Ba)	> 936.67	> 63.33	> 926.67	> 73.33	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 972.67	> 18.68
Beryllium (Be)	0.53	0.24	0.43	0.28	0.30	0.10	< 0.33	> 0.15	< 0.43	> 0.17	< 0.41	> 0.08
Bismuth (Bi)	< 0.30	> 0.00	< 0.33	> 0.09	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.27	> 0.03
Boron (B)	6.33	0.67	15.00	6.00	3.00	1.00	11.67	3.76	8.67	4.33	8.93	1.80
Bromine (Br)	6.67	0.88	3.33	0.88	2.67	1.20	6.00	1.00	1.67	0.33	4.07	0.62
Cadmium (Cd)	< 0.57	> 0.03	< 0.43	> 0.07	< 0.33	> 0.09	< 1.13	> 0.45	< 0.43	> 0.17	< 0.58	> 0.11
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	28.00	14.19	33.67	4.91	31.67	12.57	23.67	9.84	59.00	45.51	35.20	9.16
Cesium (Cs)	7.33	2.73	1.33	0.33	1.93	1.03	2.33	0.67	1.30	0.35	2.85	0.80
Chlorine (Cl)	236.67	48.07	62.00	11.00	64.67	22.70	276.67	180.03	54.33	22.53	138.87	41.20
Chromium (Cr)	88.33	11.89	154.33	39.65	530.00	162.89	82.67	37.78	380.00	240.00	247.07	68.98
Cobalt (Co)	13.33	1.67	12.00	1.53	21.33	11.35	10.67	0.33	7.33	1.45	12.93	2.33
Copper (Cu)	40.33	21.17	58.33	11.26	37.67	20.19	34.33	12.00	65.00	52.56	47.13	11.03
Dysprosium (Dy)	< 1.10	> 0.49	2.67	0.33	1.33	0.33	2.67	0.67	< 1.10	> 0.49	< 1.77	> 0.27
Erbium (Er)	< 0.30	> 0.00	1.17	0.43	< 0.43	> 0.24	< 0.40	> 0.15	< 0.40	> 0.10	< 0.54	> 0.12
Europium (Eu)	0.57	0.12	1.20	0.40	1.03	0.50	0.67	0.13	0.73	0.15	0.84	0.13
Fluorine (F)	216.67	43.72	> 466.67	> 268.22	43.67	19.94	221.67	112.04	89.00	41.00	> 207.53	> 63.84
Gadolinium (Gd)	< 0.70	> 0.21	2.33	0.33	1.50	0.50	1.60	0.40	0.90	0.10	< 1.41	> 0.20
Gallium (Ga)	21.67	3.33	18.67	0.33	31.67	16.23	25.33	12.14	14.67	5.36	22.40	3.91
Germanium (Ge)	0.93	0.07	< 0.57	> 0.23	0.60	0.21	0.73	0.27	0.63	0.09	< 0.69	> 0.08
Gold (Au)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02

Table (A)-4
Trace element concentration (ppm) in soil samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Hafnium (Hf)	< 0.30	> 0.00	< 1.17	> 0.92	< 0.20	> 0.06	< 0.83	> 0.58	< 0.37	> 0.07	< 0.57	> 0.21
Holmium (Ho)	< 0.47	> 0.17	1.33	0.33	0.73	0.12	1.23	0.39	< 0.70	> 0.21	< 0.09	> 0.15
Iodine (I)	< 1.77	> 0.79	0.80	0.20	1.40	0.80	1.47	0.79	< 0.33	> 0.15	< 1.15	> 0.27
Iridium (Ir)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Iron (Fe)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Lanthanum (La)	31.33	14.52	31.67	14.24	30.00	15.53	15.00	5.86	57.33	40.83	33.07	8.98
Lead (Pb)	10.00	1.00	7.67	0.33	4.00	0.58	11.33	0.67	5.67	0.33	7.73	0.76
Lithium (Li)	31.33	24.88	13.67	6.69	7.00	2.65	11.60	7.49	8.33	2.67	14.39	5.15
Lutetium (Lu)	< 0.30	> 0.00	< 0.30	> 0.06	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.26	> 0.02
Magnesium (Mg)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Manganese (Mn)	> 1000.00	> 0.00	> 993.33	> 6.67	> 1000.00	> 0.00	> 906.67	> 93.33	> 826.67	> 173.33	> 945.33	> 38.07
Mercury (Hg)	0.16	0.02	0.07	0.03	0.07	0.01	0.09	0.01	0.04	0.00	0.09	0.01
Molybdenum (Mo)	3.00	0.50	3.00	1.53	2.33	0.67	5.00	1.00	1.00	0.00	2.67	0.49
Neodymium (Nd)	7.67	0.33	9.00	1.00	7.67	3.28	7.67	3.18	18.33	11.86	10.07	2.43
Nickel (Ni)	42.33	7.31	60.00	30.45	60.00	30.45	36.33	13.78	29.00	6.43	45.53	8.51
Niobium (Nb)	9.33	2.33	17.33	6.74	16.33	6.98	15.33	7.80	8.67	0.33	13.40	2.36
Osmium (Os)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Palladium (Pd)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Phosphorus (P)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 756.67	> 243.33	> 951.33	> 40.67
Platinum (Pt)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Potassium (K)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Praseodymium (Pr)	5.67	0.88	5.00	1.00	5.67	2.33	4.00	1.53	15.00	12.01	6.67	2.38
Rhenium (Re)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Rhodium (Rh)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Rubidium (Rb)	64.33	1.20	37.67	10.40	74.33	48.03	52.00	26.00	44.67	10.20	54.60	10.19

Table (A)-4

Trace element concentration (ppm) in soil samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Ruthenium (Ru)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Samarium (Sm)	2.67	0.67	6.67	2.67	6.00	3.06	3.33	0.67	3.00	0.00	4.33	0.03
Scandium (Sc)	8.67	1.67	14.00	3.00	8.67	4.18	48.33	32.11	17.67	4.33	19.47	6.02
Selenium (Se)	< 2.97	> 2.02	2.00	1.00	2.33	0.88	< 1.27	> 0.37	2.33	0.33	< 2.18	> 0.44
Silicon (Si)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Silver (Ag)	< 1.27	> 0.87	< 1.03	> 0.50	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.60	> 0.21
Sodium (Na)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Strontium (Sr)	463.33	226.00	233.33	43.33	> 566.67	> 227.47	206.67	54.87	400.00	115.47	> 378.00	> 69.65
Sulfur (S)	230.00	5.77	123.33	34.80	75.33	52.34	> 783.33	> 216.67	48.67	14.95	> 252.13	> 82.31
Tantalum (Ta)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Tellurium (Te)	< 0.53	> 0.23	< 0.33	> 0.09	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.31	> 0.06
Terbium (Tb)	< 0.30	> 0.00	0.67	0.18	0.40	0.12	0.50	0.10	0.37	0.03	< 0.45	> 0.05
Thallium (Tl)	< 0.30	> 0.00	< 0.50	> 0.25	< 0.20	> 0.06	< 0.27	> 0.03	< 0.27	> 0.03	< 0.31	> 0.05
Thorium (Th)	< 4.67	> 0.67	7.33	2.40	4.67	1.76	< 5.00	> 1.73	< 5.33	> 0.88	< 5.40	> 0.67
Thulium (Tm)	< 0.30	> 0.00	< 0.23	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.23	> 0.07	< 0.25	> 0.02
Tin (Sn)	> 337.33	> 331.33	24.33	14.44	23.33	9.91	5.33	2.60	35.67	25.10	> 85.20	> 65.61
Titanium (Ti)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 943.33	> 56.67	> 1000.00	> 0.00	> 988.67	> 11.33
Tungsten (W)	< 0.30	> 0.00	< 0.27	> 0.03	< 0.20	> 0.06	< 0.27	> 0.03	< 0.30	> 0.00	< 0.27	> 0.02
Uranium (U)	< 4.33	> 1.33	4.33	1.33	< 3.00	> 1.15	< 3.67	> 0.88	< 2.67	> 0.88	< 3.60	> 0.47
Vanadium (V)	386.67	124.14	277.67	108.04	376.67	107.45	194.00	125.04	253.00	158.50	297.60	51.56
Ytterbium (Yb)	< 0.30	> 0.00	< 1.43	> 0.57	< 0.20	> 0.06	< 0.27	> 0.03	< 0.40	> 0.10	< 0.52	> 0.16
Yttrium (Y)	20.33	4.18	35.00	14.11	16.00	4.16	15.00	4.00	15.33	7.84	20.33	3.61
Zinc (Zn)	115.67	42.69	92.33	19.97	225.67	130.60	220.00	68.07	82.00	0.00	147.13	31.06
Zirconium (Zr)	103.67	21.53	76.00	22.48	155.33	107.34	> 385.00	> 308.48	60.67	11.84	> 156.13	> 63.95

Table (A)-5

Trace element concentration (ppm) in shrub samples collected during October 1976

Element	Site 1 Mean	Site 1 Std err	Site 2 Mean	Site 2 Std err	Site 3 Mean	Site 3 Std err	Site 4 Mean	Site 4 Std err	Site 5 Mean	Site 5 Std err	Overall Mean	Overall Std err
Aluminum (Al)	> 53.33	> 13.30	53.00	29.14	> 29.00	> 22.07	> 71.33	> 14.75	> 80.67	> 35.41	> 57.47	> 10.38
Antimony (Sb)	< 0.40	> 0.25	< 0.50	> 0.26	< 0.20	> 0.06	< 0.17	> 0.03	< 0.20	> 0.00	< 0.29	> 0.07
Arsenic (As)	< 0.60	> 0.15	< 0.97	> 0.52	< 0.37	> 0.03	< 0.60	> 0.12	< 0.47	> 0.07	< 0.60	> 0.11
Barium (Ba)	71.67	5.84	24.33	1.33	45.67	9.33	104.00	28.59	193.33	41.77	87.80	18.06
Beryllium (Be)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Bismuth (Bi)	< 0.80	> 0.60	< 0.30	> 0.15	< 0.27	> 0.12	< 0.23	> 0.03	< 0.17	> 0.03	< 0.35	> 0.12
Boron (B)	10.67	2.03	11.67	0.88	46.67	13.28	16.67	3.71	111.00	40.05	39.33	12.47
Bromine (Br)	3.00	0.58	1.27	0.37	3.33	0.33	7.00	4.51	3.67	0.88	3.65	0.93
Cadmium (Cd)	< 0.87	> 0.13	< 0.33	> 0.07	< 0.30	> 0.10	< 0.83	> 0.09	< 0.47	> 0.09	< 0.56	> 0.07
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	< 0.17	> 0.07	0.27	0.12	< 0.20	> 0.06	0.20	0.00	0.13	0.03	< 0.19	> 0.03
Cesium (Cs)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.10	> 0.00	< 0.10	> 0.00	< 0.10	> 0.00	< 0.11	> 0.01
Chlorine (Cl)	106.67	72.00	56.33	11.39	204.67	91.11	196.67	40.55	556.67	107.13	220.20	55.31
Chromium (Cr)	2.00	0.00	1.67	0.33	9.00	5.29	3.33	0.88	6.00	3.21	4.40	1.29
Cobalt (Co)	0.43	0.12	3.93	2.56	4.00	1.53	0.93	0.07	1.43	0.81	2.15	0.66
Copper (Cu)	100.00	90.00	31.33	13.53	14.33	3.84	10.67	1.76	21.33	4.26	35.53	17.76
Dysprosium (Dy)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Erbium (Er)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Europium (Eu)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Fluorine (F)	263.33	78.81	110.67	19.80	78.00	37.32	> 706.67	> 293.33	115.00	37.75	> 254.73	> 81.66
Gadolinium (Gd)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Gallium (Ga)	0.13	0.03	< 0.17	> 0.03	0.13	0.03	0.27	0.17	< 0.20	> 0.10	< 0.18	> 0.04
Germanium (Ge)	< 0.13	> 0.03	< 0.13	> 0.03	< 0.17	> 0.07	< 0.13	> 0.03	< 0.17	> 0.07	< 0.15	> 0.02
Gold (Au)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02

Table (A)-5

Trace element concentration (ppm) in shrub samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Hafnium (Hf)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Holmium (Ho)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Iodine (I)	0.37	0.03	0.17	0.03	< 0.27	> 0.03	0.27	0.03	0.33	0.13	< 0.28	> 0.03
Iridium (Ir)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Iron (Fe)	123.00	41.22	56.67	5.17	86.67	29.29	141.00	29.57	138.33	61.87	109.13	16.06
Lanthanum (La)	< 0.23	> 0.09	< 0.23	> 0.07	< 0.33	> 0.19	0.37	0.03	0.33	0.09	< 0.30	> 0.04
Lead (Pb)	5.67	1.20	10.00	4.04	< 3.00	> 0.58	< 3.00	> 1.00	5.00	0.58	< 5.33	> 1.01
Lithium (Li)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.10	> 0.00	0.43	0.28	0.27	0.12	< 0.21	> 0.06
Lutetium (Lu)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Magnesium (Mg)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Manganese (Mn)	117.67	13.62	21.00	8.00	160.00	73.71	219.33	76.34	> 456.67	> 271.00	> 194.93	> 62.94
Mercury (Hg)	0.07	0.00	0.10	0.01	0.04	0.00	0.05	0.01	0.10	0.02	0.07	0.01
Molybdenum (Mo)	5.00	2.00	4.00	1.00	5.00	1.53	6.67	2.67	5.00	0.58	5.13	0.69
Neodymium (Nd)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.13	> 0.03	< 0.14	> 0.02
Nickel (Ni)	2.67	0.33	9.33	5.33	10.67	5.04	5.33	0.88	12.67	4.06	8.13	1.73
Niobium (Nb)	< 0.13	> 0.03	< 0.13	> 0.03	< 0.17	> 0.07	< 0.17	> 0.03	< 0.13	> 0.03	< 0.15	> 0.02
Osmium (Os)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Palladium (Pd)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Phosphorus (P)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Platinum (Pt)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Potassium (K)	> 966.67	> 33.33	> 668.67	> 331.33	> 966.67	> 33.33	> 1000.00	> 0.00	> 1000.00	> 0.00	> 920.40	> 65.93
Praesodymium (Pr)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Rhenium (Re)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Rhodium (Rh)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Rubidium (Rb)	3.00	1.53	0.90	0.06	1.33	0.33	3.33	0.33	0.50	0.06	1.01	0.41

Table (A)-5
Trace element concentration (ppm) in shrub samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Ruthenium (Ru)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Samarium (Sm)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Scandium (Sc)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.23	> 0.09	< 0.13	> 0.03	< 0.15	> 0.02
Selenium (Se)	< 0.40	> 0.15	< 0.30	> 0.00	< 0.43	> 0.19	0.40	0.06	< 0.43	> 0.03	< 0.39	> 0.04
Silicon (Si)	> 463.33	> 260.35	381.67	274.26	> 636.67	> 223.33	> 470.00	> 265.39	> 1000.00	> 0.00	> 590.33	> 105.51
Silver (Ag)	< 0.37	> 0.22	< 0.23	> 0.09	< 0.17	> 0.07	0.10	0.06	< 0.10	> 0.00	< 0.19	> 0.05
Sodium (Na)	> 152.33	> 48.02	122.00	79.25	82.33	53.87	> 206.67	> 29.06	> 283.33	> 28.48	> 169.33	> 26.93
Strontium (Sr)	26.33	1.76	101.67	29.28	87.00	7.51	44.33	11.84	273.33	63.33	106.53	26.37
Sulfur (S)	> 446.67	> 43.33	> 700.00	> 35.12	> 690.00	> 162.58	> 860.00	> 120.55	> 600.00	> 70.24	> 675.33	> 51.44
Tantalum (Ta)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Tellurium (Te)	< 0.13	> 0.03	< 0.20	> 0.06	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.15	> 0.02
Terbium (Tb)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Thallium (Tl)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Thorium (Th)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Thulium (Tm)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Tin (Sn)	> 345.00	> 327.60	> 883.33	> 116.67	61.33	33.22	> 398.67	> 305.32	25.33	22.34	> 342.73	> 113.82
Titanium (Ti)	5.00	1.53	5.67	2.19	5.67	1.76	10.67	5.67	9.33	3.76	7.27	1.41
Tungsten (W)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Uranium (U)	< 0.70	> 0.15	< 0.60	> 0.25	< 0.93	> 0.56	< 0.63	> 0.23	< 0.77	> 0.07	< 0.73	> 0.12
Vanadium (V)	0.27	0.03	< 0.17	> 0.03	0.43	0.23	0.37	0.12	0.27	0.09	< 0.30	> 0.05
Ytterbium (Yb)	< 0.13	> 0.03	< 0.10	> 0.00	< 0.17	> 0.07	< 0.17	> 0.03	< 0.10	> 0.00	< 0.13	> 0.02
Yttrium (Y)	< 0.13	> 0.03	< 0.13	> 0.03	< 0.13	> 0.03	< 0.13	> 0.03	< 0.10	> 0.00	< 0.13	> 0.01
Zinc (Zn)	106.67	30.44	156.67	3.33	69.00	30.99	313.33	63.33	383.33	47.02	221.00	33.94
Zirconium (Zr)	0.33	0.07	0.33	0.09	0.50	0.17	0.33	0.09	0.63	0.15	0.43	0.06

Table (A)-6

Trace element concentration (ppm) in grass samples collected during October 1976

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	55.33	38.32	97.67	46.17	52.33	38.96	13.00	2.00	> 147.00	> 68.55	> 73.07	> 20.72
Antimony (Sb)	< 0.23	> 0.03	< 0.47	> 0.09	< 0.30	> 0.06	< 0.20	> 0.00	< 0.37	> 0.03	< 0.31	> 0.03
Arsenic (As)	< 0.50	> 0.21	< 1.83	> 1.09	0.40	0.06	0.23	0.03	0.33	0.03	< 0.66	> 0.25
Barium (Ba)	102.33	18.89	186.80	135.35	56.33	5.70	121.67	7.26	100.67	25.83	113.56	26.15
Beryllium (Be)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Bismuth (Bi)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Boron (B)	2.67	0.67	3.00	1.00	2.33	0.33	5.00	1.53	2.33	0.88	3.07	0.45
Bromine (Br)	1.30	0.35	19.00	17.00	1.90	0.67	2.33	0.33	1.27	0.37	5.16	3.42
Cadmium (Cd)	< 0.27	> 0.03	< 0.33	> 0.03	< 0.30	> 0.06	< 0.30	> 0.12	< 0.37	> 0.03	< 0.31	> 0.03
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	0.17	0.03	< 0.37	> 0.12	0.23	0.03	0.30	0.06	< 1.03	> 0.50	< 0.42	> 0.12
Cesium (Cs)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Chlorine (Cl)	197.67	122.71	187.67	82.86	124.00	88.43	54.33	18.55	22.00	5.03	117.13	34.79
Chromium (Cr)	3.67	1.20	8.33	2.33	3.67	1.20	< 1.10	> 0.47	6.67	1.67	< 4.69	> 0.09
Cobalt (Co)	< 0.23	> 0.03	< 0.53	> 0.24	< 0.27	> 0.07	< 0.20	> 0.00	< 0.30	> 0.06	< 0.31	> 0.05
Copper (Cu)	5.33	1.45	13.67	4.48	6.33	2.85	4.67	0.88	6.67	0.33	7.33	1.28
Dysprosium (Dy)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Erbium (Er)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Europium (Eu)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Fluorine (F)	29.00	12.49	24.00	1.53	22.00	6.51	14.00	1.53	13.33	2.19	20.47	2.92
Gadolinium (Gd)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Gallium (Ga)	0.33	0.03	0.40	0.06	0.43	0.09	0.20	0.00	0.47	0.17	0.37	0.04
Germanium (Ge)	< 0.13	> 0.03	< 0.23	> 0.03	< 0.17	> 0.03	< 0.17	> 0.03	< 0.20	> 0.00	< 0.18	> 0.01
Gold (Au)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01

Table (A)-6

Trace element concentration (ppm) in grass samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Hafnium (Hf)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Holmium (Ho)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Iodine (I)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.47	> 0.27	< 0.20	> 0.00	< 0.25	> 0.05
Iridium (Ir)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Iron (Fe)	101.67	45.73	207.67	23.21	230.00	190.01	152.33	38.97	210.00	73.71	180.33	38.25
Lanthanum (La)	< 0.25	> 0.03	< 0.40	> 0.12	< 0.20	> 0.00	< 0.30	> 0.06	< 0.67	> 0.24	< 0.36	> 0.06
Lead (Pb)	< 4.00	> 0.00	< 21.67	> 15.71	< 4.00	> 0.00	< 4.00	> 0.00	< 4.00	> 0.00	< 7.53	> 3.26
Lithium (Li)	< 0.14	> 0.06	< 0.27	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.17	> 0.03	< 0.19	> 0.02
Lutetium (Lu)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Magnesium (Mg)	> 1000.00	> 0.00	> 766.67	> 233.33	> 783.33	> 216.67	> 1000.00	> 0.00	> 1000.00	> 0.00	> 910.00	> 61.37
Manganese (Mn)	49.00	16.01	107.00	53.11	52.33	10.49	> 432.00	> 284.60	111.33	54.70	> 150.33	> 62.90
Mercury (Hg)	0.19	0.03	0.12	0.02	0.18	0.08	0.12	0.01	0.08	0.00	0.14	0.02
Molybdenum (Mo)	5.00	0.58	11.00	3.79	6.33	0.88	4.00	0.58	4.33	1.20	6.13	0.98
Neodymium (Nd)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.23	> 0.03	< 0.30	> 0.10	< 0.23	> 0.02
Nickel (Ni)	3.00	0.58	9.00	1.53	1.35	0.65	< 2.73	> 2.15	4.00	1.00	< 4.02	> 0.86
Niobium (Nb)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.23	> 0.03	< 0.17	> 0.03	< 0.27	> 0.03	< 0.21	> 0.02
Osmium (Os)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Palladium (Pd)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Phosphorus (P)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Platinum (Pt)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Potassium (K)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Praesodymium (Pr)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.27	> 0.07	< 0.21	> 0.02
Rhenium (Re)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Rhodium (Rh)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Rubidium (Rb)	2.63	0.91	< 0.97	> 0.52	1.37	0.82	3.67	0.33	0.47	0.18	< 1.82	> 0.39

Table (A)-6

Trace element concentration (ppm) in grass samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Ruthenium (Ru)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Samarium (Sm)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Scandium (Sc)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Selenium (Se)	< 2.23	> 1.30	< 2.30	> 0.70	< 3.33	> 1.33	< 0.93	> 0.54	< 6.67	> 2.33	< 3.09	> 0.74
Silicon (Si)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Silver (Ag)	< 0.13	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Sodium (Na)	102.33	88.85	28.00	13.61	20.00	9.02	34.33	4.84	230.67	174.69	83.07	39.45
Strontium (Sr)	19.00	2.52	45.67	18.89	19.00	5.00	13.33	1.86	27.33	8.25	24.87	4.72
Sulfur (S)	543.33	180.22	> 493.33	> 257.51	> 620.00	> 294.62	< 776.67	> 97.35	258.67	81.62	< 538.40	> 88.41
Tantalum (Ta)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Tellurium (Te)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Terbium (Tb)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Thallium (Tl)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Thorium (Th)	< 0.17	> 0.03	< 0.23	> 0.03	< 1.40	> 0.60	< 0.17	> 0.03	< 0.80	> 0.60	< 0.55	> 0.19
Thulium (Tm)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Tin (Sn)	10.33	4.98	131.33	65.38	31.02	29.50	23.67	11.41	161.33	149.40	71.54	32.64
Titanium (Ti)	5.00	0.58	41.67	5.46	6.00	0.00	7.00	3.06	28.33	13.30	17.60	4.68
Tungsten (W)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Uranium (U)	< 0.87	> 0.09	< 1.33	> 0.33	< 1.30	> 0.35	< 0.83	> 0.09	< 1.67	> 0.33	< 1.20	> 0.13
Vanadium (V)	0.43	0.09	1.60	0.70	< 0.27	> 0.07	0.80	0.60	0.67	0.24	< 0.75	> 0.20
Ytterbium (Yb)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.19	> 0.01
Yttrium (Y)	< 0.13	> 0.03	< 0.33	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	0.43	0.13	< 0.26	> 0.04
Zinc (Zn)	20.67	3.84	23.33	3.28	14.00	4.93	35.67	5.36	16.67	4.81	22.07	2.64
Zirconium (Zr)	0.63	0.09	0.87	0.13	0.80	0.12	0.33	0.09	1.50	0.76	0.83	0.17

Table (A)-7

Trace element concentration (ppm) in lichen samples collected during October 1976

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	> 186.67	> 13.35	> 216.67	> 51.75	> 170.00	> 20.00	> 196.67	> 3.33	> 161.33	> 39.10	> 186.27	> 12.02
Antimony (Sb)	< 0.37	> 0.03	< 0.33	> 0.13	< 0.27	> 0.03	< 0.33	> 0.03	< 0.47	> 0.12	< 0.35	> 0.04
Arsenic (As)	0.63	0.12	1.57	0.72	1.20	0.40	0.93	0.03	0.73	0.22	1.01	0.17
Barium (Ba)	55.33	7.84	63.33	11.22	68.33	3.84	101.67	35.04	63.33	13.53	70.40	9.15
Beryllium (Be)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Bismuth (Bi)	< 0.27	> 0.07	< 0.23	> 0.03	< 0.23	> 0.03	< 0.23	> 0.03	< 0.27	> 0.12	< 0.25	> 0.03
Boron (B)	1.57	0.45	1.80	1.11	2.57	0.98	1.83	1.08	2.27	0.93	2.01	0.37
Bromine (Br)	1.90	1.05	3.33	0.33	3.67	0.33	3.67	0.33	2.67	0.88	3.05	0.31
Cadmium (Cd)	< 0.33	> 0.03	< 0.40	> 0.06	< 0.33	> 0.03	< 0.30	> 0.00	< 0.33	> 0.03	< 0.34	> 0.02
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	1.23	0.38	5.33	2.40	2.27	0.93	2.00	0.58	1.33	0.33	2.43	0.61
Cesium (Cs)	< 0.17	> 0.03	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.23	> 0.03	< 0.19	> 0.01
Chlorine (Cl)	10.33	0.67	19.00	0.58	32.33	5.61	19.00	4.00	8.33	1.76	17.80	2.57
Chromium (Cr)	5.67	0.67	9.67	2.67	11.33	4.26	5.00	0.00	7.00	1.53	7.73	1.10
Cobalt (Co)	< 1.20	> 0.42	1.83	0.73	0.93	0.07	2.00	0.58	< 1.57	> 1.22	< 1.51	> 0.29
Copper (Cu)	12.00	7.51	9.67	4.26	8.67	0.88	16.33	4.70	32.33	9.33	15.80	5.26
Dysprosium (Dy)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Erbium (Er)	< 0.20	> 0.00	< 0.23	> 0.05	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Europium (Eu)	0.20	0.00	0.27	0.07	0.20	0.00	< 0.20	> 0.00	0.23	0.03	< 0.22	> 0.01
Fluorine (F)	16.00	1.15	157.00	116.52	49.00	20.03	46.67	9.84	52.00	34.00	64.13	24.52
Gadolinium (Gd)	< 0.20	> 0.00	< 0.33	> 0.09	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.23	> 0.02
Gallium (Ga)	0.40	0.10	0.83	0.17	0.47	0.07	0.40	0.10	< 0.60	> 0.21	< 0.54	> 0.07
Germanium (Ge)	< 0.17	> 0.03	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.23	> 0.03	< 0.21	> 0.01
Gold (Au)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01

Table (A)-7

Trace element concentration (ppm) in lichen samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Hafnium (Hf)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Holmium (Ho)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Iodine (I)	0.27	0.07	0.57	0.03	< 0.23 >	0.03	0.30	0.00	0.33	0.03	< 0.34 >	0.03
Iridium (Ir)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Iron (Fe)	573.33	136.42	570.00	173.88	593.33	124.41	386.67	83.53	443.33	112.15	513.33	53.71
Lanthanum (La)	0.87	0.07	4.67	1.20	1.53	0.47	0.93	0.07	0.87	0.09	1.77	0.45
Lead (Pb)	29.33	1.76	53.33	6.01	17.67	1.67	14.67	2.73	36.67	4.63	30.33	4.00
Lithium (Li)	0.67	0.18	0.57	0.23	0.53	0.12	0.60	0.21	< 0.37 >	0.09	< 0.55 >	0.07
Lutetium (Lu)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Magnesium (Mg)	> 1000.00 >	0.00	> 756.67 >	233.40	> 1000.00 >	0.00	> 1000.00 >	0.00	> 793.33 >	206.67	> 910.00 >	60.45
Manganese (Mn)	174.67	118.41	115.33	49.75	308.00	184.62	283.33	54.57	232.00	204.01	222.67	55.45
Mercury (Hg)	0.58	0.15	0.25	0.03	0.48	0.03	0.56	0.11	0.47	0.08	0.47	0.05
Molybdenum (Mo)	4.67	0.33	5.67	2.03	4.33	0.33	8.00	1.00	4.33	1.86	5.40	0.62
Neodymium (Nd)	0.53	0.09	1.90	1.05	0.60	0.10	0.57	0.12	0.60	0.06	0.84	0.23
Nickel (Ni)	3.33	0.88	4.67	1.20	6.00	2.00	6.67	1.33	6.33	1.67	5.40	0.65
Niobium (Nb)	< 0.27 >	0.03	< 0.57 >	0.17	< 0.37 >	0.03	< 0.43 >	0.15	< 0.23 >	0.03	< 0.37 >	0.05
Osmium (Os)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Palladium (Pd)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Phosphorus (P)	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00
Platinum (Pt)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Potassium (K)	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00
Praesodymium (Pr)	0.33	0.03	1.03	0.48	0.33	0.07	0.27	0.07	0.37	0.03	0.47	0.11
Rhenium (Re)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Rhodium (Rh)	< 0.20 >	0.00	< 0.23 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.06	< 0.21 >	0.01
Rubidium (Rb)	3.67	0.33	2.33	0.67	4.67	1.20	4.67	1.20	1.33	0.33	3.33	0.47

Table (A)-7
Trace element concentration (ppm) in lichen samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Ruthenium (Ru)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Samarium (Sm)	0.83	0.09	0.93	0.07	0.80	0.15	< 0.67	> 0.24	0.90	0.06	< 0.83	> 0.06
Scandium (Sc)	0.23	0.03	0.93	0.53	0.67	0.23	0.33	0.03	0.50	0.06	0.53	0.12
Selenium (Se)	< 1.07	> 0.47	< 1.47	> 0.53	< 1.17	> 0.43	< 0.67	> 0.07	< 1.10	> 0.45	< 1.09	> 0.17
Silicon (Si)	> 820.00	> 180.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 820.00	> 180.00	> 770.00	> 122.88	> 882.00	> 54.50
Silver (Ag)	< 0.20	> 0.00	< 0.20	> 0.06	< 0.20	> 0.00	< 0.20	> 0.00	< 0.23	> 0.03	< 0.21	> 0.01
Sodium (Na)	223.33	90.62	> 240.00	> 95.39	> 430.00	> 50.00	> 549.33	> 145.92	> 413.33	> 103.66	> 331.20	> 44.00
Strontium (Sr)	14.33	5.90	29.00	12.66	46.00	8.96	19.00	6.66	23.67	4.91	26.40	4.29
Sulfur (S)	130.67	43.06	300.00	95.04	430.00	190.00	240.00	85.05	> 394.00	> 305.61	> 298.93	> 71.04
Tantalum (Ta)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Tellurium (Te)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Terbium (Tb)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Thallium (Tl)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Thorium (Th)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Thulium (Tm)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Tin (Sn)	> 380.67	> 312.22	51.00	34.53	> 354.00	> 323.35	304.67	193.91	239.00	133.84	> 265.87	> 91.56
Titanium (Ti)	99.33	45.51	228.00	107.23	153.00	37.85	81.00	11.14	81.00	12.77	128.47	25.76
Tungsten (W)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Uranium (U)	< 1.00	> 0.00	< 1.33	> 0.33	< 0.97	> 0.03	< 1.00	> 0.00	< 1.67	> 0.33	< 1.19	> 0.11
Vanadium (V)	2.33	0.33	6.00	2.08	3.67	1.20	3.00	0.00	2.33	0.33	3.47	0.55
Ytterbium (Yb)	< 0.20	> 0.00	< 0.23	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.06	< 0.21	> 0.01
Yttrium (Y)	0.67	0.20	4.67	3.18	1.00	0.50	0.60	0.06	0.70	0.06	1.53	0.69
Zinc (Zn)	25.33	2.33	31.00	9.02	55.33	17.61	57.67	16.90	67.00	51.51	47.27	10.60
Zirconium (Zr)	2.33	0.67	26.67	22.67	3.67	0.88	3.67	0.67	1.67	0.67	7.60	4.61

Table (A)-8

Trace element concentration (ppm) in small mammal samples collected during October 1976

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Aluminum (Al)	13.00	9.54	10.67	6.33	20.33	16.84	3.00	0.58	> 61.00	> 49.57	> 21.60	> 10.58
Antimony (Sb)	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.80	> 0.60	< 0.27	> 0.07	< 0.33	> 0.12
Arsenic (As)	< 0.83	> 0.09	< 0.73	> 0.12	3.27	2.37	3.67	1.76	< 0.77	> 0.03	< 1.85	> 0.61
Barium (Ba)	103.00	58.76	46.00	9.24	51.67	9.82	89.33	20.37	33.33	6.36	64.67	12.96
Beryllium (Be)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Bismuth (Bi)	< 0.30	> 0.00	< 0.30	> 0.06	< 0.23	> 0.03	< 0.47	> 0.27	< 0.27	> 0.03	< 0.31	> 0.05
Boron (B)	0.40	0.12	0.73	0.22	0.37	0.03	1.23	0.88	1.10	0.45	0.77	0.20
Bromine (Br)	5.67	0.33	5.00	2.08	13.67	0.33	6.00	0.58	18.00	14.50	9.67	2.85
Cadmium (Cd)	< 0.40	> 0.06	< 0.33	> 0.07	< 0.37	> 0.07	< 0.60	> 0.21	< 0.60	> 0.21	< 0.46	> 0.06
Calcium (Ca)	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00	> 1000.00	> 0.00
Cerium (Ce)	0.53	0.24	0.23	0.03	0.40	0.20	0.23	0.03	0.60	0.23	0.40	0.08
Cesium (Cs)	< 0.10	> 0.00	< 0.10	> 0.00	< 0.10	> 0.00	< 0.13	> 0.03	< 0.13	> 0.03	< 0.11	> 0.01
Chlorine (Cl)	> 583.33	> 212.79	> 516.67	> 241.82	633.33	164.96	> 676.67	> 197.01	476.67	123.47	> 577.33	> 75.30
Chromium (Cr)	3.67	0.88	3.00	0.58	2.00	0.00	4.00	1.00	5.33	2.03	3.60	0.51
Cobalt (Co)	< 0.87	> 0.57	< 0.47	> 0.22	< 0.27	> 0.03	< 1.77	> 1.13	< 1.43	> 0.57	< 0.96	> 0.28
Copper (Cu)	70.67	54.67	11.67	2.40	171.67	164.17	23.67	12.17	13.33	7.88	58.20	33.53
Dysprosium (Dy)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Erbium (Er)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Europium (Eu)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Fluorine (F)	97.00	24.01	153.00	32.13	91.33	39.49	109.67	10.33	139.00	47.06	118.00	14.07
Gadolinium (Gd)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Gallium (Ga)	1.33	0.33	6.27	4.88	1.33	0.33	6.67	4.67	0.83	0.17	3.29	1.34
Germanium (Ge)	< 0.37	> 0.03	< 0.33	> 0.09	< 0.40	> 0.00	< 0.37	> 0.03	< 0.37	> 0.09	< 0.37	> 0.02
Gold (Au)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01

Table (A)-8

Trace element concentration (ppm) in small mammal samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Hafnium (Hf)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Holmium (Ho)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Iodine (I)	0.50	0.15	< 0.50 >	0.25	1.17	0.43	0.73	0.03	0.90	0.55	< 0.76 >	0.14
Iridium (Ir)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Iron (Fe)	122.33	24.74	144.00	34.78	616.67	219.27	213.33	54.57	165.33	73.00	252.33	64.02
Lanthanum (La)	1.10	0.47	< 0.50 >	0.12	0.73	0.03	0.97	0.52	1.07	0.47	< 0.87 >	0.16
Lead (Pb)	< 2.67 >	0.67	< 2.50 >	0.29	< 2.00 >	0.00	< 10.33 >	6.44	< 8.50 >	5.77	< 5.20 >	1.74
Lithium (Li)	< 0.10 >	0.00	< 0.10 >	0.00	0.10	0.00	< 0.13 >	0.03	< 0.17 >	0.03	< 0.12 >	0.01
Lutetium (Lu)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Magnesium (Mg)	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00
Manganese (Mn)	12.00	10.00	1.33	0.33	2.00	0.58	2.67	0.33	2.00	0.00	4.00	2.01
Mercury (Hg)	< 0.02 >	0.00	< 0.02 >	0.00	< 0.02 >	0.00	< 0.02 >	0.00	< 0.04 >	0.02	< 0.03 >	0.00
Molybdenum (Mo)	4.67	0.33	3.67	0.67	4.33	0.33	4.00	0.58	4.67	0.33	4.27	0.21
Neodymium (Nd)	< 0.30 >	0.06	0.37	0.07	< 0.33 >	0.07	< 0.30 >	0.06	< 0.33 >	0.07	< 0.33 >	0.02
Nickel (Ni)	3.67	1.20	3.00	0.58	< 4.00 >	1.00	9.00	7.00	4.33	1.20	< 4.00 >	1.36
Niobium (Nb)	< 0.50 >	0.06	0.43	0.07	< 0.80 >	0.06	< 0.40 >	0.15	< 0.57 >	0.12	< 0.54 >	0.05
Osmium (Os)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Palladium (Pd)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Phosphorus (P)	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00
Platinum (Pt)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Potassium (K)	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00	> 1000.00 >	0.00
Praseodymium (Pr)	< 0.20 >	0.00	0.13	0.03	0.20	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.18 >	0.01
Rhenium (Re)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Rhodium (Rh)	< 0.20 >	0.00	< 0.17 >	0.03	< 0.20 >	0.00	< 0.20 >	0.00	< 0.20 >	0.00	< 0.19 >	0.01
Rubidium (Rb)	5.33	1.45	3.67	0.88	4.33	0.88	11.00	1.73	4.33	0.88	5.73	0.85

Table (A)-8

Trace element concentration (ppm) in small mammal samples (continued)

Element	Site 1		Site 2		Site 3		Site 4		Site 5		Overall	
	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err	Mean	Std err
Ruthenium (Ru)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Samarium (Sm)	< 0.40	> 0.20	< 0.30	> 0.10	< 0.20	> 0.00	< 0.20	> 0.00	< 0.37	> 0.17	< 0.29	> 0.05
Scandium (Sc)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Selenium (Se)	0.57	0.03	< 0.67	> 0.18	< 0.83	> 0.03	< 0.77	> 0.19	< 0.60	> 0.12	< 0.69	> 0.06
Silicon (Si)	> 528.33	> 275.74	306.67	103.98	250.00	78.10	34.67	9.35	270.00	145.26	> 277.93	> 70.09
Silver (Ag)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.47	> 0.27	< 0.20	> 0.00	< 0.25	> 0.05
Sodium (Na)	> 440.00	> 35.12	> 390.00	> 80.83	> 436.67	> 21.86	> 420.00	> 34.64	> 443.33	> 38.44	> 426.00	> 18.43
Strontium (Sr)	50.67	24.67	34.67	6.36	42.17	21.03	15.17	7.38	34.33	10.93	35.40	6.78
Sulfur (S)	> 990.00	> 10.00	> 840.00	> 85.05	> 1000.00	> 0.00	> 723.33	> 276.67	> 993.33	> 6.67	> 909.33	> 57.20
Tantalum (Ta)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Tellurium (Te)	< 0.20	> 0.00	< 0.23	> 0.09	< 0.20	> 0.00	< 0.40	> 0.06	< 0.20	> 0.00	< 0.25	> 0.03
Terbium (Tb)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Thallium (Tl)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Thorium (Th)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Thulium (Tm)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Tin (Sn)	46.00	27.59	50.33	28.03	> 385.33	> 310.13	> 342.00	> 329.05	177.00	146.89	> 200.13	> 69.15
Titanium (Ti)	6.00	1.15	4.00	1.00	4.67	0.67	4.33	0.88	4.33	0.33	4.67	0.37
Tungsten (W)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Uranium (U)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.47	> 0.27	< 0.47	> 0.27	< 0.20	> 0.00	< 0.30	> 0.07
Vanadium (V)	0.33	0.03	0.27	0.07	< 0.23	> 0.03	0.20	0.06	< 0.20	> 0.00	< 0.25	> 0.02
Ytterbium (Yb)	< 0.20	> 0.00	< 0.17	> 0.03	< 0.20	> 0.00	< 0.20	> 0.00	< 0.20	> 0.00	< 0.19	> 0.01
Yttrium (Y)	< 0.23	> 0.13	< 0.13	> 0.03	< 0.10	> 0.00	< 0.13	> 0.03	< 0.13	> 0.03	< 0.15	> 0.03
Zinc (Zn)	146.33	81.18	165.00	72.63	126.67	57.32	93.33	3.76	92.00	25.51	124.67	22.61
Zirconium (Zr)	3.33	0.88	2.67	0.33	2.33	0.33	< 5.33	> 2.40	1.33	0.33	< 3.00	> 0.57