Environmental Implications of Element Emissions from Phosphate-Processing Operations in Southeastern Idaho

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March 3, 1849

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By R. C. SEVERSON *and* L. P. GOUGH

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Element concentrations in plants and soils
near point sources of contamination and
their possible effects on plant
and animal health

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By R. C. SEVERSON and L. P. GOUGH

ABSTRACT

In order to assess the contribution to plants and soils of certain elements emitted by phosphate processing, we sampled sagebrush, grasses, and A- and C-horizon soils along upwind and downwind transects at Pocatello and Soda Springs, Idaho. Analyses for 70 elements in plants showed that, statistically, the concentration of 7 environmentally important elements, cadmium, chromium, fluorine, selenium, uranium, vanadium, and zinc, were related to emissions from phosphate-processing operations. Two additional elements, lithium and nickel, show probable relationships. The literature on the effects of these elements on plant and animal health is briefly surveyed. Relations between element content in plants and distance from the phosphate-processing operations were stronger at Soda Springs than at Pocatello and, in general, stronger in sagebrush than in the grasses. Analyses for 58 elements in soils showed that, statistically, beryllium, fluorine, iron, lead, lithium, potassium, rubidium, thorium, and zinc were related to emissions only at Pocatello and only in the A horizon. Moreover, six additional elements, copper, mercury, nickel, titanium, uranium, and vanadium, probably are similarly related along the same transect. The approximate amounts of elements added to the soils by the emissions are estimated. In C-horizon soils, no statistically significant relations were observed between element concentrations and distance from the processing sites. At Soda Springs, the nonuniformity of soils at the sampling locations may have obscured the relationship between soil-element content and emissions from phosphate processing.

INTRODUCTION

In phosphate processing, the mechanical operations of grinding, sorting, and drying, as well as the chemical and thermal processes of calcination and beneficiation, may release into the atmosphere the potentially toxic and therefore environmentally important elements cadmium, chromium, fluorine, lead, lithium, mercury, nickel, selenium, silver, uranium, vanadium, and zinc. Ore stockpiles, slag, and settling ponds can also serve as sources of wind-blown contaminants and, therefore, we consider processing sites and not strictly stack emissions as the source area of emitted elements. Except for fluorine (University of Idaho, 1955–74), no studies have been made to evaluate the contribution, if any, of these elements to local plants and soils in the southeastern Idaho phosphate-processing areas. Therefore, we conducted this study in May 1975 to assess the impact of element emissions on selected plants and soils by comparing the element concentrations in samples with distance of sampling sites upwind and downwind from these operations at Pocatello and Soda Springs. Our second goal was to delineate zones of maximum influence along selected transects. Our final goal was to apply our findings to the analysis of potential, but unproven, effects of the emitted elements on the present and future health of plants, animals, and humans located within the zones of influence.

Interest in the health-related aspects of biologically active trace elements has expanded greatly during the past 30 years. Comparisons of data from the present study with examples of trace-element toxicity to plants and animals reported in the literature (for example, Gough and Shacklette, 1976) suggest the potential health effects of element emissions from phosphate processing.

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COLLECTION AND ANALYSIS OF DATA

SAMPLING DESIGN

Sampling was designed to determine whether the element content of selected plants and soils decreased systematically with increasing distance from processing sites at Pocatello and Soda Springs, and if so, which decreases could be demonstrated at an acceptable confidence level. Transects originating at and extending in two directions from the processing sites were established in relation to the predominant wind vectors (fig. 1). At Pocatello, the predominant winds are from the southwest; at Soda Springs, the frequency of winds from the southeast and northwest is about equal. Six points representing ideal sampling locations were selected along each transect at increasing geometric intervals away from the processing sites, the nearest point being 2 km, and the farthest, 64 km. The actual locations (fig. 2) deviated from the preselected points according to the availability of the desired sampling media. At each location, paired samples of two plants and two soil horizons were collected within 100 m of each other.

SAMPLING MEDIA

PLANTS

Sagebrush Steppe (Küchler, 1964) is the dominant plant community in the eastern Snake River Plain near Pocatello and in the valleys around Soda Springs. The phosphate-processing sites are in this community, and ranching and dryland farming are also concentrated here. At Pocatello, we collected basin big sagebrush, the dominant shrub, and cheatgrass, the dominant annual grass (fig. 3). (See table 1 for scientific names of plants cited by common name in this report.) At Soda Springs, the sagebrush we collected included some mountain big sagebrush and some basin big sagebrush. Because of differences in the overall climate of the two areas and because samples were collected in early spring, cheatgrass was not found at Soda Springs; however, bluebunch wheatgrass was abundant and was sampled. When we collected the latter samples, we could not positively identify the grass species because there were no diagnostic fertile culms. However, a return visit to the exact collecting sites by one of us (Gough) in September 1976 enabled us to confirm that the analysis samples were primarily bluebunch wheatgrass and some rough fescue.

Paired samples of sagebrush and grass were collected at each sampling location at both Pocatello and Soda Springs (fig. 2), except at the sampling location in an agricultural-residential area 3 km north of Pocatello where sagebrush was absent.

Samples included the terminal 8 to 12 cm of the stems (including leaves and flowers) of sagebrush at Pocatello and Soda Springs, the leaves, stems, and flowers of cheatgrass at Pocatello, and the leaves and stems of the bluebunch wheatgrass at Soda Springs. Only plants that appeared to be healthy were sampled.

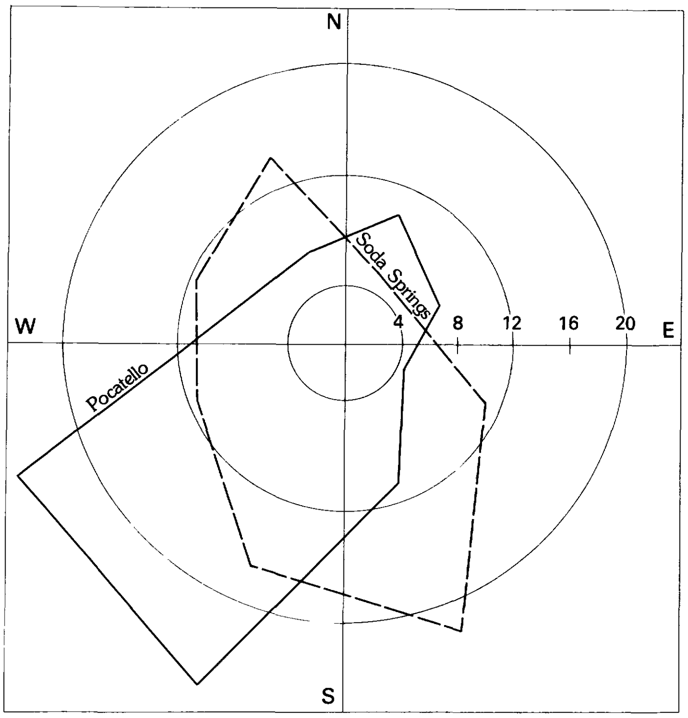

FIGURE 1.—Annual wind-direction distribution at Pocatello and Soda Springs, Idaho. Numbered scale indicates the percent frequency for a given wind direction. Modified from Cramer and Bowers, 1974.

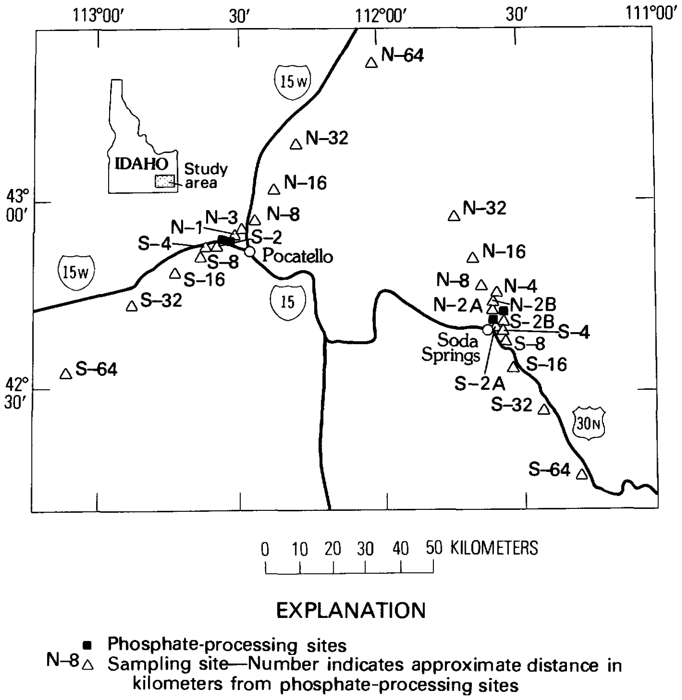

FIGURE 2.—Location of sampling sites along transects near Pocatello and Soda Springs, Idaho.

FIGURE 3.—Elemental-phosphorus processing plant at Pocatello, Idaho. Vegetation in the foreground is almost exclusively big sagebrush (*Artemisia tridentata*) and cheatgrass (*Bromus tectorum*). Photographed May 16, 1975.

SOILS

Paired samples of both A- and C-horizon soils, defined according to traditional usage (U.S. Department of Agriculture, 1962, p. 173–188), were collected at each sampling location. The paired samples from the C horizon were combined at each location in the field to yield one sample. The A horizon was sampled by removing plant debris from the surface of the ground and excavating with a garden spade to a depth of about 5 cm. The C horizon was sampled by hand augering to the necessary depth and saving, to the extent possible, the centermost part of the auger core. Depth of sampling of this horizon was controlled by the character of the soil at individual sites—at places samples were as shallow as 50 cm where the underlying rock was near the surface or where the composition of the parent material changed. Most C-horizon samples were from depths of 80 to 100 cm.

Soils sampled along the transects near Pocatello are remarkably uniform. These soils developed from relatively unweathered aeolian sediments derived from the Snake River flood plain, and they range in thickness from less than 50 to more than 200 cm (Lewis and others, 1975). Conversely, the soils near Soda Springs are highly variable in character (Youngs and others, 1925). Those sampled had developed on such varied parent materials as limestone residuum, aeolian sediments, basalt, valley-fill material of stream origin, and colluvium (fig. 4).

SAMPLE PREPARATION AND CHEMICAL ANALYSIS

Plant samples were cleaned, pulverized, and dry ashed. Cleaning consisted of agitation in tap water, followed by ultrasonic agitation in deionized distilled water. After cleaning, the samples were dried in an oven at about 38° C and were then pulverized in a Wiley mill to pass through a 1.3-mm-mesh screen. The pulverized samples were dry ashed in a muffle furnace at 500° C for about 24 hours, and the ash was used for analysis of most elements. Pulverized samples were prepared for fluorine and selenium analysis by wet digestion.

TABLE 1.—*Common and scientific plant names used in this report*

Common name	Scientific name
Alfalfa	*Medicago sativa* L.
Anemone	*Pulsatilla patens* (L.) Mill.
Barley	*Hordeum vulgare* L.
Bean, navy	*Phaseolus vulgaris* L.
Beet	*Beta vulgaris* L.
Bluegrass	*Poa* sp.
Bog bilberry	*Vaccinium uliginosum* L.
Cabbage	*Brassica oleracea* var. *capitata* L.
Cheatgrass	*Bromus tectorum* L.
Corn	*Zea mays* L.
Citrus	*Citrus* sp.
Fescue, rough	*Festuca scabrella* Torr.
Fireweed	*Epilobium angustifolium* L.
Gumweed	*Grindelia aphanactis* Rydb.
Lettuce	*Lactuca sativa* L.
Oats	*Avena sativa* L.
Pea	*Pisum sativum* L.
Poppy	*Papaver macrostomum* B. et H.
Princesplume	*Stanleya pinnata* (Pursh) Britt.
Sagebrush, basin big	*Artemisia tridentata* Nutt. subsp. *tridentata*
Sagebrush, mountain big	*Artemisia tridentata* subsp. *vaseyana* (Rydb.) Beetle
Soybean	*Glycine max* Merr.
Sweetpea	*Lathyrus* sp.
Tomato	*Lycopersicum esculentum* Mill.
Turnip	*Brassica napus* L.
Violet	*Viola* sp.
Wheat	*Triticum* spp.
Wheatgrass, bluebunch	*Agropyron spicatum* (Pursh) Scribn. and Smith

Analyses of these two elements are expressed on a dry-weight basis, whereas all other analyses are expressed on an ash-weight basis.

The mineralogy of the wash residue from samples of bluebunch wheatgrass, collected 2 km northwest (downwind) of the elemental-phosphorus plant at Soda Springs, was examined by X-ray diffraction techniques. The dry residue was ground using a mortar and pestle and the resulting powders were X-rayed on a diffractometer using CuK_α radiation. Diffraction patterns were recorded for each powder over a 2θ range of 2° to about 55° at a rate of 2° per minute.

Soil samples were dried under forced air at ambient temperature, and the dried material was passed through a 2-mm-mesh sieve. The minus–2-mm fraction was further ground to pass a 100-mesh sieve (150 μm openings), and this material was used for all analytical determinations.

All sample preparations and analytical determinations for both plant and soil materials were done in U.S. Geological Survey laboratories at Denver, Colo. The analyses of plant materials followed the procedures for specific analytical methods, other than emission spectrography, described by Harms and Papp (1975). Soil analyses followed the X-ray fluorescence procedures described by Wahlberg (1975), the neutron activation procedures described by Millard (1975), and the atomic absorption spectroscopy procedures described by Huffman (1975). Meyers, Havens, and Dunton (1961) described the emission spectrography analytical technique used for both plants and soils. Table 2 lists the analytical method and the detection limit for each element in each sampling medium.

STATISTICAL ANALYSIS

The error associated with sample preparation and analysis was evaluated by examining duplicate analytical determinations from splits of samples that were randomly selected from the complete sample suite. All samples of plants or soils, including the splits, were then placed in a randomized sequence and submitted for analysis. Analysis of the samples in this sequence randomizes any systematic bias that may result from the analytical and sample-handling procedures. Analysis of variance was then used to estimate the relative error variance due to sample preparation and analysis, according to the technique of Miesch (1967). Sample preparation and analysis caused excessive error variance in the data for lead and molybdenum in plants and for antimony, arsenic, barium, boron, germanium, lanthanum, phosphorus, scandium, strontium, yttrium, and zirconium in soils (Severson and Gough, 1976); these elements were not examined further.

Some elements in plant and soil material were not detectable by the analytical methods used. If an element was not detectable in one-fourth or more of the total number of plant or soil samples, the data were not examined further in this study. If an element was not detected in only a few samples of either plants or soils (table 3), the concentration of the element in these samples was considered to be equal to seven-tenths of the lower detection limit. (The justification for these substitutions is discussed by Severson and Gough, 1976.)

Variations of element concentrations in plants and soils, relative to distance from each phosphate-processing site, were examined by linear regression. The regression model was of the form:

$$\log_{10}X=b_0+b_1\log_{10}D$$

where X is the concentration of the element, D is the distance from the processing site, and b_0 and b_1 are, respectively, the regression constant and regression coefficient. The statistical significance of each regression was determined by analysis of variance procedures (for example, Davis, 1973, p. 192–204). Coefficients of determination between log element concentration and log distance provide estimates of the propor-

FIGURE 4.—Diverse rocks and soils characteristic of the area north of Soda Springs, Idaho. Loess agricultural soils (foreground) as well as soils derived from the weathering of basalt (middleground) and limestone (background) are common. Photographed May 18, 1975.

tions of the total variance in concentration that is associated with distance from the processing sites. The covariation between logarithms of element content in plant and soil samples among the sample locations along each of the transects was estimated by the product-moment correlation coefficient.

Figure 5 illustrates the types of relations between concentrations and distances that were observed along the transects upwind and downwind of the processing sites. Figure 5*A* shows element concentration in a single sampling medium decreasing with increasing distance from the processing site along both upwind and downwind transects. The regressions that describe these relations are statistically significant at a probability level of 0.05. This type of relation provides strong evidence that the elevated element concentrations in a sampling medium close to the processing site are related to emissions. We consider these relations to be "significant."

Figures 5*B* and 5*C* show element concentrations in a sampling medium decreasing significantly with increasing distance from a processing operation along only one transect; the other transect shows a nonsignificant increase or decrease in element concentration with distance. This distribution pattern is probably related to element emissions from the processing site and is considered "important."

Figures 5*D* and 5*E* show element concentrations increasing significantly with increasing distance from the processing site along one transect. An increase in concentration with distance does not describe accumulation of wind-related emissions from processing operations; therefore, these relations are "unimportant" in this study and probably are intrinsic to the natural environment.

ESTIMATING ELEMENT BURDEN IN SOILS

We estimated the approximate concentrations of elements added to the soil by phosphate-processing operations along transects showing statistically significant relations between element content in soil

TABLE 2.—*Analytical methods and their detection limits for element analysis in soil plants and soils*

[Elements in plants determined on ash, except as indicated. LLD, lower limit of determination expressed in parts per million; AA, atomic-absorbtion spectroscopy; COL, colorimetric; FLU, fluorimetric; IF, induction furnace; NA, neutron activation; SIE, selective ion electrode; SQS, multielement semiquantitative spectrography; and XRF, X-ray fluorescence, (...), not determined]

Elements	Plants Method	Plants LLD	Soils Method	Soils LLd
Al	SQS	100	XRF	10,000
B	SQS	20	SQS	20
Ba	SQS	2	SQS	2
Be	...	...	SQS	1
C	...	...	IF	500
Ca	...	...	XRF	1,000
Cd	AA	.2	...	...
Co	AA	1	SQS	3
Cr	SQS	1	SQS	1
Cu	SQS	1	SQS	1
F[1]	SIE	1	SIE	10
Fe	SQS	10	XRF	1,000
Ga	...	...	SQS	5
Hg	...	...	AA	.01
K	...	...	XRF	1,000
Li	AA	4	AA	5
Mg	SQS	20	XRF	300
Mn	SQS	1	XRF	1
Na	AA	25	AA	100
Nb	...	...	SQS	10
Ni	SQS	5	SQS	5
P	COL	100	XRF	2,000
Pb	SQS	10	SQS	10
Rb	...	...	AA	1
Se[1]	FLU	.01	XRF	.1
Si	AA	100	XRF	10,000
Sn	...	...	XRF	10
Sr	SQS	5	SQS	5
Th	...	...	NA	1
Ti	SQS	2	XRF	2
U	FLU	.4	NA	.1
V	SQS	7	SQS	7
Yb	SQS	1	SQS	10
Zn	AA	20	AA	10
Zr	SQS	10	SQS	10

[1] Determined on dried plant material.

TABLE 3.—*Detection ratios for selected elements in plants and soils at Pocatello and Soda Springs, Idaho, that have some values below the limits of determination*

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed; leaders (..), element not included in the study of a given sampling medium]

Element	Plants: Big sagebrush	Plants: Cheatgrass	Plants: Bluebunch wheatgrass	Soils: A horizon	Soils: C horizon
Be	...	...	...	49:50	22:25
Cd	48:48	19:24	26:26	50:50	25:25
Co	48:48	21:24	21:26	50:50	22:25
Hg	...	...	...	50:50	23:25
Mn	48:48	24:24	26:26	50:50	24:25
Mo	48:48	23:24	26:26	...	...
Nb	...	...	...	49:50	22:25
Ni	48:48	16:24	21:26	50:50	25:25
Pb	48:48	23:24	26:26	50:50	25:25
Zr	48:48	21:24	22:26	...	...

and distance. The estimation method was first used by Miesch and Huffman (1972) and was described in detail, as applied to this study, by Severson and Gough (1976). Using the processing site as the center of the circle of influence, the estimation is made by integrating the regression equation over a pie-shaped segment of the circle between two distances from the processing site.

RESULTS OF ANALYSES

SIGNIFICANCE OF EMISSION-RELATED ELEMENT DISTRIBUTIONS

Tables 4, 5, 6, and 7 present results for all elements included in this study in both plants and soils along upwind and downwind transects at Pocatello and Soda Springs. The first two columns under a sampling medium contain estimates for the intercept (b_0) and slope (b_1) of the regression line for a specific constituent. A negative slope indicates that the element concentration tends to decrease with increasing distance from the processing site. Conversely, a positive slope indicates a tendency for the element concentration to increase with distance.

The third column of tables 4, 5, 6, and 7 shows the probability that the slope of the regression line is actually zero. We consider as significant a probability of 0.05. The fourth column in the tables presents the probability that the departure of the data from the linear regression model could have arisen by chance. Probabilities greater than the critical value of 0.05 indicate that the linear model is not appropriate at this level of significance.

The fifth column gives the coefficient of determination between element concentration in each sampling medium and distance. This value is a measure of the proportion of the total variation in the dependent variable, in this case, log element concentration, that is accounted for by the regression. For example, a value of 0.75 indicates that 75 percent of the observed variation in element concentration is accounted for simply by distance from the processing site.

The following classes were established to determine important relations between concentration of an element in a sampling medium and emissions from phosphate-processing operations: (1) "Significantly related," where negative regression slopes were significant at a probability of 0.05 for both downwind and upwind transects and a coefficient of determination equal to or greater than 0.50 was observed for one of the two transects; (2) "of probable importance," where a significant negative regression slope and a coefficient of determination equal to or greater than 0.50 were

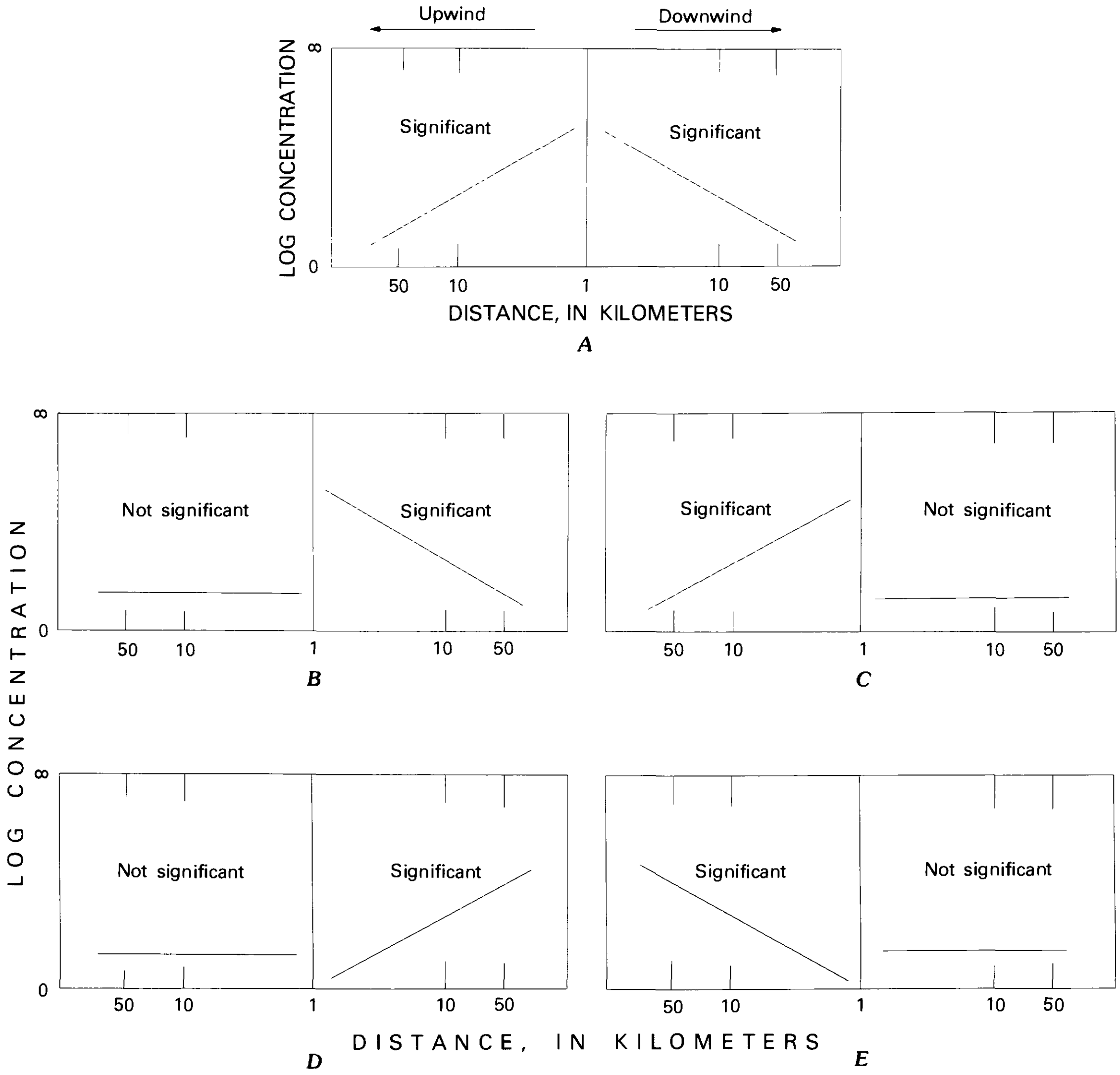

FIGURE 5.—Typical relations between element concentrations in a sampling medium and distance of sampling site from phosphate processing operations. Trend line significance noted in figure. *A*, Important and related to phosphate processing. *B*, *C*, Important and probably related to phosphate processing. *D*, *E*, Not related to phosphate processing.

observed for one of the two transects. Also considered to be important in soils were a few elements for which the regression was significant at a probability level of 0.10 or whose coefficients of determination were less than 0.50. The reasons for these exceptions will be discussed under "Element concentrations in soils."

ELEMENT CONCENTRATIONS IN PLANTS

Of the 23 elements listed in table 4, six in sagebrush at Pocatello (cadmium, chromium, fluorine, uranium, vanadium, and zinc) possessed significant negative regression slopes and acceptable coefficients of determination along both downwind and upwind transects. These elements, therefore, meet our criteria as being significantly related to phosphate-processing operations. Selenium probably should also be added to this list because the downwind regression slope was significant and the upwind slope was important at the 0.07 probability level. Two additional elements, nickel and phosphorus, are of probable importance because they possess significant negative slopes as well as acceptable coefficients of determination along only one—the downwind—transect.

Selenium is the only element in cheatgrass that qualified as being significantly related to phosphate operations near Pocatello. Chromium and vanadium may be considered important as they possessed significant negative slopes for either the downwind or up-

TABLE 4.—*Regression statistics for elements and ash in plants sampled near Pocatello, Idaho*

[Regression equations are based on element concentrations expressed in parts per million of the ashed material, except as indicated; b_0 is the intercept and b_1 is the slope of the regression equation; significance of the slope is the probability level at which the slope is different from zero; significance of the model is the probability level at which the linear regression model adequately describes the relation; coefficient of determination is an expression of the proportion of the total variation in the dependent variable, element concentration, that is accounted for by the linear model]

	Northeast (downwind) transect										Southwest (upwind) transect									
	Big sagebrush					Cheatgrass					Big Sagebrush					Cheatgrass				
	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination
Constituent	b_0	b_1	slope	model		b_0	b_1	slope	model		b_0	b_1	slope	model		b_0	b_1	slope	model	
Ash[1,2]	0.822	−0.062	0.21	0.82	0.18	0.938	−0.053	0.19	0.90	0.16	0.698	0.053	0.20	0.48	0.16	0.798	0.011	0.82	0.89	<0.01
Al[1]	.369	.050	.56	.12	.04	−.482	.334	.06	.41	.31	.412	−.029	.72	.07	.01	.116	−.070	.56	.62	.04
B	2.62	−.025	.74	.16	.01	1.92	.016	.82	.03	<.01	2.46	.065	.51	.04	.05	2.21	−.174	.18	.74	.17
Ba	2.55	.168	.01	.12	.58	2.47	.104	.26	.34	.12	2.71	.019	.80	.52	.01	2.84	−.238	.02	.12	.43
Cd	2.30	−.865	<.01	.86	.96	1.25	−.633	.04	.69	.35	1.72	−.748	<.01	.78	.90	.954	−.724	.18	.34	.17
Co	.526	−.075	.52	.69	.06	−.105	.322	.04	.14	.35	.535	−.020	.86	.07	.02	.479	−.121	.50	.25	.05
Cr	2.98	−.792	<.01	.60	.85	1.91	−.442	.03	.12	.40	2.08	−.397	<.01	.89	.76	1.46	−.204	.08	.08	.28
Cu	1.82	.179	.12	.28	.27	1.73	.039	.40	.07	.07	1.88	.069	.36	.15	.09	1.68	.074	.31	.92	.10
F[1,2]	−.903	−1.14	<.01	.96	.84	−1.89	−.562	<.01	.97	.62	−2.24	−.273	<.01	.21	.60	−2.59	−.119	.19	.42	.16
Fe[1]	.026	.011	.87	.25	<.01	−.744	.282	.02	.91	.43	.106	−.065	.37	.01	.08	−.298	.029	.77	.05	.01
Li	1.55	−.163	.10	.28	.30	.506	.114	.32	.02	.10	1.40	−.061	.60	.87	.03	.795	.001	.94	.28	<.01
Mg	.549	−.004	.91	.69	<.01	.228	−.059	.57	.36	.03	.423	.035	.36	.18	.08	.201	−.055	.52	.93	.04
Mn	2.82	.033	.56	.01	.04	2.80	−.060	.48	.56	.05	2.80	.007	.88	.02	<.01	2.88	−.08	.42	.29	.07
Na[1]	.762	−.096	.10	.66	.30	.189	−.032	.72	.70	.01	.756	−.007	.89	.60	<.01	.356	−.094	.26	.94	.12
Ni	1.91	−.477	.01	.39	.81	1.03	−.116	.53	.92	.04	1.22	−.025	.69	.02	.02	1.16	−.194	.24	.81	.13
P	4.64	−.179	.01	.20	.61	4.43	−.202	.01	.61	.57	4.32	.035	.33	.11	.10	4.13	−.045	.71	.97	.01
Se[2]	−.198	−.536	<.01	.62	.88	−.462	−.427	<.01	.32	.70	−.944	−.154	.07	.59	.28	−.948	−.277	.02	.48	.41
Si	4.81	.040	.64	.64	.03	5.34	.124	.11	.99	.24	5.01	−.045	.39	.34	.08	5.52	.014	.72	.78	.01
Sr	3.32	−.029	.25	.12	.16	2.76	−.125	.32	.39	.10	3.09	.143	.14	.50	.20	2.65	−.023	.81	.40	.01
Ti[1]	−1.05	.086	.24	.37	.17	−2.13	.509	<.01	.59	.59	−.871	−.045	.66	.29	.02	−1.48	.041	.79	.10	.01
U	1.45	−.780	<.01	.80	.94	.682	−.331	.05	.94	.34	.633	−.332	<.01	.37	.74	.473	−.162	.30	.94	.11
V	3.04	−.794	<.01	.66	.85	1.96	−.375	.07	.73	.29	2.08	−.225	.03	.22	.39	1.65	−.270	.02	.51	.41
Zn	3.11	−.310	<.01	.53	.91	2.58	−.146	.08	.19	.27	2.81	−.189	.01	.99	.54	2.47	−.092	.21	.71	.15
Zr	1.92	.013	.89	.70	<.01	1.08	.323	.15	.26	.19	2.05	−.081	.46	.16	.06	1.57	−.006	.92	.05	<.01

[1] Percent

[2] Determined on the dried material

TABLE 5.—*Regression statistics for elements and ash in plants sampled near Soda Springs, Idaho*

[Regression equations are based on element concentrations expressed in parts per million of the ashed material, except as indicated; b_0 is the intercept and b_1 is the slope of the regression equation; significance of the slope is the probability level at which the slope is different from zero; significance of the model is the probability level at which the linear regression model adequately describes the relation; coefficient of determination is an expression of the proportion of the total variation in the dependent variable, element concentration, that is accounted for by the linear model]

	Northwest (downwind) transect										Southeast (upwind) transect									
	Big sagebrush					Bluebunch Wheatgrass					Big Sagebrush					Bluebunch Wheatgrass				
	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination
Constituent	b_0	b_1	slope	model		b_0	b_1	slope	model		b_0	b_1	slope	model		b_0	b_1	slope	model	
Ash[1,2]	0.690	−0.117	0.01	0.61	0.47	0.880	−0.092	0.22	0.40	0.19	0.623	−0.008	0.84	0.78	<0.01	0.892	−0.033	0.18	0.43	0.14
Al[1]	.250	−022	.70	.28	.02	−.365	.276	.18	.99	.17	.141	.007	.86	.23	<.01	−.165	−.034	.77	.03	.01
B	2.56	.123	.43	.76	.06	1.69	.203	.08	.05	.26	2.51	.084	.31	.75	.09	1.83	.097	.15	.01	.16
Ba	2.55	.176	.24	.22	.14	2.56	.101	.50	.52	.05	2.46	.139	.11	.67	.19	2.57	−.007	.89	.01	<.01
Cd	2.41	−.643	.01	.93	.50	2.34	−.937	<.01	.42	.60	1.78	−.428	<.01	.97	.54	1.55	−.600	<.01	.32	.72
Co	.275	−.009	.91	.12	<.01	.113	.101	.71	.10	.01	.357	−.099	.25	.18	.11	.271	−.212	.04	.28	.31
Cr	2.78	−.736	<.01	.67	.63	2.00	−.439	.02	.68	.45	2.37	−.634	<.01	.66	.82	1.69	−.319	.12	.61	.19
Cu	1.98	.285	.08	.11	.28	1.88	.024	.81	.37	.01	1.92	.100	.28	.14	.10	1.79	−.028	.52	.17	.04
F[1,2]	−1.39	−1.25	<.01	.99	.86	−2.14	−.431	<.01	.83	.60	−2.36	−.396	<.01	.42	.55	−2.37	−.351	<.01	.83	.69
Fe[1]	.039	−.117	.13	.59	.21	−.491	.161	.30	.67	.11	−.108	−.118	.07	.30	.24	−.435	.032	.73	.12	.01
Li	1.60	−.834	<.01	.46	.79	.524	−.099	.48	.25	.05	.807	.193	.17	.25	.15	.413	−.049	.51	.11	.04
Mg	.780	−.198	.28	.26	.11	−.146	.127	.22	.02	.15	.448	.024	.72	.07	.01	−.100	.126	.21	.03	.13
Mn	2.60	.173	.25	.65	.13	2.27	.298	.03	.59	.39	2.66	.087	.23	.09	.12	2.61	.084	.42	.30	.06
Na[1]	.766	−.325	.02	.32	.45	.017	.151	.35	.19	.09	.366	.004	.92	.96	<.01	−.011	−.037	.42	.13	.06
Ni	1.56	−.220	<.01	.01	.61	1.35	−.199	.10	.31	.25	1.38	−.119	.15	.12	.16	.833	.107	.57	.55	.03
P	4.69	−.191	.02	.14	.45	3.85	.189	.19	.31	.16	4.45	.007	.87	.20	<.01	4.12	−.038	.66	.01	.02
Se[2]	.305	−1.04	<.01	.91	.79	.340	−.911	<.01	.97	.84	−.660	−.291	.01	.93	.48	−.299	−.474	<.01	.81	.84
Si	4.98	−.327	.28	.16	.12	5.66	−.063	.08	.44	.27	4.54	−.031	.69	.98	.01	5.58	.013	.53	.92	.03
						1.99	.372	.05	.12	.32										
Sr	3.31	−.075	.48	.20	.05						3.00	.206	.07	.88	.25	2.48	−.084	.39	.36	.06
Ti[1]	−1.10	−.115	.38	.43	.08	−1.70	.174	.39	.78	.08	−1.30	−.054	.42	.60	.06	−1.69	−.009	.86	.09	<.01
U	1.08	−.496	<.01	.96	.73	.874	−.354	<.01	.32	.70	.671	−.334	<.01	.93	.66	.546	−.303	<.01	.96	.58
V	3.24	−1.11	<.01	.77	.85	2.58	−.725	<.01	.19	.70	2.41	−.486	<.01	.96	.63	2.19	−.639	<.01	.97	.63
Zn	3.54	−.559	<.01	.96	.56	3.16	−.442	.01	.60	.56	2.95	−.146	.02	.92	.36	2.70	−.219	<.01	.90	.59
Zr	1.78	−.132	.38	.39	.08	1.16	.279	.15	.74	.19	1.48	−.010	.86	.32	<.01	1.23	.050	.68	.05	.02

[1] Percent

[2] Determined on dried material

TABLE 6.—*Regression statistics for elements in soils sampled near Pocatello, Idaho*

[Regression equations are based on element concentrations expressed in parts per million, except as indicated; b_0 is the intercept and b_1 is the slope of the regression equation; significance of the slope is the probability level at which the slope is different from zero; significance of the model is the probability level at which the linear regression model adequately describes the relation; coefficient of determination is an expression of the proportion of the total variation in the dependent variable, element concentration, that is accounted for by the linear regression model; leaders (.....), no data available]

	Northeast (downwind) transect												Southwest (upwind) transect											
	A horizon					C horizon							A horizon					C horizon						
	Regression estimates		Significance		Coefficient of	Regression estimates		Significance		Coefficient of			Regression estimates		Significance		Coefficient of	Regression estimates		Significance		Coefficient of		
Element	b_0	b_1	slope	model	determination	b_0	b_1	slope	model	determination			b_0	b_1	slope	model	determination	b_0	b_1	slope	model	determination		
Al[1]	0.726	−0.011	0.56	0.07	0.04	0.626	0.045	0.35	.....	0.22			0.763	−0.018	0.34	0.12	0.09	0.695	−0.031	0.58	.....	0.09		
Be	.269	.−132	.01	.02	.58	.186	.008	.87	.....	.01			.260	−.055	.51	.07	.05	.136	−.002	.93	.....	<.01		
C[1]	.158	.029	.73	.92	.01	.382	−.049	.32	.....	.24			.121	.061	.36	.79	.08	.115	.123	.65	.....	.06		
Ca[1]	.323	.097	.44	.93	.06	.804	−.049	.41	.....	.18			.232	.110	.28	.79	.12	.561	.105	.68	.....	.05		
Co	.876	−.022	.22	.08	.22	.845	0	.99	.....	<.01			.845	0	.99	.99	<.01	.835	−.013	.83	.....	.01		
Cr	1.93	−.116	.21	.07	.23	1.71	.085	.05	.....	.65			1.82	.001	.92	.82	<.01	1.75	.045	.61	.....	.07		
Cu	1.33	−.070	.10	.27	.24	1.18	0	.99	.....	<.01			1.23	.008	.85	.11	<.01	1.25	−.049	.39	.....	.19		
F[1]	−.936	−.248	.01	.08	.60	−1.19	−.035	.70	.....	.04			−1.28	.033	.52	.64	.04	−1.18	−.026	.39	.....	.19		
Fe[1]	.341	−.072	.01	.11	.51	.204	.008	.80	.....	.02			.340	−.048	.01	.09	.53	.274	−.036	.50	.....	.12		
Ga	1.18	0	.99	.99	<.01	1.18	0	.99	.....	<.01			1.20	−.011	.69	.23	.02	1.18	0	.99	.....	<.01		
Hg	−1.43	−.228	.05	.01	.33	−1.78	−.058	.74	.....	.03			−1.65	−.137	.29	.30	.11	−1.83	−.017	.89	.....	<.01		
K[1]	.295	−.045	.01	.44	.76	.179	.023	.39	.....	.19			.300	−.029	.02	.68	.42	.242	−.020	.66	.....	.05		
Li	1.42	−.103	.01	.85	.64	1.31	−.019	.72	.....	.04			1.35	−.023	.20	.58	.16	1.30	.008	.78	.....	.02		
Mg[1]	−.034	.038	.47	.91	.06	.304	−.086	.14	.....	.45			−.019	.046	.22	.72	.14	.164	−.014	.89	.....	<.01		
Mn[1]	−1.15	−.093	.11	.28	.24	−1.57	.146	.17	.....	.40			−1.06	−.074	.08	.19	.26	−1.21	−.135	.36	.....	.22		
Na[1]	−.023	−.010	.19	.20	.11	.019	−.052	.14	.....	.44			−.015	−.005	.69	.66	.02	.029	−.063	.04	.....	.69		
Nb	1.20	−.017	.22	.08	.22	1.18	0	.99	.....	<.01			1.19	.006	.84	.18	<.01	1.16	.020	.84	.....	.01		
Ni	1.44	−.143	.07	.54	.27	1.15	.031	.18	.....	.39			1.26	−.016	.73	.13	<.01	1.18	0	.99	.....	<.01		
Pb	1.48	−.172	.01	.29	.75	1.26	−.016	.75	.....	.03			1.31	.020	.59	.17	.02	1.14	.042	.13	.....	.47		
Rb	1.95	−.110	.01	.50	.58	1.77	.016	.44	.....	.10			1.88	−.032	.20	.08	.15	1.82	−.023	.80	.....	.02		
Si[1]	1.51	.010	.59	.84	.03	1.46	.023	.13	.....	.46			1.52	.007	.55	.06	.04	1.48	.001	.93	.....	<.01		
Sn	.106	.052	.64	.03	.02	.071	.135	.36	.....	.21			.186	−.022	.74	.01	.01	.028	.126	.17	.....	.40		
Th	1.17	−.155	.01	.02	.71	.965	−.011	.81	.....	.01			1.14	−.063	.13	.01	.21	1.16	−.134	.07	.....	.60		
Ti[1]	−.489	−.063	.02	.89	.49	−.591	.004	.85	.....	.01			−.464	−.045	.05	.17	.33	−.542	−.022	.62	.....	.07		
U	.584	−.100	.04	.31	.35	.505	−.033	.51	.....	.18			.496	−.029	.43	.13	.06	.427	.010	.50	.....	.12		
V	2.07	−.167	.07	.88	.28	1.82	.039	.18	.....	.39			1.87	−.013	.69	.23	.02	1.84	−.013	.83	.....	.01		
Yb	.586	−.034	.71	.42	.01	.433	.014	.82	.....	.01			.613	−.075	.40	.14	.08	.466	−.015	.83	.....	.01		
Zn	2.12	−.236	.01	.99	.76	1.75	−.005	.86	.....	.01			1.92	−.058	.01	.14	.50	1.79	−.027	.68	.....	.05		

[1] Percent

TABLE 7.—*Regression statistics for elements in soils sampled near Soda Springs, Idaho*

[Regression equations are based on element concentrations expressed in parts per million, except as indicated; b_0 is the intercept and b_1 is the slope of the regression equation; significance of the slope is the probability level at which the slope is different from zero; significance of the model is the probability level at which the linear regression model adequately describes the relation; coefficient of determination is an expression of the proportion of the total variation in the dependent variable, element concentration, that is accounted for by the linear regression model; leaders (.....), no data available]

	Northwest (downwind) transect										Southeast (upwind) transect									
	A horizon					C horizon					A horizon					C horizon				
	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination	Regression estimates		Significance		Coefficient of determination
Element	b_0	b_1	slope	model		b_0	b_1	slope	model		b_0	b_1	slope	model		b_0	b_1	slope	model	
Al[1]	0.660	0.117	0.04	0.51	0.35	0.397	0.320	0.12	.....	0.49	0.750	−0.021	0.65	0.96	0.02	0.498	0.077	0.71	.....	0.03
Be	.058	.155	.18	.14	.17	−.224	.394	.02	.....	.76	.293	−.011	.84	.68	<.01	−.151	.205	.13	.....	.39
C[1]	.710	−.277	.08	.81	.27	1.06	−.806	.06	.....	.63	.763	−.268	.06	.97	.27	.872	−.375	.24	.....	.26
Ca[1]	.784	−.670	.01	.96	.50	1.48	−.846	.08	.....	.57	.747	−.352	.14	.97	.17	1.20	−.329	.42	.....	.13
Co	.870	.022	.73	.32	.01	.714	.109	.14	.....	.46	.923	−.055	.36	.22	.07	.529	.176	.23	.....	.27
Cr	1.68	.116	.24	.07	.13	1.44	.324	.05	.....	.65	1.68	−.014	.84	.97	<.01	1.45	.108	.61	.....	.06
Cu	1.25	.183	.02	.82	.46	1.10	.095	.54	.....	.10	1.34	.021	.71	.47	.01	1.11	.028	.82	.....	.01
F[1]	−.969	−.243	.02	.93	.45	−1.17	−.028	.73	.....	.03	−1.10	−.078	.13	.77	.18	−1.12	−.113	.30	.....	.21
Fe[1]	.236	.105	.08	.70	.27	.014	.269	.10	.....	.53	.356	−.041	.46	.90	.05	.115	.060	.73	.....	.02
Ga	1.22	.033	.68	.58	.02	1.10	.131	.14	.....	.46	1.25	−.015	.78	.99	.01	1.11	−.004	.92	.....	<.01
Hg	−1.68	.026	.75	.01	.01	−2.25	.441	.06	.....	.63	−1.56	−.106	.03	.01	.34	−1.94	.139	.53	.....	.09
K[1]	.237	.060	<.01	.35	.50	.046	.165	.03	.....	.72	.235	.023	.63	.99	.02	−.039	.122	.42	.....	.13
Li	1.43	.014	.55	.42	.04	1.36	.047	.40	.....	.18	1.48	−.087	.03	.35	.34	1.30	.0003	.95	.....	<.01
Mg[1]	.299	−.421	.02	.89	.44	.432	−.384	.16	.....	.43	−.059	−.061	.05	.48	.27	−.060	.069	.70	.....	.03
Mn[1]	−1.24	.198	.02	.59	.41	−1.82	.513	.09	.....	.54	−.950	−.093	.10	.08	.21	−1.55	.159	.43	.....	.13
Na[1]	−.215	.154	.01	.92	.46	−.407	.282	.04	.....	.68	−.177	.006	.87	.99	<.01	−.640	.138	.76	.....	.02
Nb	1.11	.098	.20	.41	.16	.848	.300	.10	.....	.52	1.12	.091	.24	.71	.11	.951	.107	.43	.....	.13
Ni	1.15	.180	.10	.49	.25	.980	.315	.17	.....	.41	1.34	−.095	.23	.91	.12	.906	.186	.37	.....	.16
Pb	1.19	.172	.08	.64	.27	1.19	.093	.14	.....	.46	1.39	−.023	.70	.63	.01	1.09	.080	.44	.....	.11
Rb	1.80	.167	.03	.81	.39	1.64	.172	.33	.....	.23	1.93	−.007	.87	.94	<.01	1.53	.134	.53	.....	.08
Si[1]	1.38	.105	.01	.60	.48	1.22	.233	.06	.....	.63	1.35	.104	.07	.98	.25	1.16	.178	.33	.....	.20
Sn	.274	−.142	.21	.04	.15	−.226	.334	.05	.....	.67	.199	−.041	.67	.39	.02	.275	−.191	.09	.....	.46
Th	.973	.123	.03	.83	.40	.806	.222	.13	.....	.47	1.10	.019	.74	.85	.01	1.07	−.066	.70	.....	.03
Ti[1]	−.575	.100	.03	.72	.37	−.732	.208	.11	.....	.50	−.540	.018	.70	.94	.01	−.727	.057	.78	.....	.02
U	.410	.102	.05	.04	.33	.157	.261	.03	.....	.75	.346	.030	.61	.95	.02	.094	.109	.65	.....	.05
V	1.84	.032	.47	.15	.04	1.52	.273	.14	.....	.46	1.80	.012	.71	.10	.01	1.39	.217	.35	.....	.17
Yb	.256	.215	.01	.26	.59	.208	.224	.14	.....	.46	.422	.046	.67	.94	.02	.129	.174	.37	.....	.16
Zn	1.96	.031	.52	.12	.04	1.64	.158	.19	.....	.34	2.00	−.085	.04	.56	.30	1.72	.006	.91	.....	<.01

[1] Percent

wind transect; they have, however, lower than acceptable coefficients of determination.

At Soda Springs (table 5), seven elements in sagebrush (cadmium, chromium, fluorine, selenium, uranium, vanadium, and zinc) are significantly related to phosphate-processing operations. Lithium and nickel show significant negative regression slopes and acceptable coefficients of determination along the downwind transect but not along the upwind transect; therefore, they are considered to be importantly associated with the processing operations. Phosphorus and sodium may also be important for they too show significance only along the downwind transect; however, they lack sufficiently high coefficients of determination.

In the bluebunch wheatgrass samples, cadmium, fluorine, selenium, uranium, vanadium, and zinc are significantly related to the phosphate-processing operations. The only other element of possible importance is chromium; however, along the upwind transect its negative regression slope is not significant, whereas along the downwind transect its negative slope is significant but its coefficient of determination is unacceptably low.

Overall, seven elements in plant tissue (cadmium, chromium, fluorine, selenium, uranium, vanadium, and zinc) are significantly associated with phosphate-processing operations. Two additional elements, lithium and nickel, show frequent importance. Phosphorus and sodium may also reflect the impact of the phosphate operations, but unlike the first nine elements, which demonstrate importance along several transects and in a variety of plants sampled, these two show only questionable infrequent importance.

Although basically the same elements are involved in important relations at Pocatello and Soda Springs, there appear to be, in general, higher concentrations of these elements in the plants sampled at Soda Springs. This condition may be due either to differences in climate, phosphate-processing activity, element availability, and plant species or varieties, or to combinations of all these factors. Table 8 compares the relative concentrations of these elements to be expected in the plants at Pocatello and Soda Springs 3 km from the processing sites, according to the regression equations.

At Pocatello, where the downwind vector is greater than the upwind vector (fig. 1), many more downwind samples than upwind samples showed associations between elements in plants and the phosphate operations. At Soda Springs, however, the two main wind patterns, which are opposite but of about equal frequency, suggest that the effect of emissions on plants should reflect the somewhat stronger influence of the wind from the southeast. Table 5 shows that this is generally true, particularly for the chemical data on grasses. Still, concentrations of emission-related elements were generally higher downwind than upwind at both sites (table 8). Furthermore, the concentrations of cadmium, chromium, fluorine, uranium, vanadium, and zinc calculated for plants from the regression equations were unusually high 3 km from the processing operations, as compared with similar plant materials sampled in the Powder River Basin of Wyoming and Montana (Gough and Severson, 1976). Emissions from the phosphate operations, therefore, contributed substantial quantitites of certain trace elements to the plants that were sampled.

TABLE 8.—*Comparison of the estimated concentrations of selected trace elements in big sagebrush, cheatgrass, and bluebunch wheatgrass at distances of 3 km from phosphate-processing sites at Pocatello and Soda Springs, Idaho.*

[Estimated concentration values (parts per million, in ash, except as indicated) were calculated using regression equations from tables 4 and 5. Leaders(.....), relation between element concentration in plant material and distance was not significant. Values in parentheses indicate that the relation is of questionable significance]

		Estimated concentrations in big sagebrush		Estimated concentrations in grass	
Element	Transect	Pocatello	Soda Springs	Pocatello (cheatgrass)	Soda Springs (bluebunch wheatgrass)
Cd	downwind	78	130	(9)	78
	upwind	23	38	......	18
Cr	downwind	400	270	(50)	(62)
	upwind	77	117	......	......
F[1]	downwind	360	100	70	45
	upwind	43	28	......	29
Li	downwind	......	16	......	......
	upwind	......	......	......	......
Ni	downwind	48	28	......	......
	upwind	......	......	......	......
Se[1]	downwind	.35	.64	.22	.80
	upwind	......	(.16)	(.08)	.30
U	downwind	12	7	......	5
	upwind	3	3	......	2
V	downwind	460	510	......	170
	upwind	(95)	150	(33)	77
Zn	downwind	920	1,870	......	890
	upwind	520	(760)	......	390

[1] Concentrations determined on dry weight of material analyzed.

ELEMENT CONCENTRATIONS IN SOILS

Tables 6 and 7 present regression statistics for 28 elements in soils from the transects near Pocatello and Soda Springs, respectively. As discussed earlier, important relations between the concentrations of an element in soil and distance from processing sites are recognized as those that (1) show a statistically significant decrease in element concentration with increasing distance along at least one of the two transects, and (2) have a coefficient of determination of at least 0.50.

Nine elements (beryllium, fluorine, iron, lead, lithium, potassium, rubidium, thorium, and zinc) in

A-horizon soils downwind of the Pocatello operations (table 6) meet our criteria for being importantly related to processing-plant emissions. Six additional elements (copper, mercury, nickel, titanium, uranium, and vanadium) have regression lines whose slopes are significant at the 0.10 probability level and have coefficients of determination less than 0.50. Of these 15 relations, departures from the linear model are nonsignificant at the 0.10 probability level for 4 elements (beryllium, fluorine, mercury, and thorium). Therefore, for 11 of the 15 relations, a more complicated model might better describe the relation between element concentration and distance. In A-horizon soils upwind of the Pocatello operations (table 6), only two elements (iron and zinc) meet our criteria for being importantly related to processing-plant emissions.

In A-horizon soils downwind of the Soda Springs operations, only calcium meets our criteria; upwind, there are no elements that we consider importantly related to phosphate-processing emissions. Most relations in A-horizon soils attributable to Pocatello processing-plant emissions occur in the transect which, according to the wind patterns shown in figure 1, are downwind of the emission sources and hence reflect the typical primary path of airborne emissions in this area. The wind patterns at Soda Springs suggest that processing-plant emissions should appear in A-horizon soils along both transects. However, because of the soil variability at Soda Springs, element concentrations were not interpreted as being significantly related to distance from the emission sources.

Along all transects, only five elements in C-horizon soils meet our criteria for being important. We believe, however, that these element concentrations are not associated with processing operations because it is improbable that the precipitation in this area (about 50 cm annually) could have transported them through the soil profile to the C horizon in sufficient quantities since the processing factories began operations (about 50 years ago) to account for the statistically significant relations. Therefore, these relations are probably intrinsic to the natural environment (fig. 5).

Table 9 lists the estimated accumulations of those elements that presumably reflect processing-plant emissions in the soils near Pocatello, as well as the estimated average concentrations of selected elements in surface soils reported in the literature. The accumulation estimates are based on the linear regression model that describes the relationship between the logarithm of element concentration in soil and the logarithm of distance from the emission source. These element concentrations are total concentrations and may not represent in direct proportions the amounts of elements available to plants or subject to movement by percolating water. Table 9 includes nickel, uranium, and vanadium even though they do not meet our criteria for determining important relations. These elements are included because the slopes of their regression lines are significant between 0.05 and 0.10 probability levels and because they are demonsrated to be important in both sagebrush and cheatgrass along the same transect. Of the 12 elements in table 9, we consider fluorine, vanadium, and zinc to be present in unusually large amounts in the upper 5 cm of soil close to the processing plants.

CORESPONDENCE BETWEEN ELEMENTS IN PLANTS AND SOILS

Table 10 indicates for each transect the correlations between element concentrations in plants and total element concentrations in A-horizon soils and their levels of significance. Eleven elements (chromium, copper, fluorine, iron, lead, lithium, magnesium, nickel, uranium, vanadium, and zinc) showed correlations that are significant at the 0.10 probability level between soil and at least one plant species along at least one sample transect. A significant correlation may reflect a sensitive plant response to soil variation or direct introduction of airborne emissions to both plant and soil, or both.

Iron, lithium, magnesium, and lead showed significant correlations between soil and sagebrush but not between soil and grasses at both Pocatello and Soda Springs. However, the correlations were observed for the upwind transects only (table 9), and it is unlikely, therefore, that these relations reflect emissions from processing operations. Also, it is not possible to generalize that the concentrations of any of these elements in plants are due entirely to extraction of the elements from the soils because there are no consistent correlations for any single element among all transects.

We have discussed elsewhere the prediction of element concentrations in either plants or soils by using correlations between the fluorine and zinc concentrations in plants and the total concentrations of elements in soil along the downwind transect at Pocatello (Severson and Gough, 1976). We also discussed the difficulty of using such relations for prediction purposes at Soda Springs (Gough and Severson, 1976).

Other investigators have also reported the general lack of relation between element concentrations in plant ash and the total element concentration in soil. Shacklette, Sauer, and Miesch (1970) noted that the correlations between element concentrations in the ash of parts of trees or garden vegetables and the total ele-

TABLE 9.—*Estimated element concentrations in surface soils northeast (downwind) of phosphate-processing sites near Pocatello, Idaho, and average concentration of elements in soils as reported in the literature*

[Element concentrations (in ppm) between selected distances (in km) are calculated by intergration of prediction equations using the appropriate regression estimates for slope and intercept in table 6; estimates for background concentration represent the arithmetic means of element concentrations in surface soils sampled in this study 32 and 64 km northeast of Pocatello; percent variation explained is an estimate of the proportion of the total variation in element concentration along a transect that is accounted for by the regression; averages from the literature are arithmetic means and represent soil and surficial material from the conterminous United States; leaders (.....), no data availiable]

	Present Study						
	Estimated concentration between selected distances						Other studies[1] (average concentration)
Element	1-2 km	2-4 km	4-16 km	16-64 km	Estimated background	Percent variation explained	
Be	1.8	1.6	1.4	1.1	1.1	58.1	1
F	1,040	880	650	460	480	59.9	400
Fe	21,300	20,200	18,500	16,800	16,800	51.0	25,000
K	19,300	18,600	17,700	16,600	16,700	76.3	23,000
Li	25	23	20	18	18	64.4	25
Ni	26	24	20	16	19	27.4	20
Pb	28	25	20	16	16	75.2	20
Rb	86	80	69	60	61	57.9	.....
Th	13.9	12.5	10.3	8.3	8.3	70.9	.....
U	3.4	3.2	2.8	2.4	2.8	35.4	.....
V	110	98	82	63	78	28.1	76
Zn	120	102	76	55	58	76.3	54

[1] Shacklette, Boerngen, Cahill, and Rahill (1973); Shacklette, Boerngen, and Keith (1974); Shacklette, Boerngen, and Turner (1971); Shacklette, Hamilton, Boerngen, and Bowles (1971).

TABLE 10.—*Correlations between element concentrations in plants and in A-horizon soils along transects beginning near phosphate-processing sites at Pocatello and Soda Springs, Idaho*

[*r*, product-moment correlation coefficient between logarithms of concentration; *N*, number of sample pairs; **, *, indicate significance of the correlation at the 0.01 and 0.05 probability levels respectively; (...), no data availiable]

	Pocatello								Soda Springs							
	Northeast (downwind) transect				Southwest (upwind) transect				Northwest (downwind) transect				Southeast (upwind) transect			
	Big sagebrush		Cheatgrass		Big sagebrush		Cheatgrass		Big sagebrush		Bluebunch wheatgrass		Big sagebrush		Bluebunch wheatgrass	
Element	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*
Al	0.03	5	−0.37	6	0.39	6	0.10	6	0.48	6	−0.25	6	0.74	7	0.73	7
Co	...	...	...	...	...	...	...	...	−.34	6	−.25	6	.30	7	.64	7
Cr	.85	5	.76	6	.13	6	−.53	6	−.85*	6	−.83*	6	−.53	7	−.04	7
Cu	−.46	5	.32	6	0	6	0	6	.89*	6	−.52	6	−.05	7	.16	7
F	.95*	5	.99**	6	−.29	6	−.33	6	−.84*	6	−.84*	6	.10	7	.17	7
Fe	−.24	5	−.15	6	.67	6	−.13	6	−.13	6	.10	6	−.79*	7	.64	7
Li	.47	5	−.11	6	.89*	6	−.42	6	−.51	6	.32	6	.12	7	.58	7
Mg	−.09	5	.61	6	.24	6	...	...	.23	6	−.41	6	.83*	7	−.12	7
Mn	−.03	5	.41	6	...	...	−.16	6	.52	6	.09	6	.18	7	.14	7
Na	.03	5	.46	6	−.19	6	−.12	6	−.72	6	−.01	6	.67	7	.21	7
Ni	.78	5	.59	6	.94**	6	.52	6	−.70	6	.03	6	.29	7	.34	7
Pb	.13	5	−.48	6	−.87*	6	−.62	6	−.03	6	−.23	6	−.14	7	.17	7
Si	−.39	5	.48	6	.60	6	−.22	6	.07	6	−.25	6	.17	7	−.18	7
Ti	−.19	5	−.39	6	.75	6	0	6	.22	6	.15	6	−.38	7	.67	7
U	.93*	5	.86*	6	.49	6	.14	6	−.79	6	−.58	6	−.30	7	−.29	7
V	.80	5	.76	6	.40	6	−.09	6	−.57	6	−.18	6	.03	7	.06	7
Zn	.96**	5	.87*	6	.77	6	.80	6	−.80	6	−.59	6	.82*	7	.34	7

ment concentration in soil in a study in Georgia were inconsistent, were not reproducible, and probably resulted largely from chance. J. A. Erdman (botanist, U.S. Geol. Survey, oral commun., 1976) reported no good correspondence between chemistry of plant ash and total element concentration in soil for 29 elements in sagebrush and soil in the Powder River Basin of Wyoming and Montana.

This lack of correspondence between soil and plant chemistry is not surprising. Mitchell (1964, p. 342) reported that no two plant species growing in the same soil will necessarily extract the same quantity of an element. Furthermore, he reported that the element uptake by a single plant species varies if the plant is grown in different soils. Soil properties, such as pH, organic-matter content, microbial population, oxidation-reduction potential, and water regime, certainly affect the element availability in soil and influence the absorption of elements by plants. In addition, the gross composition of the soil, the total concentration of the element of interest, its concentration relative to that of other elements, and its compositional form or forms also affect the amount of the element available to, and absorbed by, a plant species.

ENVIRONMENTAL IMPLICATIONS

GENERAL IMPACT OF ELEMENT EMISSIONS ON HEALTH

Having assessed the elements contributed to selected plants and soils by emissions from phosphate-processing operations and having delineated zones of maximum influence along selected transects, we now apply the results of this study to an analysis of the potential, but unproven, effects of the emitted elements on the present and future health of plants and animals within the zones of influence. Such an application must be approached with caution because little is known about the biologic responses to chronic chemical insult at the molecular level. In the following discussion, we speculate on a few potential health effects, keeping in mind the constraints originally imposed on the study by its design and major purpose. Table 11 summarizes information from the literature on the toxicity of elements, determined to be important in this study, on plant and animal health. We did not attempt to review the literature relative to human health.

A very important aspect of element toxicity is the interaction between the elements. Bowen (1966) listed six basic mechanisms of toxic action of elements within the cell; these are their ability to (1) inactivate enzymes, particularly by the more electronegative metals such as copper, mercury, and silver (these metals are highly reactive with the amino, imino, and sulphydryl groups in proteins and thereby render them inactive); (2) function as antimetabolites (arsenate and chlorate substitute for phosphate and nitrate, respectively); (3) form stable precipitates or chelates with essential metabolites (aluminum, beryllium, scandium, titanium, yttrium, and zirconium react with phosphate); (4) catalyze the decomposition of ATP (adenosine triphosphate); (5) combine with the cell membrane and thereby affect its permeability (gold, cadmium, copper, mercury, lead, and free halogens affect the transport of sodium, potassium, and organic molecules across membranes); and (6) replace structurally or electrochemically important elements

TABLE 11.—*Suspected and known toxic effects of selected elements in plants and animals*

	On plants		On animals	
Element	Under natural conditions	Under man-induced conditions	Under natural dietary conditions	Under man-induced dietary conditions
Cadmium ..	Not demonstrated (Fleischer and others, 1974).	Moderate (Brooks, 1972). 3 ppm Cd in plant tissue caused growth depression (no species mentioned)[1] (Allaway, 1968). Growth reduction when nutrient solution contained 0.2 ppm—beets, beans, turnips; 1 ppm—corn, lettuce; 5 ppm—tomato, barley; 9 ppm—cabbage (Page and others, 1972).	Not demonstrated (Fleischer and others, 1974).	Moderate to high (Allaway, 1968). Suspected of killing a horse—80 ppm Cd in liver, 410 ppm Cd in Kidney (Lewis, 1972). 30–60 ppm Cd in diet of sheep for 191 days reduced growth and feed intake (Doyle and others, 1972). 45 ppm Cd in diet of rats for 6 months caused slight toxic symptoms (Underwood, 1971).
Chromium .	Probable. Growth of only certain species on serpentine soils (Brooks, 1972); excessive Ni, unfavorable Mg:Ca ratios, and deficiency of Mo may be limiting factors (Vanselow, 1966). Soil from "poison spots" in Oregon contain as much as 2–3 percent chromic oxide (McMurtrey and Robinson, 1938).	Severe (Brooks, 1972), moderate (Allaway, 1968). Cr in the form of chromates particularly toxic (McMurtrey and Robinson, 1938). 1,370–2,740 ppm Cr in soil caused chlorosis in citrus; 10–15 ppm Cr (as $K_2Cr_20_7$) in nutrient solution toxic to barley (Mertz, 1974a). 4–8 ppm Cr in leaves of corn was toxic[2] (Soane and Saunder, 1959).	Not demonstrated (Underwood, 1971).	Of little significance (Mertz, 1974a). Toxicity low (Allaway, 1968). 30–40 mg/kg (ppm) zinc chromate lethal to calves within 1 month, about 20 times that amount lethal to cows; 30 ppm Cr in liver diagnostic of Cr toxicity[3]. Potentially carcinogenic (Bowen, 1966). 50 ppm in diet associated with growth depression in experimental animals (Underwood, 1971).
Fluorine ...	Unusual. Plants growing in acid soils have accumulated toxic levels of F (Allaway, 1968).	Moderate when absorbed through the roots (Bowen, 1966). 30–300 ppm F in plant tissue generally reduced growth (depending on species and conditions)[4]; 200 ppm F in mature leaves of citrus associated with reductions in yield and growth[4]; <200 ppm F in tops of alfalfa caused no toxic effects[4] (National Research Council, 1971).	Unusual. Lethal fluorosis of sheep and other livestock reported following volcanic eruption on Iceland (Thorarinsson, 1970). Endemic fluorosis reported from areas where drinking water contained unusually high F (Underwood, 1971).	Moderate (Allaway, 1968). Ambient air primary source of F in forage as F not readily absorbed through roots (National Research Council, 1971). Concentration of F in dietary dry matter above which normal performance may be affected: beef or dairy heifers, 40 ppm; horses, 60 ppm; finishing cattle, 100 ppm; broiler chickens, 300 ppm; breeding hens, 400 ppm; turkeys, 400 ppm (National Research Council, 1974).

TABLE 11.—*Suspected and known toxic effects of selected elements in plants and animals—Continued*

Element	On plants		On animals	
	Under natural conditions	Under man-induced conditions	Under natural dietary conditions	Under man-induced dietary conditions
Lithium	Unusual. Citrus appears sensitive to an Li concentration in soil of about 12 ppm (Mertz, 1974b).	Slight (Brooks, 1972). Many crops susceptible to "injury" when Li is applied to soil in form of soluble salts (McMurtrey and Robinson, 1938). Many plants tolerant of "high" Li levels (Mertz, 1974b). Toxic to citrus when Li concentration in soil (as Li_2SO_4) was 2-5 ppm and in leaves 140-220 ppm[2] (Aldrich and others, 1951).	Unknown.	Of little significance (Mertz, 1974b).
Nickel	Probable. Growth of only certain species on serpentine soils (Brooks, 1972); excessive Cr, unfavorable Mg:Ca ratios, and deficiency of Mo may be limiting factors (Vanselow, 1966). Apetalous forms of anemone growing over nickel silicate deposit (Malyuga, 1964).	Severe (Brooks, 1972). Toxic to plant growth (McMurtrey and Robinson, 1938). Poisonous to plants even at relatively "low" concentrations; 40 ppm in tomato toxic, 150 ppm stopped growth[1] (Sauchelli, 1969). 12-246 ppm Ni in leaves of corn toxic, 14-34 ppm Ni in leaves of tobacco toxic[2] (Soane and Saunder, 1959).	Probably none. Relatively nontoxic (Underwood, 1971), like Zn, Mn, and Cr.	Moderate to low (Allaway, 1968). 700 ppm Ni in diet depressed growth of chicks; 1,600 ppm Ni depressed growth of young mice; 1,000 ppm Ni had no effect on rats or monkeys (Underwood, 1971). Potentially carcinogenic (Bowen, 1966).
Selenium	Probable. Toxic to most plants (McMurtrey and Robinson, 1938). Only certain species grow on seleniferous soils (Cannon, 1971).	Moderate (Brooks, 1972). 700 ppm Se in wheat caused no effects when sulfur content of plant high, <250 ppm Se caused chlorosis of leaves when sulfur content was low[4] (Trelease and Beath, 1949). Chlorosis and dwarfing of gumweed when grown in seleniferous test plots (Cannon, 1964). Toxic at levels of 50-100 ppm[4] (Allaway, 1968). Ability to absorb Se highly variable among species (Ganje, 1966).	Toxic effects by 3-5 ppm Se in forage produced in "animals"[4] (Oldfield, 1974). 4 ppm Se is tolerance limit in forage plants used for cattle and sheep[4] (Sullivan and Garber, 1947, cited by Sauchelli, 1969). Water containing 0.5 ppm Se potentially dangerous (Ganje, 1966).	High. >4-5 ppm Se in animal diets generally depressed growth rates (Allaway, 1968). Soils having >0.5 ppm Se regarded as potentially hazardous to livestock; 10-15 ppm Se in diet of swine produced selenosis within 2-3 weeks (Underwood, 1971).
Uranium	Probable. Long-term low-level natural radiation from pitchblende outcrops suspected as cause of deformities in fruit of bog bilberry, and of flower color variation in fireweed (Shacklette, 1962, 1964). Variation in flowers of princesplume growing over carnotite (Cannon, 1960).	Moderate (Brooks, 1972). Abnormal flowers noted on princesplume grown in test plots having a radiation source (Cannon, 1960).	Unknown, either from its chemical or radiation properties.	Unknown, either from its chemical or radiation properties.
Vanadium	Unknown.	Moderate (Brooks, 1972). Stunting of plants grown in test plots treated with sodium vanadate (Cannon, 1960). With "very low" levels of V in nutrient solutions plant growth was depressed (Allaway, 1968). >2 ppm V in tops probably toxic to peas and soybeans[2] (Pratt, 1966).	Unknown.	Moderate (Allaway, 1968). >20-25 ppm V in diet caused growth depression in chicks; 25 ppm V in diet of rats was toxic, 50 ppm caused diarrhea and mortality; relative toxicity of five elements to rats when fed 25 ppm diets: As<Mo<Te<Se (Underwood, 1971).
Zinc	Probably none (Allaway, 1968). Flower modifications in poppy growing in soils high in Zn (Malyuga, 1964). Chlorosis of plants growing in Zn peat underlain with sphalerite and dolomite (Cannon, 1955).	Moderate (Brooks, 1972). "Large" quantities in soil toxic to plants (McMurtrey and Robinson, 1938). Chlorosis of leaves of sweetpea, tomato, bluegrass, and violet when grown in nutrient solutions containing zinc acetate (Cannon, 1955). About 150 ppm Zn in leaves of corn, soybeans, wheat, barley, and oats appeared to be toxic; about 200 ppm in citrus leaves is toxic[1] (Sauchelli, 1969). >50 ppm Zn in navy bean decreased yields[1] (Melton and others, 1970). 2,000 ppm Zn in certain bryophytes produced no apparent toxic effects[5] (Shacklette, 1965).	Probably none (Allaway, 1968).	Low (Allaway, 1968). >1,000 ppm Zn in diet (as $ZnCO_4$) of weanling pigs depressed growth and caused arthritis and internal hemorrhage; 4,000 ppm, mortality high; 1,000 ppm Zn in diet of lambs reduced gains, 900 ppm Zn in diet of feeder cattle reduced gains (Underwood, 1971).

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[1] Concentrations assumed to be determined on the ashed material.

[2] Concentrations determined in the dried material.

[3] A. A. Case, clinical veterinarian, University of Missouri, written commun., 1977.

[4] Concentrations assumed to be determined on the dried material.

[5] Concentrations determined on the ashed material.

(lithium replaces sodium, cesium replaces potassium).

Figure 6 illustrates the major paths traveled by elements emitted into the air from phosphate-processing operations. Soils and ground water are more stable reservoirs for these elements; however, the elements may be incorporated into animals and humans either directly through the air or by first passing into vegetation that is then consumed. In an agronomic system, the food chain terminates at the herbivore level (if humans as omnivores are not considered) and can result in the concentration of elements in animal tissue. If there is no physiological mechanism to eliminate these elements, acute or chronic pathological symptoms may develop. Relative toxicity, however, depends on many interrelated factors, which we will discuss shortly. Monitoring the concentration of these elements in forage plants is an important method of predicting the quality of animal health.

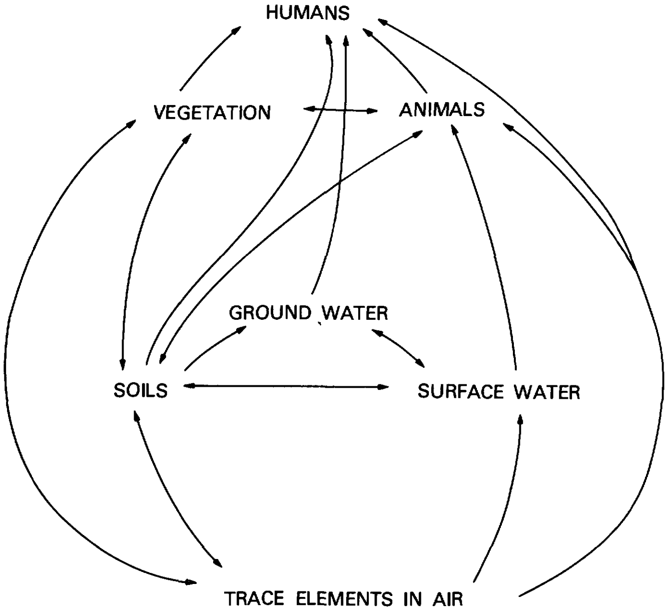

FIGURE 6.—Major pathways in the natural migration of trace elements from phosphate-processing emissions.

EMISSION-RELATED SURFACE CONTAMINATION OF VEGETATION

The influence of washing on the element concentration in vegetation was determined from a suite of washed and unwashed grasses. We collected 24 samples of bluebunch wheatgrass within a 100-m radius 2 km downwind of the elemental-phosphorus plant at Soda Springs. We washed one-half of these samples, using the methods discussed earlier, and then submitted for analysis these samples, along with the transect study samples, in a randomized sequence.

Of the 24 elements reported from washed and unwashed grass in table 12, 13 occurred in significantly greater amounts (probability level ⩽0.05) in the unwashed samples than in the washed samples. Washing removed aluminum, boron, cadmium, chromium, fluorine, iron, lead, nickel, selenium, silver, titanium, uranium, and zirconium. Of these 13 elements, aluminum, iron, titanium, and zirconium may be more closely linked to local dust contamination than to the processing-site emissions. The remaining nine elements are known constituents of the local phosphate rock and probably reflect, in one form or another, the elemental-phosphorus operation; of these elements, the concentrations of cadmium, chromium, fluorine, nickel, selenium, and uranium were identified in this study as increasing in sagebrush and grasses toward the phosphate-processing operations. Fluorine and silver are of particular interest because the unwashed grass samples contained more than three times more fluorine and almost three times more silver than did the washed samples.

TABLE 12.—*Chemistry of 24 washed and unwashed bluebunch wheatgrass samples collected 2 km downwind from an elemental-phosphorus plant, Soda Springs, Idaho*

[Values determined on plant ash, except as indicated. Values are in parts per million (ppm), except as indicated. Detection ratio is the number of samples having measurable property relative to the number of samples analyzed for that property; significance of *F* values were determined using 1 and 11 degrees of freedom of the numerator and denominator mean square, respectively; *, significant *F* value at the 0.05 probability level (critical value of 4.84);**, significant *F* value at the 0.01 probability level (critical value of 9.65). The number of samples having a measurable amount of each constituent is the same as the number of samples analyzed for that constituent, except for Ag, for which 22 samples had measurable amounts and Zr, for which 23 samples had measurable amounts]

Constituent	Geometric mean Washed grass	 Unwashed grass	*F* value
Ash[1]	6.7	8.6	34 **
Ag	2.7	6.1	92 **
Al[1]	.54	1.4	117 **
B	70	100	20 **
Ba	340	400	1.5
Ca[1]	4.5	3.9	0.8
Cd	57	82	13 **
Cr	78	200	55 **
Cu	72	66	2
F[1,2]	.0050	.0167	155 **
Fe[1]	.35	.74	41 **
Mg[1]	1.4	1.0	11 **
Mn	320	320	0
Mo	22	21	0
Ni	16	28	22 **
P	11,300	12,400	2
Pb	79	110	21 **
Se[2]	1.3	1.6	7.4 *
Si	390,100	380,400	0
Sr	250	190	8 *
Ti[1]	.020	.054	41 **
U	4.1	6.1	14 **
V	230	280	3
Zn	920	920	0
Zr	29	54	8.3 *

[1] Values in percent
[2] Value determined on dry materal.

The presence of apatite, shown by X-ray diffractograms of the dried plant-wash residue, suggests that the concentrations of calcium and phosphorus should, like fluorine, have differed significantly in washed and unwashed samples. The fact that they did not is possibly because these two elements are major constituents of the plants that were studied, and any additional amount present on the unwashed samples probably is relatively small compared to the total content of these elements in the plants.

Although the washed samples in this comparison study were more rigorously cleaned than they would be in nature, animals grazing near the processing operations following a heavy rain may be less likely to consume high levels of certain potentially toxic trace elements such as cadmium, chromium, fluorine, nickel, and silver. This comparison also demonstrates that precipitation may account for the highly variable fluorine values obtained on different sampling dates in the University of Idaho studies (University of Idaho, 1955–74). The great differences observed in our study between washed and unwashed plant samples exemplify the need to consider carefully the objectives of any sampling program conducted near a point source of emissions. The analysis of washed samples reveals the presence of elements largely incorporated by the plants—the type of information necessary to determine the concentrations of elements, suspected to be related to some emission source, that are potentially toxic to the plants. The analysis of unwashed forage plants, however, is more important in veterinary toxicology, but such analysis should consider the frequency of natural cleansing mechanisms (relative to sampling times).

IMPACT OF ELEMENT EMISSIONS ON PLANT HEALTH

In this report we correlate elevated levels of seven elements in vegetation as being significantly associated with phosphate-processing operations. Table 11 lists cases described in the literature where these and two additional elements, considered to be important in this study, have been demonstrated to be toxic to plants under both natural and man-induced conditions. (Table 1 lists the scientific names of the plants mentioned by their common names in table 11.)

Of the nine elements considered in table 11, chromium, nickel, and selenium generally are most toxic if absorbed from the soil. Fluorine, which is moderately toxic to plants if absorbed through the roots, is highly toxic if absorbed through foliage. The remaining five elements (cadmium, lithium, uranium, vanadium, and zinc) have little toxic effect under natural conditions. Radiation from uranium ore, however, was thought to have caused mutations in plants (Shacklette, 1962, 1964). Even under man-induced conditions, the relative toxicity of these last-mentioned five elements is considered to be low.

In this study, we did not attempt to identify specific plants having symptoms of element toxicity. The concentrations of toxic elements in plants presented in table 8 may be compared to levels of toxicity given in table 11. Several interdependent extrinsic and intrinsic factors influence relative element toxicity: (1) the genetics of the plant involved (differences being found even between varieties), (2) the availability of the emission-related elements to the plant, (3) the distance from the processing operations, and (4) the climate of the area. The values in table 8 indicate that, of the nine elements suspected as being contributed to vegetation 3 km from phosphate-processing operations, only chromium and zinc have concentration ranges known to be toxic to some plants. Fluorine may also affect plants but probably only along downwind transects. As discussed earlier, relatively high values for these elements occur only within about 4 km of the processing sites. Outside this zone, element concentrations in tissue are probably not sufficiently high to produce toxicity symptoms.

Even if conditions favor the development of toxicity symptoms in plants near the processing operations, the exact cause of the symptoms would remain uncertain. For example, Brewer (1966, p. 181) stated: "Although fluoride toxicity symptoms are relatively characteristic, a number of other factors, such as excessive salts, extreme moisture stress, and certain mineral deficiencies, will produce similar symptoms. For this reason, visual diagnosis must usually be confirmed by chemical analysis of the leaves or other plant tissues."

IMPACT OF ELEMENT EMISSIONS ON ANIMAL HEALTH

Since the early 1950's, farmers and ranchers have charged that the health of the livestock grazing near phosphate-processing operations at Soda Springs was being affected (Ben Gomm, U.S. Bureau of Land Management, written commun., 1976). Losses from fluorosis have been documented, and financial settlements for individual animals and, in some cases, whole herds have been made. All occurrences of fluorosis were reported from locations relatively near the processing plant and presumably were the result of the ingestion of forage having high concentrations of fluorine. Studies by scientists of the University of Idaho College of Agriculture (University of Idaho, 1955–74), have confirmed the existence of high levels of fluorine in alfalfa and grasses and certain cultivated plants near the processing sites at Pocatello and Soda Springs.

Comparison of tables 8 and 11 shows that fluorine may have concentrations in sagebrush and cheatgrass that are high enough to produce fluorosis in horses and cattle. Of the other elements, cadmium may be sufficiently high to affect the growth of sheep. The concentrations of chromium, vanadium, and zinc are high and under certain circumstances could be toxic. The concentrations of lithium, nickel, selenium, and uranium are relatively low in the plants sampled and probably pose an insignificant health hazard.

As with plant toxicity, the potential toxicity of these elements to grazing animals in the area depends on several factors: (1) the species and feeding habit of the animal (horses and sheep are more likely than cattle to consume contaminated soil as well as plants); (2) the animal's diet (a diet of predominantly perennial, as opposed to annual, plants likely would contain higher concentrations of the contaminants; supplemental feeds imported from outside the area would lessen the impact of locally grown forage); (3) the distance between animal grazing and emission source (an animal grazing more than 8 km from a source is unlikely to consume highly contaminated forage); (4) the season of the year (contaminants are more likely to be concentrated in forage plants at the end of the growing season than at the beginning), (5) the general activity of the phosphate-processing operations through time; (6) the winds and their influence on the distribution of emissions, which tend to settle out more downwind than upwind; and (7) the amount, form, and frequence of precipitation, which may wash and therefore dilute the surface contamination of forage.

SUMMARY

1. The concentrations of several elements in plants and soils tend to increase nearer the phosphate-processing operations. The southwest wind vector at Pocatello is the predominant vector; therefore, we found most of the significant relations between concentrations and processing emissions along the northeast (downwind) transect. At Soda Springs, both transect directions had strong wind vectors, although the wind is more frequent from the southeast. In the plants sampled near Soda springs, we found significant relations along both transect directions, but the more significant ones were along the northwest transect; in the soils, relations may have been obscured by the variability of the soil materials sampled.

2. The concentrations of cadmium, chromium, fluorine, selenium, uranium, vanadium, and zinc in plants were significantly associated with phosphate-processing operations. Lithium and nickel had frequent importance, and phosphorus and sodium had infrequent and questionable importance. Cadmium, chromium, fluorine, uranium, vanadium, and zinc had unusually high concentrations within 4 km of the processing sites. Concentrations of fluorine and uranium were highest at Pocatello; those of cadmium and zinc were highest at Soda Springs. Element content in plants decreased most precipitously within about 4 km of the processing sites and continued to decrease steadily but less dramatically as far as 16 to 32 km from the sites.

3. In general, sagebrush reflected higher concentrations of element emissions from the processing operations than did grasses.

4. In the A-horizon soils along the northeast (downwind) transect at Pocatello, beryllium, fluorine, iron, lead, lithium, potassium, rubidium, thorium, and zinc are interpreted as being significantly related to phosphate processing. Southwest (upwind) of Pocatello, the concentrations of iron and zinc in A-horizon soil decreased with increasing distance from the emission sources, but we believe that only zinc is possibly associated with the emissions.

5. Both transects at Soda Springs showed many conflicting relations in A-horizon soils, the element concentrations in some cases increasing with increasing distance from the emission sources; in others, decreasing. Because of these conflicts, we could not determine with confidence which relations, if any, were caused by the processing emissions.

6. We interpret all relations in C-horizon soils along all transects as not being caused by processing emissions.

7. We could discern no clear patterns for relations between the content of any element in the ash of plants and the total concentration of that element in A-horizon soils for any transect at either study area. Therefore, we could make no generalizations about plant uptake of emission-related elements from the soil or about the availability of these elements to plants.

8. Of the nine elements (cadmium, chromium, fluorine, lithium, nickel, selenium, uranium, vanadium, and zinc) commonly added to vegetation near phosphate-processing operations, the concentrations of only chromium, zinc, and possibly fluorine are within the ranges documented as being toxic to some plants. These high levels generally occur only downwind and within 8 km of the processing operations. In this study, however, we did not try to identify instances of toxicity of these or any other elements in the plants studied.

9. Of the same nine elements commonly added to vegetation near the processing sites, we speculate that only cadmium and fluorine may be present in sufficiently high concentrations, at some times and under certain circumstances, to be toxic to grazing animals. However, chromium, vanadium, and zinc concentrations are also high, and these elements could potentially be toxic. Of these five elements, only fluorine has been positively implicated with adverse effects on animal health. As in the soils, the high concentrations of these five elements are generally downwind and within 8 km of the processing operations. Additional studies are needed to assess adequately the effects of element emissions from phosphate processing on animal and human health.

10. By comparing the chemistry of washed and unwashed grass samples collected 2 km downwind of an elemental-phosphorus plant at Soda Springs, we discovered that the unwashed samples had significantly higher concentrations of 13 elements, most of which are considered to be environmentally important. Periodic cleansing by rainfall may alter appreciably the concentration of elements consumed by grazing animals. Washed plants contained high concentrations of the potentially toxic elements fluorine and silver, and unwashed samples contained as much as three times these concentrations.

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