Draft

2001 Fugitive Dust Data Report

DeLong Mountain Regional Transportation System, Alaska

Prepared for

Teck Cominco Alaska Incorporated
Anchorage, Alaska

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Acronyms and Abbreviations

ADEC	Alaska Department of Environmental Conservation
DMTS	DeLong Mountain Regional Transportation System
NPS	National Park Service
the haul road	DMTS Road
the port	DMTS Port facility

Executive Summary

This report presents the results of sampling work performed in 2001 on behalf of Teck Cominco Incorporated to gain a better understanding of elevated levels of metals detected along the DeLong Mountain Regional Transportation System (DMTS) road. This haul road is used by trucks to transport zinc and lead concentrates from Red Dog Mine to the DMTS port facility for shipping.

The 2001 sampling program expanded on the moss sampling work conducted by NPS in the Cape Krusenstern National Monument in 2000 in order to gain a better understanding of the sources, transport, and deposition of fugitive dust. Samples collected include road surface soil, road soil cores, fine-grained material on the road shoulder, dustfall collected along the road, and vegetation (moss, lichen, willow, and berries). Soil and water samples were also collected from material sites along the DMTS road, from which construction rock for road grading and water for road watering are obtained. Surface water samples were collected from five creeks that the DMTS road crosses between the mine and the port site.

Road sampling results indicate that the elevated metals concentrations occur primarily on the surface of the road and that construction materials are not a significant source. The most likely primary source appears to be the tracking of metals in the form of powdered concentrates by haul trucks. Truck spills do not appear to be a significant source of metals to the road surface. (Note that the word "tracking," as used in this report, refers to the process of transport of dusts on all surfaces of the haul trucks, not just an obvious visible tracking by truck tires.)

A comparison of results for various sample types, including vegetation samples, indicates a fairly consistent pattern of elevated concentrations near each end of the DMTS road, and lower concentrations through the middle section of road. Results for moss samples collected on transects in the central portion of the road were similar to results published by NPS in the Cape Krusenstern National Monument study. Samples on transects nearer to either end of the DMTS road were higher.

This study shows that the entire DMTS road is not a uniform source of metals to the surrounding environment. Rather, the findings show that elevated metals largely occur at either end of the DMTS road, and that operational improvements to minimize tracking of concentrates are likely to result in a significant reduction in fugitive dust deposition in surrounding areas.

The results of the berry sampling are consistent with the berry sampling done by ADEC to assess potential risks to human health. The potential ecological effects of elevated metals in vegetation will be evaluated in follow-on work to be performed in 2002.

1 Introduction

1.1 Background/Overview

The Red Dog Mine is located approximately 50 miles east of the Chukchi Sea, in the western end of the Brooks Range of northern Alaska (see Figure 1), which is an area of widespread natural mineralization containing exceptionally high concentrations of metals. The mine is located on lands owned by NANA Regional Corporation (NANA) and operated by Teck Cominco Alaska Incorporated (Teck Cominco). Ore containing zinc and lead is processed at the Red Dog Mine to produce zinc and lead concentrates in a powder form. The zinc concentrate contains approximately 55 percent (550,000 ppm) zinc, and 0.298 percent (2,980 ppm) cadmium, which is associated with the zinc mineral. The lead concentrate contains approximately 59 percent (590,000 ppm) lead and 0.082 percent (820 ppm) cadmium. These concentrates are hauled year-round from Red Dog Mine via the DeLong Mountain Regional Transportation System (DMTS) Road (the haul road) to concentrate storage buildings at the DMTS Port facility (the port), where they are stored for subsequent loading onto ships during the summer months.

The haul road is a 52-mile long, 30-ft wide all-weather gravel-surface overland road connecting the Red Dog Mine with the port (see Figure 2). The haul road crosses land owned by NANA, the state, and the federal government (leased to NANA). The road was constructed in 1987−1988 using a 6-ft-thick gravel bed laid over a geotextile mat placed directly on the original ground surface. The haul road includes nine bridges spanning drainages between the port and Red Dog Mine. The DMTS is owned by Alaska Industrial Development and Export Authority, which has contracted with Teck Cominco for its use, operation, and maintenance.

Fugitive dust control has been a high priority at Red Dog Mine, port, and along the haul road over the years. A moss study done in the year 2000 by the National Park Service (NPS) (Ford and Hasselbach 2001) indicated that there are elevated concentrations of metals in mosses along the haul road, bringing increased interest in fugitive dust issues at Red Dog Mine. NPS conducted an additional study in 2001; however, the results of that study are not yet available, and have not been published.

This report presents the results of sampling work done in 2001 by Teck Cominco and by Exponent, under contract to Teck Cominco. This sampling program expanded on the moss sampling work conducted by NPS in the Cape Krusenstern National Monument in order to broaden the understanding of potential ecological effects of fugitive dust from the Red Dog Mine, the port, and the haul road. The 2001 sampling efforts were focused on characterizing the conditions along the haul road in order to gain a better understanding of the sources, transport, and deposition of fugitive dust. This sampling program was designed to link vegetation sampling stations with road dustfall collection and road surface sampling stations in order to facilitate evaluation of source/receptor relationships. The vegetation data will be used subsequently to conduct an ecological risk screening evaluation and to establish relationships between moss sample results and sample results for other forage species. In addition, surface water sampling was conducted along the haul road to assess potential transport of fugitive dust to water surrounding the transportation corridor.

1.2 Exponent Sampling Program

The Exponent sampling program for 2001 included several types of samples collected along the haul road. Samples included surface soil, soil cores, road shoulder fines, dustfall, and vegetation (moss, lichen, willow, and berries). Samples were also collected from material sites along the haul road, from which construction rock for road grading and water for road watering are obtained. Figure 2 illustrates all of the sampling locations from the Exponent 2001 sampling program.

Samples were analyzed for a suite of metals, including aluminum, arsenic, cadmium, calcium, iron, lead, magnesium, and zinc. The primary metals of interest are zinc, lead, and cadmium, as these are present at concentrations of potential concern, and because zinc and lead are primary components of the ore concentrates produced by the mine and trucked down the haul road to the port site.

Each of the focus areas of the Exponent sampling program is described further in the following sections. Additional details are provided in the work plans and quality assurance project plan (Exponent 2001a,b,c). Variations from the work plans are summarized in Appendix A.

1.2.1 Road Soil Sampling

Soil samples were collected along the haul road to better understand the source of fugitive dust and the potential for resuspension or transport of dust away from the roadway. The work involved collecting composite surface samples and core samples from the road, and fine material samples from the edge of the road shoulder. This part of the sampling program was designed to investigate how metals concentrations in the road surface vary with distance from Red Dog Mine and the port (e.g., as a result of tracking of concentrate dust by haul trucks), and how they vary with depth within the road surface. (Note that the word "tracking," as used in this report, refers to the process of transport of dusts on all surfaces of the haul trucks, not just an obvious visible tracking by truck tires.)

1.2.2 Material Site Sampling

Samples of construction rock materials used for road surfacing, and water applied to the road for dust control, were collected from various source sites. The purpose of these samples was to determine whether these construction rock or water sources could be contributing metals to the haul road.

1.2.3 Dustfall Sampling

Dustfall collectors were installed along the length of the haul road to provide a way to assess the performance of dust control measures implemented by Teck Cominco. Four dustfall collectors were placed at each of seven sampling stations along the haul road (two on each side of the road). This arrangement allows for the possibility of rejecting samples (e.g., freeze breakage of jars, etc.) and for comparison between stations and between time periods. Dustfall collection methods were implemented using equipment similar to that which has been used previously for dustfall collection around Red Dog Mine and the port. The collection equipment and methods are based on established procedures (ASTM 1998), with the exception that aerodynamic collars have not been used. Instead, water has been used in the jars to prevent carryout of the deposited dust.

1.2.4 Vegetation Sampling

In the summer of 2000 and 2001, NPS conducted studies of the effects of fugitive dust from the haul road on metals deposition in Cape Krusenstern National Monument (Ford and Hasselbach 2001). As part of the 2000 study, NPS sampled *Hylocomium splendens* (a feather moss used in long-term atmospheric deposition monitoring programs) along transects running perpendicular to the haul road, in order to document concentrations of cadmium, lead, zinc, and other metals in moss with respect to distance from the road (Ford and Hasselbach 2001). Mosses generally obtain their nutrients from the atmosphere, either in precipitation or dustfall, rather than from the soil, and therefore concentrations of metals in moss reflect atmospheric sources such as fugitive dust (Rühling and Steinnes 1998). When unwashed moss samples are analyzed for metals concentrations, the results include not only the metals content of the moss tissue (i.e., the metals actually taken up into the moss) but also the metals content of the dust particles adhering to the surface of the moss. NPS submitted unwashed moss samples for analysis in its dustfall study (Ford and Hasselbach 2001).

Exponent expanded the geographic scope of the pilot NPS study by sampling *H. splendens* along haul road transects outside the national monument, at locations where NPS did not sample, including transects near the mine and port facility (Figure 1). Exponent also collected moss samples at former truck spill sites along the haul road, and in a grid pattern within the port site (Figure 1). To allow for data comparisons, Exponent used collection and processing methods virtually identical to those employed by NPS (Ford and Hasselbach 2001) as described in Exponent (2001b) and in Appendix A of this report.

Another objective of Exponent's vegetation sampling program was to obtain metals data for forage species for use in evaluating ecological risks associated with fugitive dust. Exponent sampled lichen (*Peltigera aphthosa*), willow leaves (*Salix pulchra*), and salmonberries (*Rubus chamaemorus*) along haul road transects and at the port site, and submitted the unwashed samples for metals analyses. Resident and migratory wildlife may eat these or comparable species more frequently than they consume *H. splendens*, and thus metals concentrations in these species may be more relevant to ecological risk assessment than metals concentrations in *H. splendens*. Exponent selected *Peltigera aphthosa*, a foliar lichen, as the representative lichen species, because it was abundant in several habitat types, was straightforward to identify in the field, and often co-occurred with *H. splendens*, which facilitated collecting both species at the same sampling station. There are also baseline metals data available for this species in Alaska (Crock et al. 1992a). *Salix pulchra* was also common at sampling stations. *Rubus chamaemorus* was common at the port site and available along the haul road as well.

1.3 Teck Cominco Surface Water Sampling

Teck Cominco collected surface water samples from five creeks that the haul road crosses between the mine and the port site. Samples collected at each crossing included upstream samples, samples immediately downstream of the road, and samples further downstream where that stream joins another creek. Samples were collected in four consecutive months: July, August, September, and October. These samples were collected in accordance with procedures specified in the National Pollutant Discharge Elimination System quality assurance plan (Teck Cominco 1998).

2 Sampling Results

This section summarizes the results of the road soil, material sites, dustfall, vegetation, and surface water samples. Figure 2 illustrates the sample locations and types and their spatial relationship to each other. Table 1 shows the relationship between station names for the various sample types in a tabular format. Summary statistics tables are provided in Appendix B for each sample type. Sample results tables are presented in the main part of this document, as referenced below. An analytical laboratory quality assurance report is included as Appendix C.

2.1 Road Soil Sampling Results

Soil sampling along the haul road included road surface, road core, and road shoulder fine material samples. Road surface samples were collected at more closely spaced stations than the other sample types. At nine of these stations, all three types of road samples were collected: road surface, road cores, and road shoulder samples (see Figure 2 and Table 1).

2.1.1 Road Surface

Soil samples were collected from the surface of the haul road at 34 locations over its length. The sample locations were spaced closer together at either end of the road because there was reason to expect that concentrations would be higher in those areas than in the middle portion of the road. All road surface samples were analyzed for arsenic, cadmium, lead, and zinc. A select subset of stations was also analyzed for aluminum, calcium, iron, and magnesium. The metals analytical results for these samples are presented in Table 2. Lead concentrations ranged from 30.3 to 1,180 mg/kg, with an average of 250 mg/kg. Cadmium concentrations ranged from 1.2 to 39.3 mg/kg, with an average of 5.5 mg/kg, and zinc concentrations ranged from 185 to 6,610 mg/kg, with an average of 940 mg/kg. Note that the average values listed above are not representative of the entire haul road. They are conservatively high, because more samples were collected near the port and near the mine than were collected in the central section of the road. Samples collected at stations RS-11 through RS-28, representing approximately 43 miles through the central portion of the road, had average concentrations of 90.1 mg/kg lead, 2.10 mg/kg cadmium, and 369 mg/kg zinc.

Road surface concentrations are lowest throughout most of the middle section of the haul road, with the highest concentrations found near the port and the mine sites. Figure 3 illustrates concentration versus distance along the haul road for lead, zinc, and cadmium. The highest concentrations were found at the port site where the haul trucks exit from unloading at the concentrate storage buildings. Metals concentrations decline with distance from the port site. At about 4 miles from the port site, concentrations decline to a baseline level that is fairly consistent for most of the haul road. Near the mine, beginning at about mile 46 from the port site, metals concentrations begin rising again. Figure 3 also shows locations of lead and zinc truck spills. There appears to be no relationship between the former spill locations and the road surface concentrations.

In addition to metals, a grain density analysis and a particle size distribution analysis were also performed on the road surface samples. These data are presented in Table 3.

2.1.2 Road Cores

Core samples were collected at nine stations along the haul road in order to characterize the vertical distribution of metals within the material that makes up the road. Cores were collected to a depth of 12 in. Three samples were collected from each core in the following depth intervals: 0–4, 4–8, and 8–12 in. All road core samples were analyzed for aluminum, arsenic, cadmium, calcium, iron, lead, magnesium, and zinc. The analytical results for these samples are presented Table 4, and are illustrated in Figure 4 along with other road sampling results. Metals concentrations in the road core samples are generally highest in the shallow core samples, and decrease with depth. Lead concentrations ranged from 13.5 to 200 mg/kg with an average of 76 mg/kg in the 0–4 in. samples; 4.4 to 121 mg/kg with an average of 49 mg/kg in the 4–8 in. samples; and 3.8 to 61 mg/kg with an average of 20.2 mg/kg in the 8–12 in. samples. Cadmium concentrations ranged from 1.2 to 3.8 mg/kg with an average of 1.85 mg/kg in the 0–4 in. samples; 1 to 5.1 mg/kg with an average of 1.93 mg/kg in the 4–8 in. samples; and 1.3 to

1.55 mg/kg with an average of 1.43 mg/kg in the 8−12 in. samples. Zinc concentrations ranged from 90 to 566 mg/kg with an average of 292 mg/kg in the 0−4 in. samples; 42.2 to 970 mg/kg with an average of 247 mg/kg in the 4−8 in. samples; and 26.5 to 264 mg/kg with an average of 92 mg/kg in the 8−12 in. samples. Note that the average values listed above are not representative of the entire haul road. They are conservatively high, because more samples were collected near the port and near the mine than were collected in the central section of the road. Samples collected at stations RC-02 through RC-05, representing approximately 38 miles through the central portion of the road, had average concentrations of 53.7 mg/kg lead, 1.35 mg/kg cadmium, and 232 mg/kg zinc in the 0−4 in. samples; 27.3 mg/kg lead, 1.10 mg/kg cadmium, and 132 mg/kg zinc in the 4−8 in. samples; and 25.5 mg/kg lead, 1.28 mg/kg cadmium, and 141 mg/kg zinc in the 8−12 in. samples.

2.1.3 Road Shoulder Fines

Samples of fine soils were collected from the foot of the haul road shoulder at nine stations along the road. These nine stations correspond to the stations where core samples were collected from the road. The road shoulder samples were collected to characterize the finest material from the haul road that is most likely to be representative of fine source material that may become airborne. All road shoulder fines samples were analyzed for aluminum, arsenic, cadmium, calcium, iron, lead, magnesium, and zinc. The metals analytical results for these samples are presented in Figure 4 and Table 5. Lead concentrations ranged from 116 to 2,440 mg/kg with an average of 610 mg/kg. Cadmium concentrations ranged from 3.75 to 29.3 mg/kg with an average of 11.4 mg/kg. Zinc concentrations ranged from 565 to 4,910 mg/kg with an average of 2,050 mg/kg. Note that the average values listed above are not representative of the entire haul road. They are conservatively high, because more samples were collected near the port and near the mine than were collected in the central section of the road. Samples collected at stations RF-02 through RF-05, representing approximately 38 miles through the central portion of the road, had average concentrations of 185 mg/kg lead, 4.67 mg/kg cadmium, and 964 mg/kg zinc.

In addition to metals, a grain density analysis and a particle size distribution analysis were also performed on the road shoulder fines samples. These data are presented in Table 6.

2.2 Material Site Sampling Results

Samples of soil and water were collected from several material sites that are used to supply fill for road repair and water for road watering to minimize dust. These samples were collected to determine whether these materials could be sources of the metals observed on the haul road. All material site soil and water samples were analyzed for aluminum, arsenic, cadmium, calcium, iron, lead, magnesium, and zinc. The analytical results for the soil samples are presented in Table 7, and water samples are presented in Table 8.

Composite soil samples were collected from material sites MS-2, MS-3, MS-5, MS-6, and MS-9. Lead concentrations in these samples ranged from 8.6 to 36.9 mg/kg with an average of 24.4 mg/kg. Cadmium concentrations ranged from 1.1 to 3.3 mg/kg with an average of 1.9 mg/kg. Zinc concentrations ranged from 87.4 to 199 mg/kg with an average of 129 mg/kg.

Water samples were collected from ponded water that is used for road watering, from material sites MS-2, MS-3, MS-6, and MS-10. Cadmium, lead, and zinc were all undetected in these samples. Lead detection limits in these samples were 2.2 μg/L or lower, cadmium detection limits were 5 μg/L, and zinc detection limits were between 10 and 78 μg/L.

2.3 Dustfall Sampling Results

Dustfall samplers were installed at seven stations along the haul road, corresponding to seven stations where road surface, road core, and road shoulder fines samples, as well as vegetation sample transects, were located. The first set of monthly dustfall data is included in this report for comparison with other sample results to help evaluate fugitive dust sources and deposition patterns. This first set of dustfall data will also serve as a baseline for comparison of future data, allowing an assessment of whether metals concentrations in the dustfall decline over time in response to dust control measures. The first 1-month dustfall collection was completed before Teck Cominco replaced the older-style haul trucks with new trucks, which have a hydraulically closed steel cover and fewer external surfaces to collect dust. The dustfall results are expected to vary due to a number of factors, including meteorological conditions such as precipitation, wind direction and speed, as well as the volume of traffic on the haul road, road maintenance conditions, and so forth. As a result, direct month-to-month comparisons may not always be valid. Instead, the monthly data sets need to be thoroughly evaluated relative to factors potentially affecting the results. The comparison of longer-term trends (i.e., year-to-year) will likely be more meaningful. As additional sets of dustfall data are collected, the data will be evaluated in accordance with the dustfall collector sampling and analysis plan (Exponent 2001d).

All dustfall samples were analyzed for aluminum, arsenic, cadmium, calcium, iron, lead, magnesium, and zinc. Results of the first round of dustfall collection results (August 21 through September 20, 2001, referred to as the September 2001 results) are provided in Table 9. The results are converted to deposition rates, which are presented in Table 10 and illustrated in Figure 5. Deposition rates for lead ranged from 20.9 to 851 $\mu g/m^2$/day with an average of 214 $\mu g/m^2$/day. Deposition rates for cadmium ranged from 0.809 to 36.4 $\mu g/m^2$/day with an average of 7.61 $\mu g/m^2$/day. Zinc deposition rates ranged from 54.9 to 6,230 $\mu g/m^2$/day with an average of 1,250 $\mu g/m^2$/day. The total mass deposition rate ranged from 41.6 to 937 mg/m^2/day with an average of 405 mg/m^2/day. Note that the average values listed above are not representative of the entire haul road. They are conservatively high, because more samples were collected near the port and near the mine than were collected in the central section of the road. Samples collected at stations D-02 through D-05, representing approximately 38 miles through the central portion of the road, had average dustfall deposition rates of 178 $\mu g/m^2$/day lead, 6.01 $\mu g/m^2$/day cadmium, 1,040 $\mu g/m^2$/day zinc, and 418 mg/m^2/day total dustfall.

2.4 Vegetation Sampling Results

2.4.1 Moss

Exponent collected *Hylocomium splendens* along seven transects established perpendicular to the haul road between the mine and port facility (Figure 2). At all transects, moss samples were collected at distances approximately 3, 100, and 1,000 m from the haul road. At transects HR-06 and HR-07, additional moss samples were collected approximately 2,000 m from the road. Moss samples were analyzed for aluminum, arsenic, cadmium, calcium, iron, lead, magnesium, and zinc. The results of the metals analyses are reported in Table 11.

Exponent also collected *Hylocomium splendens* at 9 spill sites along the haul road (Figure 6) and at 14 stations around the port facility corresponding to dustfall sampling locations positioned on a 1,000 by 1000-ft grid pattern (Figures 7, 8, and 9). These moss samples were analyzed for cadmium, calcium, lead, and zinc, and the results are reported in Tables 12 and 13, respectively.

Cadmium, lead, and zinc were detected in all moss samples collected along haul road transects (Table 11). Cadmium, lead, and zinc concentrations ranged from 0.502 to 27.2 mg/kg, 9.54 to 875 mg/kg, and 59.2 to 4,180 mg/kg dry weight, respectively (Table 11). Moss collected along transects HR-01 and HR-02, near the port facility, and transects HR-06 and HR-07, near the mine, tended to have higher metal concentrations than moss collected along other haul road transects. For all transects except HR-06, concentrations of all three metals were highest in samples collected 3 m from the road, and decreased with increasing distance from the road (Table 11; Figures 10, 11, and 12). At HR-06, the highest concentrations were seen in samples collected at 1,000 m from the road, but decreased about 3-fold at 2,000 m.

For all transects, concentrations of aluminum, arsenic, calcium, iron, and magnesium were highest in moss collected at 3 m and decreased with increasing distance from the road, with the exception of calcium, which increased in concentration from 1,000 m to 2,000 m along transects HR-06 and HR-07 (Table 11). The trend of greatest metal concentrations at transects near the mine and port that was observed for cadmium, lead, and zinc was less apparent for the other five metals, particularly for calcium and magnesium, which exhibited highest concentrations at transects HR-03 and HR-04 (Table 11).

Concentrations of cadmium, lead, and zinc in spill site moss samples ranged from 6.65 to 15.5 mg/kg, 338 to 995 mg/kg, and 822 to 2,580 mg/kg dry weight, respectively (Table 12; Figure 6). There are no discernible spatial trends in metals concentrations in spill site moss samples with distance from the mine or port site.

Moss collected at port site stations included samples with the highest individual cadmium, lead, and zinc concentrations measured in vegetation in this study. Cadmium, lead, and zinc concentrations in port site moss ranged from 5.53 to 48.4 mg/kg, 323 to 1,670 mg/kg, and 1,260 to 6,480 mg/kg dry weight, respectively (Table 13). The distribution patterns of lead and zinc among port site sampling stations were very similar (Figures 7 and 8), with highest concentrations of both metals measured at stations PO-05 and PO-06. The distribution pattern for cadmium was different than for the other two metals with highest concentrations occurring at stations PO-10 and PO-16 (Figure 9).

2.4.2 Lichen

Exponent collected *Peltigera aphthosa* at various locations along haul road transects HR-01, HR-02, HR-03, HR-05, and HR-07 (Figure 10), and at port stations PO-04, PO-11, and PO-17 (Figure 7). These samples were submitted for laboratory analysis in an unwashed condition. Lichen samples were analyzed for cadmium, calcium, lead, and zinc. Haul road and port site results are reported in Tables 14 and 13, respectively. Cadmium, lead, and zinc concentrations in lichen collected from haul road transects ranged from 0.259 to 11.9 mg/kg, 6.86 to 660 mg/kg, and 82.2 to 1,720 mg/kg dry weight, respectively (Table 14; Figures 10, 11, and 12). Along haul road transects, metal concentrations in lichen samples were consistently lower than the levels measured in moss samples collected from the same sampling location. On transects HR-02 and HR-07 where lichen was sampled at multiple distances, metal concentrations decreased with increasing distance from the road.

Cadmium, lead, and zinc concentrations in port site lichen ranged from 5.42 to 5.94 mg/kg, 182 to 218 mg/kg, and 1,010 to 1,050 mg/kg dry weight, respectively (Table 13). At the port, metal concentrations were consistently lower in lichen than in moss samples collected from the same location, and variability in lichen metal concentrations was low relative to moss (Figures 7, 8, and 9).

2.4.3 Willow

Exponent collected *Salix pulchra* (diamond-leaf willow) leaves at all sampling distances along haul road transects HR-02, HR-03, and HR-07 (Figure 10), and at port sites PO-07, PO-13, and PO-17 (Figure 7). These samples were submitted for laboratory analysis in an unwashed condition. Willow leaves were analyzed for cadmium, calcium, lead, and zinc. Haul road and port site results are reported in Tables 15 and 13, respectively. Overall, willow leaves had much lower metal concentrations than co-located moss or lichen samples. Along haul road transects, cadmium, lead, and zinc concentrations in willow leaves ranged from 0.499 to 7.75 mg/kg, 0.431 to 45.6 mg/kg, and 122 to 546 mg/kg dry weight, respectively (Table 15).

Cadmium, lead, and zinc concentrations in port site willow leaves ranged from 0.753 to 1.66 mg/kg, 4.8 to 15.6 mg/kg, and 196 to 290 mg/kg dry weight, respectively (Table 13).

2.4.4 Salmonberries

Exponent collected *Rubus chamaemorus* (salmonberry or cloudberry) fruits at approximately 3 and 100 m from the haul road at transects HR-01 and HR-04 (Figure 10), as well as at port stations PO-03, PO-17, and PO-18 (Figure 7). These samples were submitted for laboratory analysis in an unwashed condition. The salmonberries were analyzed for cadmium, calcium, lead, and zinc. Haul road and port site results are reported in Tables 16 and 13, respectively. Metals concentrations in salmonberries were low in comparison to all other vegetation types sampled. Along haul road transects, cadmium, lead, and zinc concentrations in salmonberries ranged from 0.0581 to 1.58 mg/kg, 0.462 to 13.5 mg/kg, and 15.8 to 70.5 mg/kg dry weight, respectively (Table 16).

At the port, cadmium, lead, and zinc concentrations in port site berries ranged from 0.229 to 0.415 mg/kg, 0.565 to 0.820 mg/kg, and 17.7 to 25.8 mg/kg dry weight, respectively (Table 13).

2.5 Surface Water Sampling Results

Surface water samples were collected from five creeks at locations along the haul road. Samples collected at each crossing included upstream samples, samples immediately downstream of the road, and samples further downstream where that stream joins another creek. Samples were collected in four consecutive months: July, August, September, and October. All stream samples were analyzed for aluminum, cadmium, calcium, iron, lead, magnesium, and zinc. The metals concentrations in these unfiltered water samples were reported as total metals in μg/L. The analytical results for these samples are presented in Figures 13, 14, and 15, and Table 17. Lead was detected in 16 of 89 analyses. Detected lead concentrations range from 0.05 to 2.37 μg/L, with an average of 0.38 μg/L. Cadmium was detected in just 3 of 89 analyses. Detected cadmium concentrations ranged from 0.1 to 0.2 μg/L. Zinc was detected in 14 of 89 analyses. Zinc concentrations ranged from 2.07 to 34.4 μg/L, with an average of 7.5 μg/L.

3 Discussion and Evaluation of Data

This section includes discussions of patterns or trends in the data, reviews of results relative to regulatory cleanup standards or criteria, and comparisons of observed concentrations with values from available literature and published studies.

3.1 Road Soil Data Review

A comparison of the road surface, core, and shoulder sample results (Figure 16) indicates that the source of the metals is not the soils making up the road base, but is primarily a surface phenomenon. Soil and water sample results from the material source areas confirmed that these are not a significant source of metals to the road (Section 2.2).

Soil cleanup criteria provided in 18 AAC 75 for cadmium, lead, and zinc are 100, 1,000, and 30,000 mg/kg, respectively (ADEC 1999a). The cadmium and zinc criteria are for areas of Alaska with less than 40 in. of annual precipitation—the "under 40 inch zone." The lead criterion is specified separately, based on commercial or industrial land use. The "under 40 inch zone" criteria are a bit lower than "arctic zone" criteria. The "arctic zone" is defined as areas north of latitude 68° north, although areas south of that latitude can be considered an "arctic zone" on a site-specific basis, based on a demonstration that the site is underlain by continuous permafrost. The haul road crosses latitude 68° north, so a portion of the road, and the mine site, would meet that criteria. The "arctic zone" definition could potentially apply to the haul road and port site area as well. However, at this time, for the purposes of reviewing the haul road and port site soil data, we will use the more conservative cadmium and zinc criteria listed above for the "under 40 inch zone."

3.1.1 Road Surface

Road surface sample concentrations were all below the Alaska Department of Environmental Conservation (ADEC) cadmium, lead, and zinc soil cleanup levels, with the exception of one sample. A lead concentration of 1,180 mg/kg (as compared with the cleanup level of 1,000 mg/kg) was measured in sample RS-04, located just outside where the haul trucks exit from unloading at the concentrate storage buildings. The road surface sample data indicate clearly that tracking of concentrate from the unloading building has been a problem. No obvious correlation was observed between spill site locations and concentration (see Figure 3).

3.1.2 Road Cores

Metals concentrations were highest in the shallow 0−4 in. soil core samples collected from the haul road, decreasing with depth to the 8−12 in. core samples (Figure 16). All core sample concentrations for cadmium, lead, and zinc were well below the ADEC cleanup standards.

3.1.3 Road Shoulder Fines

Road shoulder fines sample concentrations of cadmium and zinc were all below the ADEC cleanup levels. However, two samples had concentrations of lead that exceeded the 1,000 mg/kg standard. Sample RF-Port, the first road shoulder sample station to the east of the concentrate storage buildings, had a lead concentration of 1,060 mg/kg (Figure 4). Sample RF-06, located on a curvy stretch of road (see close-up on Figure 2), had a lead concentration of 2,440 mg/kg. Cadmium and zinc were also elevated at this sample location, although they did not exceed cleanup levels (Figure 4).

3.2 Material Sites Data Review

Metals concentrations in soil at the material source sites were well below ADEC cleanup levels. The metals concentrations in water were well below ambient water quality criteria. The analytical results also show that the material sites are not likely to be significant sources of metals to the haul road.

3.3 Dustfall Data Review

Dustfall deposition results (Figure 5) for September 2001 show that total dustfall rate was greatest near the port site (Stations D-01 and D-02) and relatively consistent along the rest of the road (Stations D-03 through D-07). The metals (lead, zinc, cadmium) dustfall rate was also highest in the vicinity of the port site (Stations D-01 and D-02). For the rest of the stations away from the port site, the metals dustfall rate was much lower. The dustfall measurements from the north side of the haul road were generally higher than those on the south side, evidently because the prevailing wind direction was from the southeast during September.

3.4 Vegetation Data Review

In this section, the vegetation data are reviewed and compared with relevant studies and data to put Exponent's study findings into context with available information.

3.4.1 Moss

In the summer of 2000, NPS collected *Hylocomium splendens* samples along six transects established perpendicular to the haul road within Cape Krusenstern National Monument (Ford and Hasselbach 2001). Three transects were oriented north, or generally downwind, of the haul road, and the remaining three transects were oriented south, or generally upwind, of the road. Exponent did not sample vegetation within the national monument boundaries. However, north-facing transects HR-03 and HR-04 and the south-facing transect HR-05 were located between the mine and port sites along the haul road and were thus positioned similarly to the NPS transects with respect to possible metals sources (i.e., distant from possible fugitive dust sources at the mine and port).

Cadmium, lead, and zinc concentrations in moss samples collected by Exponent along transects HR-03, HR-04, and HR-05 are compared with the results of the NPS study (Ford and Hasselbach 2001) in Table 18. Ford and Hasselbach (2001) observed a trend towards greater cadmium, lead, and zinc concentrations in moss samples collected downwind (north) of the haul road compared to those of moss collected upwind (south) of the road. Exponent only sampled one upwind and two downwind transects, thus comparisons between upwind and downwind metals concentrations in moss sampled by Exponent would be inconclusive. Therefore, data from all three Exponent transects is pooled for comparison with NPS data.

Overall, mean cadmium, lead, and zinc concentrations were similar in Exponent and NPS samples collected along transects north and south of the haul road; mean values differed no more than 3-fold at all distances from the road (Table 18). Small sample sizes precluded a statistical evaluation of differences between Exponent and NPS data upwind and downwind of the haul road, but transect location along the haul road, microhabitat positions of moss relative to other vegetation that might affect dust deposition patterns, slope position, precipitation before and during sampling programs, and inherent variability in metals uptake among individual plants may have contributed to variation in metals concentrations, in addition to any effects due to wind patterns. Nonetheless, the comparability of the Exponent and NPS data sets suggests that metals deposition patterns are similar across the central portion of the haul road.

Ford and Hasselbach (2001) observed that cadmium, lead, and zinc concentrations in moss leveled off between 1,000 and 1,600 m along haul road transects. Exponent did not sample moss beyond 1,000 m along transects HR-03, HR-04, and HR-05. However, at 1,000 m, mean cadmium, lead, and zinc concentrations in moss collected from these three transects were comparable to the NPS data (Table 18), suggesting that metals levels may also be leveling off in the Exponent study, although this hypothesis cannot be verified from the available data.

In Table 2 of their study, Ford and Hasselbach (2001) compared their results to metals concentrations in *Hylocomium splendens* reported in several earlier Alaska studies. Unwashed moss samples collected from sites in northern Alaska had cadmium, lead, and zinc concentrations ranging from 0.02 to 0.98 mg/kg, 0.35 to 2.33 mg/kg, and 10.4 to 66.3 mg/kg dry weight, respectively, as reported in Table 3 of Ford et al. (1995). It could not be determined from the text of that study how Ford and Hasselbach (2001) had derived some of the concentrations that they report in Table 1 of the NPS report. Crock et al. (1992a) reported baseline ranges of cadmium, lead, and zinc concentrations from less than 0.1 to 0.7 mg/kg, 0.7 to 4.7 mg/kg, and 22 to 81 mg/kg dry weight, respectively, in washed moss samples collected near or inside Denali National Park and Preserve. In Table 18 of the Wiersma et al. (1986) report, mean lead concentrations of 1.9 and 6.8 mg/kg, and mean zinc concentrations of 58 and 65 mg/kg, measured in unwashed *H. splendens* sampled at two sites in Noatak National Preserve were presented. In Figure 22, Wiersma et al. (1986) also reported cadmium concentrations in *H. splendens* of about 5 and 10 mg/kg in moss collected from Noatak National Preserve. However, the authors advised that the cadmium values be viewed with caution, because the cadmium results for quality control samples fell outside the acceptable percent variation from the mean that they had established (Wiersma et al. 1986). Perhaps for this reason, these cadmium concentrations did not appear in the NPS report (Ford and Hasselbach 2001). Lead and zinc concentrations in *H. splendens* collected on the Kenai Peninsula were reported on an ash weight basis in Crock et al. (1992b), and Exponent could not reproduce the dry weight ranges reported in Table 1 of the NPS report without additional information not provided in Crock et al. (1992b).

Lead and zinc concentrations in moss collected by Exponent at 3 and 100 m along haul road transects and at the port site exceeded the concentration ranges reported in Ford et al. (1995) and Crock et al. (1992a) and the means reported by Wiersma et al. (1986) (Tables 11 and 13). Lead and zinc concentrations in moss samples collected at 1,000 and 2,000 m were also higher than these background concentrations, with the exception of zinc at 1,000 m on transect HR-02 (Table 11).

Cadmium concentrations in moss collected at 3 and 100 m along haul road transects and at the port were above the range of cadmium concentrations reported in Ford et al. (1995) for northern Alaska and in Crock et al. (1992a) for Denali National Park. Cadmium concentrations in moss samples collected at 1,000 m along transects HR-02, HR-03, HR-04, and HR-05 were within or slightly above the range reported in Ford et al. (1995; Table 18). Cadmium levels in samples collected at 1,000 m on transect HR-01, near the port, and at 1,000 and 2,000 m along transects HR-06 and HR-07, near the mine (Table 11), were above the range of cadmium concentrations reported in Ford et al. (1995) and Crock et al. (1992a).

Cadmium concentrations at all stations along transects HR-03, HR-04, and HR-05 were comparable to the cadmium concentrations in moss reported by Wiersma et al. (1986; Table 11).

Cadmium concentrations at 100 and 1,000 m on transect HR-02, at 1,000 m on transect HR-07, and at 2,000 m on transects HR-06 and HR-07 were also comparable to the values reported by Wiersma et al. (1986; Table 11). Six port site moss samples also had comparable cadmium concentrations (Table 13). However, as noted above, there is some uncertainty regarding the analytical accuracy of the cadmium data presented by Wiersma et al. (1986).

Ford and Hasselbach (2001) also compared the results of their study to metal concentrations in moss reported in a survey of atmospheric metal deposition in background areas of northern and central Europe, or areas outside the immediate influence of roads and facilities (Rühling and Steinnes 1998). The European survey was conducted in 1995–1996 to characterize regional patterns of metals deposition in 28 European countries, using *H. splendens* and other moss species as indicators of atmospheric deposition (Rühling and Steinnes 1998). To avoid measuring the effects of discrete local emissions, the European survey collected moss from sites at least 100 m from any roads or single houses and 300 m from main roads and populated areas, and samples were not collected in the vicinity of known sources of metals (Rühling and Steinnes 1998). Therefore, given the sampling location restrictions imposed on the European survey, comparisons with the results of the NPS or Exponent studies are relevant at distances greater than 300 m from the haul road, such as the 1,000 and 2,000 m transect sampling stations, but not at sites immediately adjacent to the road or within the air boundary of the port facility, a known source of fugitive dusts containing lead and zinc.

In addition, dust was shaken off the European moss samples prior to analysis, while Exponent and NPS picked moss free of obvious debris but did not shake dust from the samples (Rühling 2001, pers. comm.; Rühling and Steinnes 1998; Ford and Hasselbach 2001). Thus, metals concentrations reported in the European study were likely lower than would have been observed in undusted samples.

The European moss survey reported median, maximum, and minimum concentrations for 10 metals, including cadmium, lead, and zinc, for each participating nation (Rühling and Steinnes 1998). All cadmium, lead, and zinc concentrations measured in moss collected by Exponent at 1,000 and 2,000 m along haul road transects were well within the range of concentrations reported for the combined participating nations (0.01–8.40 mg/kg dry weight cadmium, 0.22–443 mg/kg dry weight lead, and 1.00–850 mg/kg dry weight zinc), with the exception of moss collected at 1,000 m along transect HR-06, which had elevated levels of all three metals relative to the concentration ranges observed in the European study (Rühling and Steinnes 1998; Table 11). Cadmium concentrations in moss collected at 1,000 m on all transects except HR-06 and HR-07, and at 2,000 m on transect HR-06, were within the range of median values reported for the combined nations (0.12–3.74 mg/kg dry weight; Rühling and Steinnes 1998). Overall, cadmium, lead, and zinc concentrations at 1,000 and 2,000 m from the haul road were comparable to levels observed in the European regional monitoring studies. Exponent samples from 3 and 100 m should not be compared with the European study results because only samples located farther than 300 m from a road were included in the European study.

3.4.2 Lichen

Crock et al. (1992a) reported baseline metals data for washed samples of *Peltigera aphthosa* collected in and around Denali National Park and Preserve, Alaska. Cadmium, lead, and zinc concentrations in these lichen samples ranged from less than 0.1 to 0.4 mg/kg, 0.2 to 3.3 mg/kg, and 20 to 95 mg/kg dry weight, respectively. Beckett and Brown (1984a) reported cadmium concentrations from 0.14 to 0.64 mg/kg and zinc concentrations from 71.9 to 222 mg/kg in washed samples of four *Peltigera* species collected from an uncontaminated area in the Mendip Hills, Somerset, United Kingdom for use in cadmium uptake studies. In another paper, Beckett and Brown (1984b) reported cadmium and zinc concentrations in washed samples of three *Peltigera* species collected at uncontaminated sites in the United Kingdom ranging from 0.14 to 0.64 mg/kg and 57 to 155 mg/kg dry weight, respectively (Beckett and Brown 1984b). Lead concentrations in *Peltigera* species were not reported in the studies by Beckett and Brown (1984a,b). The ranges of metals concentrations in unwashed lichen samples would likely be higher than those of washed lichen samples reported by Crock et al. (1992a) and Beckett and Brown (1984a,b).

Cadmium concentrations in unwashed lichen samples collected by Exponent at 1,000 m on transects HR-02, HR-03, and HR-05 were within the range of concentrations reported for washed, uncontaminated lichen by Beckett and Brown (1984a,b) and within or near the upper limit of the range of baseline concentrations reported by Crock et al. (1992a; Table 14; Figure 12). Cadmium levels in lichen samples collected at 1,000 and 2,000 m along transect HR-07, near the mine, were 4.6- and 2.4-fold higher than the maximum cadmium concentration reported by Crock et al. (2001a, and 2.8- and 1.5-fold higher than those reported by Beckett and Brown (1984a,b). Unwashed lichen samples collected at 3 and 100 m along haul road transects and at the port also had higher cadmium concentrations than washed *Peltigera* samples collected by Crock et al. (1992a) and Beckett and Brown (1984a,b; Tables 14 and 13; Figures 12 and 9).

Zinc concentrations in all lichen samples collected by Exponent at 1,000 and 2,000 m along haul road transects fell within the range reported for uncontaminated washed lichen by Beckett and Brown (1984a,b; Table 14; Figure 11). However, zinc concentrations in the unwashed lichen collected at 1,000 m on transect HR-03 and at 1,000 and 2,000 m along transect HR-07 were higher than the maximum baseline zinc concentration reported for washed *P. aphthosa* in and around Denali National Park (Crock et al. 1992a). Unwashed lichen collected at 3 and 100 m along haul road transects and at the port site had higher zinc concentrations than washed lichen reported by Beckett and Brown (1984a,b; Tables 14 and 13; Figures 11 and 8).

Lead concentrations in all lichen samples collected along haul road transects and at the port exceeded the maximum baseline lead concentration reported by Crock et al. (1992a) for *P. aphthosa* in and around Denali National Park.

3.4.3 Willow

In a study by Gough et al. (2001), cadmium concentrations in willow (*Salix glauca*) leaves sampled from the Forty-mile River watershed and Mining District in east-central Alaska ranged approximately from 0.2 to 2.5 mg/kg dry weight. Cadmium concentrations in *Salix* buds, leaves, and stems collected in mineralized areas of southwest and central Colorado ranged more broadly from 0.37 to 10.8 mg/kg dry weight (Larison et al. 2000). The authors of these two studies did not specify whether samples were washed prior to analysis. Willow samples collected by Exponent along haul road transects and at the port site had cadmium levels comparable to those reported for other mineral-rich areas by Gough et al. (2001) and Larison et al. (2000) (Tables 15 and 13). Cadmium concentrations in willow leaves had leveled off by 100 m along transects HR-02 and HR-03 in the Exponent study (Figure 12).

In a Norwegian study of lead exposure to herbivores, lead concentrations in *S. glauca* and *S. repens* leaves ranged from about 0.2 to 0.4 mg/kg dry weight in samples collected in central and northern Norway, where atmospheric deposition of lead is low, and from about 0.25 to 1.0 mg/kg dry weight in southern Norway, where atmospheric deposition of lead is higher (Kålås et al. 1999). The authors did not specify whether samples were washed prior to analysis. In a baseline study of element concentrations in soils and vegetation in Wattenmeer National Park, Germany, lead concentrations in washed willow (*S. repens*) leaves were higher, ranging from 1.3 to 4.0 mg/kg dry weight (Seversen et al. 1992).

Lead concentrations in willow samples collected by Exponent at 1,000 m on transects HR-02 and HR-03 and at 2,000 m on transect HR-07 were above the range observed in reference areas in Norway but were within the range observed in southern Norway (Kålås et al. 1999; Table 15; Figure 10). Lead levels in Exponent willow samples collected at 100 m along transects HR-02 and HR-03 were within the baseline range of concentrations reported in the German island park, while the concentration at 100 m on transect HR-07 was about 2-fold higher (Seversen et al. 1992; Table 15; Figure 10). At 3 m transect stations and at the port, lead concentrations in willow leaves were above ranges reported by Kålås et al. (1999) and Severson et al. (1992).

Zinc concentrations ranging from 130 to 480 mg/kg dry weight in washed willow leaves were also reported in Severson et al. (1992). Nissen and Lepp (1997) reported a range (means) of 105.80 to 296.15 mg/kg dry weight zinc in washed leaf samples from eight *Salix* species growing in the University of Liverpool Botanic Gardens, Ness, Wirral. Zinc concentrations in willow leaves collected by Exponent along haul road transects and at the port were within the ranges of concentrations reported in these studies, except for the sample collected at 3 m on transect HR-02, which had 546 mg/kg dry weight zinc. In the Exponent study, zinc concentrations had leveled out by 100 m along transects HR-02 and HR-03, and by 1,000 m along transect HR-07 (Figure 11).

3.4.4 Salmonberries

During August and September 2001, ADEC and local residents conducted an investigation into the quality of subsistence foods, including salmonberries, in the region around the DeLong Mountain Terminal (i.e., the port site). In order to establish what would be typical metals concentrations in salmonberries in the absence of dust deposition from the mine, haul road, or port, ADEC collected salmonberries at reference sites near Noatak and Point Hope, Alaska. ADEC assumed that these sites were far enough away from the mine, haul road, and port to be beyond the influence of fugitive dust from the Red Dog operation, and therefore assumed the sites were appropriate locations for obtaining reference metals data for this species (Trost 2001, pers. comm.). Ten unwashed berry samples from each site were analyzed for metals. At the Noatak site, cadmium, lead, and zinc concentrations in unwashed salmonberries ranged from 0.119 to 0.254 mg/kg, 0.00358 to 0.189 mg/kg, and 14.6 to 29.4 mg/kg dry weight, respectively. At Point Hope, cadmium, lead, and zinc concentrations in unwashed salmonberries ranged from 0.121 to 0.295 mg/kg, 0.00956 to 0.0187 mg/kg, and 17.6 to 24.0 mg/kg dry weight, respectively (Trost 2001, pers. comm.).

At the port site, zinc concentrations in salmonberries collected by Exponent (Table 13; Figure 8) were all within the reference range, as defined by the Noatak and Point Hope samples. The cadmium concentration in salmonberries collected at PO-18 was also within the reference range, but cadmium levels in berries collected at PO-03 and PO-17 were about 1.2- to 1.4-fold higher than the maximum cadmium concentration reported for Noatak and Point Hope samples (Table 13; Figure 9). Lead concentrations in salmonberries were above reference levels in all three port site berry samples (Table 13; Figure 7).

At 3 m along haul road transects HR-01 and HR-04, zinc concentrations in salmonberries were about 1.6- to 3.0-fold higher than the maximum zinc concentration reported for Noatak and Point Hope samples, but zinc concentrations in salmonberries collected at 100 m were within the range of reference concentrations at 100 m (Table 16; Figure 11). Along transect HR-01, near the port facility, the cadmium concentrations in berries collected at 3 and 100 m were above background levels. Along transect HR-04, located approximately half-way between the mine and port, the cadmium concentration was above reference levels in the sample collected at

3 m but was actually below the range of concentrations reported in Noatak and Point Hope berries at 100 m from the haul road (Table 16; Figure 12). Lead concentrations in salmonberries were above the range of reference concentrations in all four haul road berry samples (Table 13; Figure 10).

In addition to reference samples, ADEC also collected 10 unwashed salmonberry samples at sites approximately 2.5 miles south and 4 miles north of the port, and another five unwashed salmonberry samples at the port site. In unwashed berries collected north and south of the port, cadmium, lead, and zinc concentrations ranged from 0.103 to 0.241 mg/kg, 0.111 to 0.339 mg/kg, and 20.1 to 29.5 mg/kg dry weight, respectively (Trost 2001, pers. comm.). Salmonberries collected by Exponent at the port had a similar range of zinc concentrations as unwashed salmonberries collected by ADEC north and south of the port (Table 13). However, the mean cadmium (0.337 mg/kg dry weight) and lead (0.691 mg/kg dry weight) concentrations in Exponent port site berry samples fell above the range of concentrations reported for unwashed salmonberry samples collected north and south of the port.

Cadmium, lead, and zinc concentrations in unwashed salmonberries collected by ADEC at the port site ranged from 0.379 to 0.553 mg/kg, 1.19 to 2.12 mg/kg, and 30.4 to 33.1 mg/kg dry weight, respectively (Trost 2001, pers. comm.). Lead and zinc concentrations in all salmonberry samples collected by Exponent at the port were lower than the range of concentrations in unwashed salmonberries reported by ADEC for port site samples (Table 13). The mean cadmium concentration in salmonberries collected by Exponent at the port was below the range of cadmium concentrations reported by ADEC for unwashed salmonberry samples at the port.

3.5 Surface Water Data Review

The surface water metals concentrations are compared with EPA water quality criteria (Fed. Reg. 64:19781) in Table 17. According to ADEC 18 AAC 70 water quality standards as amended through May 27, 1999, these are the water quality criteria used by the State of Alaska (ADEC 1999b).

EPA provides hardness-dependent criteria for lead, zinc, and cadmium. Using the calcium and magnesium results for each sample, hardness (mg equivalent $CaCO_3$/L) was calculated using the following formula: 2.497 [Ca, mg/L] + 4.118 [Mg, mg/L] (Eaton et al. 1995). The resulting sample-specific hardness was used in the formulas for calculating the aquatic life criteria in terms of total recoverable metals. No samples exceeded the resulting criteria for either acute or chronic exposure. For each sample and each metal analyzed, the concentration was divided by the hardness-based criterion. This provides a ratio that can be used to consistently compare sample results to one another. Ratio values less than one indicate that the measured value does not exceed the hardness-based criterion. Figures 13, 14, and 15 illustrate these ratios for all of the lead, zinc, and cadmium sample results, respectively.

The sample results, hardness-specific criteria, and ratios are presented in Table 17. Most of the sample results (82, 84, and 97 percent of the results for lead, zinc, and cadmium, respectively) were undetected. The detections that were observed were quite low in concentration, as illustrated by the ratios plotted in Figures 13, 14, and 15. Of the 16 lead detections, 13 were in samples collected downstream of the road. The lead detections were distributed fairly evenly among the sampled creeks. Ten of 14 zinc detections were located downstream of the road. Nine of the 14 zinc detections were measured on New Heart Creek, which is the closest sampled creek to the port site. Cadmium was only detected in two samples, one upstream and one downstream of the haul road. It should be noted that variable geology, and the presence of highly mineralized areas, likely also influence these surface water results.

3.6 Comparison/Correlation of Road and Vegetation Sample Results

The road surface, core, and shoulder sample results portray a very consistent picture of metals distribution (Figure 16). Figure 17 presents a comparison of dustfall deposition, road shoulder, and moss transect concentrations for lead, zinc, cadmium, and calcium. This figure illustrates a fairly good correlation between road, dustfall, and moss sample results at each road station and corresponding vegetation transect. The moss results, especially at 3 and 100 m, appear to correlate strongly with the dustfall and road shoulder results (Figure 17). The different sample types portray a consistent pattern of elevated concentrations near each end of the haul road, and lower concentrations through the middle part. Calcium is the exception, which has higher concentrations through the middle section of the road than at the ends. This may relate to patterns of application of calcium chloride, or to differences in frequency of road maintenance on different parts of the road.

4 Conclusions

This data report summarizes characterization work performed in 2001 by Teck Cominco and Exponent. The purpose of the 2001 sampling efforts was to gain a better understanding of the sources, transport, and deposition/distribution of fugitive dust. The sampling programs included road surface, road core, and road shoulder samples; material site samples; dustfall collector samples; vegetation samples (moss, lichen, willow, and berries); and surface water samples. The following are Exponent's preliminary conclusions, subject to further review, evaluation, and possible revision:

Fugitive Dust Sources—Review of metals tracking and distribution patterns on the haul road. Review of concentrations compared to cleanup levels.

- The road surface, core, and shoulder sample results indicate that the source of the metals is not the soils making up the road base, but that the occurrence of elevated metals concentrations is primarily a surface phenomenon (Figure 16).
- Soil and water sample results from the material source areas confirmed that these samples are not a significant source of metals to the road.
- Road surface sample results indicate that tracking of metals (via haul trucks) from the port site and the mine site is most likely the primary source of metals to the haul road (Figure 3).
- Road surface data show elevated concentrations of metals at either end of the haul road, with the highest metals concentrations observed in road surface samples directly outside of the concentrate storage buildings where trucks exit after unloading (Sample RS-04, Figure 3).
- Lead and zinc truck spill locations showed no obvious correlation with the road surface results (Figure 3), indicating that spills do not constitute a significant source of metals to the road surface.

- Concentrations in excess of cleanup standards were observed in just three road samples. Road surface sample RS-04, directly outside of the concentrate storage buildings, had a lead concentration of 1,180 mg/kg (as compared with the cleanup level of 1,000 mg/kg). Two road shoulder fines samples had lead concentrations in excess of the cleanup level. Sample RF-Port, the first road shoulder sample station to the east of the concentrate storage buildings, had a lead concentration of 1,060 mg/kg. Sample RF-06, located on a curvy stretch of road (see close-up on Figure 2), had a lead concentration of 2,440 mg/kg (Figure 4). No other road samples had metals concentrations in excess of the cleanup standards.

Transport Mechanisms—Review of correlation between dustfall pattern and metals distribution on haul road and on vegetation.

- Dustfall deposition results (Figure 5) for September 2001 show that the total dustfall rate was greatest near the port site and relatively consistent along the rest of the road. The metals (lead, zinc, cadmium) dustfall deposition rate was also highest in the vicinity of the port site. For the rest of the stations away from the port site, the metals dustfall rate was much lower. The dustfall measurements from the north side of the haul road were generally higher than those on the south side, evidently because the prevailing wind direction was from the southeast during September.
- A comparison of dustfall deposition, road shoulder, and moss transect concentrations for lead, zinc, cadmium, and calcium (Figure 17) illustrates a fairly good correlation between road, dustfall, and moss sample results at each road station and corresponding vegetation transect.

Extent of Impacts—Review of metals distribution in areas surrounding the haul road and port site (vegetation, surface water). Summary of vegetation concentrations compared to other study results.

- Metals concentrations in moss were generally higher along haul road transects near the mine and port, which suggests that there were contributions of metals from these facilities (Table 11; Figures 10, 11, and 12).

- An overview comparison of different sample types (dustfall, road shoulder, and moss results; Figure 17) portrays a consistent pattern of elevated concentrations near each end of the haul road, and lower concentrations through the middle section of the road.

- Surface water samples collected from five creeks at locations along the haul road showed no exceedances of hardness-dependent water quality criteria in 4 months of data collection (July, August, September, and October 2001).

- Surface water data show little if any impact from the haul road. Most of the results (82, 84, and 97 percent of the results for lead, zinc, and cadmium, respectively) of the 89 water samples were undetected. The observed detections were quite low in concentration, as illustrated by the ratio of the measured concentration to the hardness-specific water quality criteria, plotted for lead, zinc, and cadmium (Figures 13, 14, and 15).

- Cadmium, lead, and zinc concentrations in moss samples collected by Exponent along haul road transects located between the mine and port site were comparable to NPS data (Ford and Hasselbach 2001; Table 18), indicating that the dustfall pattern was similar along most of the haul road and suggesting that metals concentrations in moss were leveling out around 1,000 m from the road.

- Metals concentrations in moss collected at spill sites were similar to levels observed in other moss samples collected near the haul road (Table 12).

- Cadmium, lead, and zinc concentrations observed in moss collected at 1,000 m along intermediate haul road transects were within the range of concentrations observed in background areas of Europe in the atmospheric deposition survey by Rühling and Steinnes (1998).

- Lead and zinc concentrations in moss samples from haul road transects and the port site were generally elevated above concentrations observed in moss elsewhere in Alaska (Ford et al. 1995; Crock et al. 1992a; Wiersma et al. 1986).

- At 1,000 m from the haul road, cadmium concentrations in moss were at or approaching levels observed in other Alaska studies, in most cases (Ford et al. 1995; Crock et al. 1992a; Wiersma et al. 1986).

- Along haul road transects and at the port site, metals concentrations in vegetation were ordered from highest to lowest: moss > lichen > willow > salmonberry.

- With the exception of transect HR-07, near the mine, cadmium and zinc concentrations in unwashed lichen samples collected at 1,000 m from the haul road were generally comparable to levels reported in unwashed *Peltigera* samples from Denali National Park and uncontaminated areas of the United Kingdom (Beckett and Brown 1984a,b; Table 14). Lichen samples collected at 3 and 100 m on haul road transects and at the port site had elevated cadmium and zinc concentrations relative to the reference samples from Denali National Park (Crock et al. 1992a) and the United Kingdom (Beckett and Brown 1984a,b; Table 14). Lead concentrations in all Exponent lichen samples were elevated relative to washed samples from Denali National Park (Crock et al. 1992a; Table 14).

- Cadmium concentrations in willow samples collected along haul road transects and at the port were similar to levels observed in other mineral-rich areas in Alaska and Colorado (Gough et al. 2001; Larison et al. 2000; Tables 15 and 13). Cadmium concentrations in willow leaves appear to level off around 100 m on transects HR-02 and HR-03 (Figure 12). Zinc concentrations in willow samples were generally comparable to concentrations measured in European willow leaves that were sampled at sites away from any local emissions sources (Nissen and Lepp 1997; Severson et al. 1992; Table 15). Lead concentrations in willow samples at 3 m from the haul road and at the port were higher than concentrations reported in European studies but declined to, or nearly declined to, those levels at 100 to 1,000 m along haul road transects (Kålås et al. 2000; Seversen et al. 1992; Table 15).

- Salmonberry samples collected at the port site and 3 m from the haul road generally had elevated cadmium and lead levels relative to reference concentrations measured in salmonberry samples from Noatak and Point Hope. Zinc concentrations in salmonberries collected 3 m from the road were elevated relative to reference concentrations, but samples collected at the port site and 100 m from the haul road were within the reference range.

- Zinc concentrations were similar in unwashed salmonberries collected by Exponent at the port site and by ADEC at sites approximately 4 miles north and 2.5 miles south of the port. Cadmium and lead concentrations were generally higher in the Exponent berry samples. Metals concentrations were typically higher in unwashed salmonberry samples collected by Exponent at the port site than in unwashed salmonberry samples collected by ADEC at the port.

5 Recommendations for Future Work

- Review and analysis of trends in dustfall deposition, in accordance with the dustfall collection sampling and analysis plan (Exponent 2001d) to evaluate effectiveness of operational improvements in reducing fugitive dust emissions
- Preliminary ecological effects evaluation, following development of the site conceptual model and identification of ecological receptors in the fugitive dust background document
- Depending on the results of the ecological effects evaluation, additional data collection may be needed in 2002.

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