RED DOG OPERATIONS ALASKA

Fugitive Dust Risk Management

Uncertainty Reduction Plan

October 2012

Teck

Teck Alaska Incorporated
3105 Lakeshore Drive
Building A, Suite 101
Anchorage, Alaska 99517

Fugitive Dust Risk Management

Uncertainty Reduction Plan

RED DOG
OPERATIONS
ALASKA

Teck

Teck Alaska Incorporated
3105 Lakeshore Drive
Building A, Suite 101
Anchorage, Alaska 99517

Contact information:
Rebecca Hager
907-426-9141
Rebeca.Hager@teck.com

Prepared by:
Exponent
15375 SE 30th Place, Suite 250
Bellevue, Washington 98007

October 2012

Document number:
8601997.012 5100 0912 JS28

Contents

List of Figures

Figure is presented at the end of the main text.

List of Tables

Tables are presented at the end of the main text.

Acronyms

ADFG	Alaska Department of Fish and Game
CAKR	Cape Krusenstern National Monument
DEC	Alaska Department of Environmental Conservation
DMTS	DeLong Mountain Regional Transportation System
EPA	U.S. Environmental Protection Agency
MOU	memorandum of understanding
PMC	Alaska Plant Materials Center
RMP	Risk Management Plan
SEIS	Supplemental Environmental Impact Statement
Teck	Teck Alaska Incorporated
USGS	U.S. Geological Survey
XRF	x-ray fluorescence

Executive Summary

In August 2008, the Draft Fugitive Dust Risk Management Plan (RMP) was released as part of a process intended to minimize risks associated with fugitive dust emissions from operations at the Red Dog Mine (Exponent 2008). The RMP combines and builds upon prior and ongoing efforts by Teck Alaska Incorporated (Teck) to reduce dust emissions. The RMP describes seven fundamental risk management objectives that address the overall goal of minimizing risk to human health and the environment, identifies and evaluates risk management options to achieve those objectives, and describes a process for developing implementation plans to achieve the fundamental objectives. Part of that process is the development of six individual risk management implementation plans that describe more specifically how the fundamental objectives will be met. This document presents one of those implementation plans, the Red Dog Uncertainty Reduction Plan.

Preparation of an Uncertainty Reduction Plan follows from risk management Objective 5, *Conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment.* To achieve this objective, the Uncertainty Reduction Plan was developed with the following goal:

- To identify and prioritize prospective research or studies to reduce uncertainties in the assessment of effects of fugitive dust to humans and the environment.

This plan includes a review of past, ongoing, and potential future actions, and selects a set of uncertainty reduction actions designed to accomplish the goals and objectives of the Uncertainty Reduction Plan.

Review of Past, Ongoing, and Potential Future Actions—Review of past and ongoing uncertainty reduction actions (e.g., including studies conducted by Teck and others such as the U.S. Geological Survey and National Park Service) provides an opportunity to review and assess efforts that have already taken place, and identifies data gaps that still need to be addressed.

The review of potential future actions includes prospective actions identified by various stakeholder groups during the RMP development process, and other possible actions that have been identified elsewhere, including those to address uncertainties identified earlier in the risk assessment process.

Selection of Uncertainty Reduction Plan Actions—The purpose of the Uncertainty Reduction Plan is to improve the understanding of fugitive dust effects, exposure, and risk through additional studies, research, or analysis. These studies will facilitate continued improvement in risk management. The Uncertainty Reduction Plan incorporates the following actions/studies:

- **Umayutsiak Creek Surface Water Sampling Study—**In comments received during the Risk Management Workshop, at public meetings, and in writing, stakeholders have expressed interest in sampling Umayutsiak Creek south of the Port, because it is used as a water source during subsistence food gathering and hunting activities. Although water contributes a small amount of overall exposure for people, analyzing water from Umayutsiak Creek would address public concerns, and thereby provide increased confidence in the protectiveness of the risk assessment. Teck plans to sample surface water from Umayutsiak Creek during the summer of 2013.
- **Berry Subsistence Foods Study—**There were some public comments about the temporal and spatial representativeness of berry samples collected for the risk assessment. A tribal representative and community member stated that sample collection occurred during a year identified as a particularly poor harvest, and that the timing of sample collection did not coincide with optimal gathering times defined by subsistence users. In order to address community concerns expressed about the timing of berry sampling, a berry subsistence foods study will be planned for the summer of 2013. The berry

sampling will be timed to occur at the end of a dry period (before a rainfall)[1], and will include harvest locations identified by the subsistence users.

- **Caribou Bone Marrow Study—**Addressing previously-expressed public concerns associated with caribou bone and bone marrow consumption would provide increased confidence in the protectiveness of the risk assessment. To address these concerns, Teck plans to analyze caribou bone and bone marrow concentrations during the next caribou sampling period in 2015. Results will be analyzed to evaluate the difference between site-related concentrations and reference/background concentrations in bone and bone marrow.

- **Caribou Site Use Study—**Uncertainty associated with the fractional intake assumption used in the Fugitive Dust Risk Assessment was a significant area of concern identified at the Risk Management Workshop. Information to support either the fractional intake used in the risk assessment or an alternative fractional intake was identified as an important data gap. Satellite telemetry data on caribou movements, as collected by the Alaska Department of Fish and Game, can potentially be used to assess how much time during the year that caribou of the Western Arctic and Teshepuk herds spend at the DeLong Mountain Regional Transportation System (DMTS) road, port, mine, and surrounding areas. This would allow for a better estimate of fractional intake, thereby reducing uncertainty in our understanding of risks at the site. Teck will work with the Alaska Department of Fish and Game to try to secure a cooperative agreement to implement this study in 2012–2013.

- **Reclamation and Recovery Study—**A study will be implemented to examine the effectiveness of different reclamation and remediation activities that have been conducted to date at various sites around the Red Dog Mine, road, and port. This study will involve expansion of the GIS Reclamation and Recovery Database that will track scheduling, implementation, and effectiveness of reclamation activities. In addition, sites that were previously

---

[1] This will maximize dust deposition on berries and minimize water content, thereby increasing metal concentrations.

studied or reclaimed will be monitored to evaluate which methods are the most effective in promoting vegetation recovery, and potentially to identify new techniques or plant species that promote recovery of vegetation at reclamation sites. Also included in this monitoring will be the evaluation of natural recovery through colonization of native species into areas that were previously vegetated with non-native species. The database expansion is scheduled to begin in 2012, and survey work to evaluate sites is expected to begin in 2013 after the database is expanded.

- **Reference Area Monitoring—**Reviewers of the Fugitive Dust Risk Assessment (Exponent 2007a) suggested that reference areas should have been located farther away from the DMTS road. Beginning in 2012, collection of reference area monitoring data (including both vegetation community and moss tissue concentrations of metals) is being added to the monitoring plan to allow assessment of trends in the reference areas that may indicate the possible influence of dust deposition or other factors, and provide for comparison with site data. The reference area vegetation community monitoring results will be used to evaluate whether changes at site-related stations are a result of dust deposition, or may be caused by climate variation or other factors that may be causing regional changes. If reference area monitoring finds an increasing trend in metals tissue concentrations that appears to be related to site sources, then the need to establish additional reference sites that are not influenced by site sources will be evaluated.

Additional details regarding these planned uncertainty reduction actions are provided in this document, along with details of plan implementation, communication and collaboration tools to be used, periodic review and reporting, milestones for completion and review of the plan, and stakeholder involvement in the plan.

1 Introduction

This Uncertainty Reduction Plan is an implementation plan associated with the fugitive dust Risk Management Plan (RMP). The RMP was developed to combine and build upon prior and ongoing efforts by Teck Alaska Incorporated (Teck) to reduce dust emissions and minimize potential effects to human health and the environment. The RMP addresses issues identified by several different studies and programs, including the DeLong Mountain Regional Transportation System (DMTS) risk assessment (Exponent 2007a,b), the mine-area ecological risk evaluation conducted as part of the closure and reclamation planning process (Exponent 2007c), the Memorandum of Understanding (MOU) between the Alaska Department of Environmental Conservation (DEC) and Teck (DEC 2007), and the Supplemental Environmental Impact Statement (SEIS) for the Aqqaluk Pit Extension (www.reddogseis.com). The RMP also incorporates stakeholder input obtained during a 3-day Risk Management Workshop held in Kotzebue, Alaska, in March 2008 (Teck Cominco 2008).

The RMP describes seven fundamental risk management objectives that address the overall goal of minimizing risk to human health and the environment in the area surrounding the mine, road, and port, over the life of the mine and during post-closure operations. These seven objectives are:

- Objective 1: Continue reducing fugitive metals emissions and dust emissions
- Objective 2: Conduct remediation or reclamation in selected areas
- Objective 3: Verify continued safety of caribou, other representative subsistence foods, and water, with respect to ongoing mine-related activities
- Objective 4: Monitor conditions in various ecological environments and habitats, and implement corrective measures when action levels are triggered
- Objective 5: Conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment

- Objective 6: Improve collaboration and communication among all stakeholders to increase the level of awareness and understanding of fugitive dust issues

- Objective 7: Protect worker health.

The RMP also identifies and evaluates risk management options to achieve those objectives, and describes a process for developing implementation plans to achieve the seven fundamental objectives. This Uncertainty Reduction Plan is one of six individual risk management implementation plans that were identified in the RMP to address these objectives. The other five implementation plans are:

- Communication Plan
- Dust Emissions Reduction Plan
- Remediation Plan
- Monitoring Plan
- Worker Dust Protection Plan.

The Uncertainty Reduction Plan specifically focuses on research or studies to reduce uncertainties in the assessment of effects of fugitive dust to humans and the environment.

The remainder of this document is organized as follows:

- *Section 2. Goal of the Uncertainty Reduction Plan*—Describes the specific goal and objective of the Uncertainty Reduction Plan

- *Section 3. Review of Past, Ongoing, and Potential Future Actions*—Describes and evaluates prior and ongoing actions, as well as actions identified as part of the RMP process

- *Section 4. Actions to be Implemented*—Identifies uncertainties in the assessment of effects of fugitive dust to humans and the environment that could be addressed through additional research and prioritizes potential additional studies

- *Section 5. Periodic Review and Reporting*—Describes the process for review and reporting on these actions
- *Section 6. Milestones*—Identifies key milestones for implementation of the plan
- *Section 7. Stakeholder Roles*—Describes stakeholder roles in the process.

2 Goal of Uncertainty Reduction Plan

The overall goal of the RMP is to minimize risks associated with fugitive dust emissions from Red Dog Mine operations. Specifically, this goal is stated as follows:

> **RMP Overall Goal:** *Minimize risk to human health and the environment surrounding the DMTS and Red Dog Mine over the life of the mine and post-closure operations.*

The RMP described seven fundamental risk management objectives that address this overall goal. This Uncertainty Reduction Plan follows from risk management Objective 5:

> **RMP Objective 5:** *Conduct research or studies to reduce uncertainties in the assessment of effects to humans and the environment.*

To achieve this objective, the Uncertainty Reduction Plan was developed with the following goal:

> **Uncertainty Reduction Plan Goal:** To identify and prioritize prospective research or studies to reduce uncertainties in the assessment of effects of fugitive dust to humans and the environment.

Thus, the Uncertainty Reduction Plan is designed to improve the understanding of fugitive dust effects, exposure, and risk through additional studies, research, or analysis. These studies will facilitate continued improvement in risk management.

The Uncertainty Reduction Plan brings together and builds upon elements from a number of ongoing efforts by Teck and others to conduct studies that address areas of uncertainty related to reducing dust emissions and minimizing effects to the environment. The plan addresses dust-related issues identified by the DMTS risk assessment, the mine-area ecological risk evaluation, the MOU between DEC and Teck, and the SEIS for the Aqqaluk Extension. In addition, the plan also addresses responses to comments on the DMTS risk assessment wherein some issues were deferred for evaluation in the RMP. These comment issues focused largely on the potential need for additional studies to address areas of uncertainty in the DMTS risk assessment (Exponent 2007a), and more generally, to address uncertainty related to fugitive dust risk management. Finally, this plan also incorporates initial stakeholder input that was obtained at a 3-day Risk Management Workshop held in Kotzebue, Alaska, in March 2008 (Teck Cominco 2008).

The objectives of this Uncertainty Reduction Plan are related to Objectives 3 and 4 regarding monitoring (Objective 3: *Verify continued safety of caribou, other representative subsistence foods, and water*; Objective 4: *Monitor conditions in various ecological environments and habitats, and implement corrective measures when action levels are triggered*). Monitoring activities provide a direct measure of current conditions and an indication of changes over time and space. Thus, the Monitoring Plan (Exponent 2011a) will also serve an important role in uncertainty reduction. Monitoring data will help risk managers and stakeholders understand the status of fugitive dust deposition and related risks, as compared with risk assessment baseline conditions. However, the focus of this Uncertainty Reduction Plan is to address areas of uncertainty that may require additional study or research efforts beyond the monitoring programs.

In addition, communication and collaboration between stakeholders is a universally applicable goal related to the Uncertainty Reduction Plan, and is encompassed by Objective 6 of the RMP: *Improve collaboration and communication among all stakeholders to increase the level of awareness and understanding of fugitive dust issues*. Therefore, recommendations and actions from the Communication Plan (Exponent 2009) are also incorporated within the Uncertainty Reduction Plan.

3 Review of Past, Ongoing, and Potential Future Actions

The following sections review past and ongoing uncertainty reduction actions (including studies that have been implemented by Teck and others), as well as potential actions that were identified during the risk management planning process. A number of studies have been undertaken to date that address areas of uncertainty regarding metals transport and fate, and human health and ecological risk. This section provides an overview of these past and ongoing actions, and compiles a list of possible actions that may be undertaken in the future to reduce uncertainties.

3.1 Evaluation of Past and Ongoing Actions

Some of the actions related to uncertainty reduction identified and discussed at the Risk Management Workshop have been or are currently being implemented. Examples of past or current uncertainty reduction efforts include the studies described in the following sections.

3.1.1 Mineral Leaching Study Using Red Dog Soils

Soil samples were collected in the vicinity of Red Dog operations, and diagnostic leaching studies were used to estimate the distribution and extractability of metal ions. Kinetic and static methods were also used to evaluate the potential for long-term leaching. The proportion of extractable zinc in samples taken close to the mill was 4.2% in standard diagnostic leaching testing, and the proportion of extractable lead from those samples was an order of magnitude lower. There was also evidence of preferential leaching of zinc from samples. The kinetic test results are consistent with oxidative products being washed out of the sample over time (Teck Cominco 2007a).

The potential for mineral leaching in the tundra environment surrounding the port, mine, and DMTS is addressed through monitoring of the plant communities and metals concentrations in various media, as outlined in the Monitoring Plan (Exponent 2011a). Therefore, at this time, no additional leaching studies are planned.

3.1.2 Particle Weathering Study Using Red Dog Soils

The potential for mineral weathering was evaluated in soils collected in the vicinity of Red Dog Operations (Teck Cominco 2007b). Analytical techniques were used to identify lead- and zinc-containing minerals. Also, diagnostic leaching techniques were used to estimate the distribution and extractability of metal ions. The main forms of lead and zinc identified in the soils were galena and sphalerite, and the presence of anglesite and plumbojarosite indicated that galena weathering had occurred. In addition, high lead-to-zinc ratios were observed in soils sampled around the Red Dog mill, and crushing and tailings areas. The higher lead-to-zinc ratios in the soil samples compared to the ore suggested that oxidation of the metals in the soil may be occurring, likely as a result of ongoing weathering.

The potential for mineral weathering in the tundra environment surrounding the port, mine, and DMTS (and any associated changes in media concentrations) is addressed through monitoring of the plant communities and metals concentrations in various media, as outlined in the Monitoring Plan (Exponent 2011a). Therefore, at this time, no additional mineral weathering studies are planned.

3.1.3 Bioaccessibility Study for Barium and Aluminum

The draft DMTS risk assessment indicated a possible increase in risk from aluminum and barium exposure through soil ingestion for herbivorous and insectivorous small mammals that inhabit tundra within 10–100 m of the DMTS road, near port facilities, or near the mine (Exponent 2005). When the draft risk assessment was conducted, bioavailability (the availability for uptake by human and ecological receptors) of metals, aluminum and barium in particular, was assumed conservatively to be 100%. The draft risk assessment findings prompted implementation of a study to evaluate the bioaccessibility[2] of aluminum and barium in site-specific materials. Based in part on the findings of this study, the final DMTS risk assessment (Exponent 2007a) concluded that potential effects on survival and reproductive performance as a result of aluminum and barium exposure were localized and unlikely to translate to risks to the general small mammal populations.

Shock et al. (2007) reported on the methods used and findings of the bioaccessibility study. Four samples that represented source materials for dust and dust that was incorporated into the tundra soils were selected for analysis. The samples were collected from the following areas:

1. Gyratory crusher dust—Ore dust accumulated directly within the gyro crusher

2. Main waste road dust—Collected from the surface of the DMTS road in the waste-rock disposal area

3. Tundra soil near the mine boundary—Represented the exposure medium for ecological receptors, and consisted of organic-rich detrital material

4. Tundra soil near the DMTS road—Collected 10 m downwind from the mine and 10 m downwind from the DTMS.

To assess the effect of grain size on bioaccessibility, the samples were sieved to three grain sizes: <2 mm, <38 µm, and <250 µm. Subsamples from each sample were analyzed using laboratory x-ray fluorescence (XRF) and portable XRF, and were digested and quantified using U.S. Environmental Protection Agency (EPA) Methods 3050B and 6010B. The extraction procedure for the *in vitro* test consisted of an aqueous extraction fluid of 0.4 M glycine titrated to a pH of 1.5 with trace-metal grade 12 N HCl. Each extraction was conducted for 1 hour. Solid-to-fluid ratios of 1:100, 1:1000, and 1:10000 were investigated.

[2] Bioaccessibility is the fraction of the substance that is soluble in a simulated gastric environment (using *in vitro* extraction tests), which provides an estimate of the amount available for absorption into the bloodstream.

The results showed that bioaccessibility generally increased as grain size decreased, such that the smallest particles exhibited the highest bioaccessibility. Based on literature research for lead, the 1:100 solid-to-fluid ratio was considered to be the most predictive of bioavailability for aluminum and barium.

Using the 1:100 solid-to-fluid ratio, barium bioaccessibility values ranged from 0.08% to 0.36% for the main waste road and gyro crusher dust, and from 3.8% to 19% for tundra soil samples. Aluminum bioaccessibility was distinguished from barium by its lower values and lower sensitivity to grain size, and solid-to-fluid ratios. The total range in aluminum bioaccessibility was less than that for barium, ranging between 0.31% and 4% for all samples, regardless of solid-to-fluid ratios and grain sizes. In summary, the results indicated that the relative bioavailability of aluminum and barium in soil at the site is considerably lower than the 100% assumed in the DMTS risk assessment (Shock et al. 2007, Exponent 2007a).

3.1.4 Vegetation and Dust Bioaccessibility Study

In 2006, the U.S. Geological Survey (USGS), in cooperation with National Park Service researchers, conducted a reconnaissance study in the Cape Krusenstern National Monument (CAKR) near the DMTS haul road, to evaluate and document relative concentrations and bioaccessibility of metals associated with surface dusts to those accumulated by vegetation. Vegetation, sub-surface peat, and road dust were sampled to document aluminum, barium, cadmium, lead, and zinc concentrations.

Four types of vegetation (birch leaves, cranberry leaves, willow leaves, and cotton grass blades/stalks) were collected near New Heart Creek and Aufeis Creek immediately north of the DMTS road, and at two reference sites. One reference site was near the Situkuyok River in the southern CAKR, more than approximately 100 km from the DMTS sites. The second reference site was a reference site adjacent to a gravel road near Kotzebue, Alaska, with is approximately 35 km south of the Situkuyok River reference site location.

At the New Heart Creek and Aufeis Creek locations, composite vegetation samples were collected at distances of 25, 100, 200, and 300 m to the north of the DMTS road. Similar samples were collected at the Situkuyok River reference site in southern CAKR. At the road reference site near Kotzebue, composite vegetation samples were only collected from 25 and 50 m distances from the road. Vegetation samples were split into two subsamples. One subsample was analyzed for both total recoverable metals and bioaccessible metals, and the other subsample was triply rinsed before analysis so that only metals that had been incorporated into plant tissue were measured.

Composite subsurface peat samples were obtained from the four individual locations in a manner similar to the vegetation sampling collections in 2006. Archived dust samples were obtained in June 2005 by shaking dust from vegetation surfaces (primarily dwarf birch and willow) at three locations adjacent to the DMTS road near Mile Post 7 (2 km northeast of the 2006 Aufeis Creek sampling site).

The study found that total recoverable concentrations in vegetation decreased significantly with increasing distance from the road. Metals concentrations at the New Heart Creek and Aufeis Creek sites were not significantly different for any of the five metals in vegetation in 2006. For subsurface peat, New Heart Creek samples had significantly greater concentrations of cadmium, lead, and zinc than Aufeis Creek samples.

The study compared 2006 results with 2001 moss data, and found that while there had been significant differences between surface vegetation concentrations at the New Heart Creek location (closer to the port boundary) than the Aufeis Creek location in 2001, the surface vegetation concentrations at these locations were not significantly different from one another in 2006. However, in 2006, there were significant differences in metals concentrations between the two sites for subsurface peat. These results likely reflect recent (2002–2003) clean-up and improvement in lead/zinc concentrate trucking activities on the DMTS road and transfer activities at the port. The authors theorized that over time, some of the metals in surface vegetation may have migrated downward to the subsurface peat through plant leaf decay processes, and metal solubilization/mobilization during rainfall and snowmelt.

Enrichment factor values were calculated as mean concentrations at the DMTS divided by either the mean concentration for like samples from the reference location, or the concentration measured at 25 m from the road reference site. Vegetation samples collected near the DMTS were significantly enriched in metals, especially lead. In vegetation samples collected 25 m from the DMTS, zinc was enriched on average by a factor of 3.5, 8.0 for barium, 20 for cadmium, and 150 for lead. The enrichment factor values were similar when compared with either reference location. The authors concluded that except for aluminum, enrichment factors for DMTS samples were similar when compared with either reference location, indicating that road dust typical for this region of Alaska was probably not a major source of barium, cadmium, lead, or zinc at the DMTS locations. However, enrichment of lead by a factor of more than 100-fold in vegetation sampled 25 m from the road from either DMTS location, as compared to enrichment of only four-fold in the subsurface peat also indicated that metals dispersion from past and/or present releases of fugitive dusts along the DMTS road may still have been contributing to elevated metals in surface vegetation. The authors also noted that differences in metals uptake or adherence by vegetation in this study as compared with that by moss may need to be considered in comparing results in these differing media.

Rinsing vegetation prior to metals analysis had moderate to minimal effects on the metals concentrations in vegetation, and had the least effect on cadmium and zinc; about 40% of those two elements were removed from cranberry leaves, about 20% from birch samples, and only about 5% from willow leaves. Somewhat greater fractions of aluminum, barium, and lead were removed by rinsing. The percentage of these three metals removed ranged from approximately 50% for each from sedge to about 20% from willow leaves. The authors concluded that because samples were collected during relatively cold and wet conditions, the amount of dust on plant surfaces might have been smaller than when drier and warmer conditions were present.

Bioaccessibility of lead was highest in dust samples (about 50%), lowest in mine concentrate (about 5%), and intermediate in vegetation, ranging from about 6 to 29%. Relative to the dust, uptake by vegetation decreased the bioaccessibility of lead from about 50% to < 30%. Bioaccessibility of all five metals in lead concentrate ranged from only about 1% to 5%. Aluminum bioaccessibility was relatively low (<6%) in all sample types. Results of barium and aluminum bioaccessibility in the concentrate and road dust mirrored those of Shock et al. (2007) who reported barium bioaccessibility as less than 0.4% in Red Dog Mine ore dust (see prior discussion in Section 3.1.3), while up to 20% in nearby tundra soil samples, and aluminum bioaccessibility of at most 4% in the same set of samples.

Bioaccessibility was greatest for cadmium and zinc in vegetation samples. Relative to the dust, uptake by vegetation greatly increased bioaccessibility of cadmium and zinc (50 to 100% in vegetation versus 15 to 20% in dust). Given the higher bioaccessibility of cadmium in vegetation versus that for lead, the authors suggested that cadmium exposure to animals that forage near the DMTS road could be as important as lead exposure, despite the relatively higher enrichment of lead in vegetation. However, consideration should be given to the competitive inhibition of cadmium uptake by zinc. At low doses, exposure and toxicity for metal mixtures may be reduced by interactions in which these constituents form less soluble mineral complexes in the gastrointestinal tract, or compete for metal carrier or binding proteins in the body. Thus, the interactions of zinc and cadmium are antagonistic, as described in Menzie et al. (2009).

3.1.5 Small Mammal and Bird Tissue Study

In the spring of 2006, to develop strategies for future monitoring, USGS and National Park Service researchers designed a study of small mammals and birds in the CAKR to assess metals exposure and sublethal biological effects in potentially at-risk animals (Brumbaugh et al. 2008, 2010). Areas along the haul road in the northwestern part of the CAKR were targeted based on previous studies that indicated that metal deposition within the CAKR was greatest along the road and nearest to the port site. Aluminum, barium, cadmium, lead, and zinc concentrations in tissues were the focus of the investigation, based on the results of Teck’s ecological risk assessment (Exponent 2007a).

Small animals that forage on terrestrial organisms or vegetation were a focus of the study, because they are likely to be at greatest risk from ingestion of fugitive dust either directly or indirectly after uptake by plants and insects. Six voles and 12 small ground-nesting birds were live-captured just north of the haul road along New Heart and Aufeis Creeks. Six voles and eight birds were also captured from a reference site at Situkuyok River in the southern CAKR. Blood, liver, kidney, ovary or testes, spleen, skeletal muscle, and ventriculus tissues (from birds) were analyzed for metals concentrations.

Compared to animals captured from the reference location, blood and liver metal concentrations of animals captured near the DMTS were about 20 times greater for lead and about 3 times greater for cadmium. Increased lead exposure in voles and small birds inhabiting areas near the DMTS was apparent, but there were no lesions in bird or vole tissues that could be associated with metals poisoning, nor was there any DNA damage apparent from the half peak coefficient of variation analysis, a measure of the DNA variability within a cell. No unusual bacteria or parasite infections were noted in any of the samples.

Concentrations of barium and zinc were not remarkably different among animals collected from different locations, and aluminum concentrations were below the analytical reporting limits in all but three samples. The study suggests that the lack of elevated aluminum and barium concentrations in tissues of animals captured near the DMTS road could be attributed to low bioavailability of these metals.

Results from this reconnaissance study suggest that no biological effects in small ground-dwelling animals are apparent along the DMTS. The study recommended continued future monitoring of blood lead to assess the potential for increased exposure (Brumbaugh et al. 2008, 2010). However, the various monitoring methods included in the Monitoring Plan (Exponent 2011a) are designed to identify any changes in exposure levels. Animal tissue monitoring is not included, because of the high variability that would be expected in results from such a program.

3.1.6 Cover Materials Study

As part of the Closure and Reclamation Plan, which is required for a Solid Waste Management Permit issued by DEC in accordance with 18 AAC 60 (solid waste regulations), an interim Revegetation Plan was prepared by ABR (ABR 2007). The Revegetation Plan was designed to satisfy the reclamation guidelines outlined in Article 9 of the NANA-Cominco Agreement.

The Revegetation Plan provides a comprehensive review of four different materials available for use as cover. These cover materials include overburden stockpile material, Siksikpuk and Ikalukrok shale, quarry material, and unconsolidated material (e.g., talus from nearby hillsides and sand, and gravels associated with floodplains). The Revegetation Plan described advantages and disadvantages of all cover materials reviewed in the study.

3.1.7 Revegetation Studies

Between 1987 and 2004, the Alaska Plant Materials Center (PMC) established a series of test plots to evaluate the germination and growth of a variety of forbs and grasses at the mine site (Wright 1990; Wright et al. 1993). These test plots were designed to identify those species and varieties that would perform best in future Red Dog Mine revegetation efforts.

In 1987, two test plots were established at the mine site: one in tundra that had been scraped down to bare soil, and the other in highly compacted gravel fill. Seeds from up to 49 plant species or varieties were planted in treatment blocks within each of the plots at a rate of 40 lb/acre, and 20-20-10 (N-P-K) fertilizer was applied to the plots at 450 lb/acre. The species were either native-grass cultivars or agronomic varieties. Plant performance was evaluated by assessing plant vigor on a scale of 1–9, along with percent cover. Results suggested that after three growing seasons (in 1990), 12–20 species were still present, with the best performers (in terms of cover and vigor) being tundra bluegrass, sourdough bluejoint, American sloughgrass, and Alyeska polargrass. In 1992 and 1993, the plots were revisited and continued to support high percentages of plant cover.

Additional test plots set up by PMC included similar fertilization and seeding at the solid waste disposal site north of the DMTS port in 1988. After three growing seasons, a high percentage (85%) of plant cover remained, and all species planted were performing well. In 1989, revegetation of several stream crossings was completed and was also successful, with all sites well vegetated after two growing seasons. Beach wildrye, a species that occurs naturally in coastal areas, was transplanted onto a portion of the waste disposal area that had reconnected with a natural dune adjacent to the pit. Preliminary results of the transplant were favorable;

however, a powerful storm surge destroyed the transplanted beach wildrye and the entire natural dune formation.

Additional test plots were set up by PMC in 2004 to test some of the species included in the original 1987 test plots, as well as additional native species, with a total of up to 62 species per plot. The sites were selected to test germination and the plants were grown in soils developed on rock types considered for reclamation use. Initial results showed that the species with the highest cover and vigor were mostly grasses, although a few forbs (Jacob's ladder and false mayweed) also showed potential. The Kivalina Formation and Okpikruak Formation soils supported better growth than the Siksikpuk soils.

Between 1997 and 2001, portions of the overburden stockpile at the south end of the tailings pond were fertilized and seeded with native-grass cultivars, following recommendations outlined by PMC. In July 2004, vegetation cover was relatively high, but this may have been due to multiple seeding efforts. Total live vascular plant cover was 50% and was dominated by the native-grass cultivar Arctared fescue.

Within the mine area, a number of other disturbed locations have been fertilized and seeded over the past several years to reduce erosion potential. These areas were revisited to measure vegetation cover in July 2004. Vegetation responses were poor, possibly due to acidity from upslope runoff. However, at a site near the airport that was fertilized and seeded in 1997, vegetation cover had persisted since the 1997 treatment.

Studies will be undertaken to determine the most effective revegetation approaches, so that these can be used to address affected areas near the mine, port, and DMTS (see planned actions in Section 4).

3.1.8 Waste-Rock Piles Reclamation Study

This section describes a revegetation study initiated by Teck in 2007 on the surface of the waste-rock pile within the mine area. In summer 2007, Teck implemented a vegetation study on a 50×50-ft experimental plot located on the main waste-rock pile. Seeds of at least three plant species (200 seeds per species) were sown in separate rows with 1 m spacing between rows. Germination, growth, and plant health were measured for each species. A balanced fertilizer (20-20-10 NPK) was applied at 400 lbs/acre (23 lbs).

Additional review of the status and results of this study is important, because it may provide useful information for improving all of the reclamation/revegetation efforts throughout the Red Dog operation. As a result, a follow-up action item will be included in Section 4 of this document.

3.1.9 Vegetation Treatment and Recovery Study

In 2006, Teck initiated a 3-year study to determine the extent to which plant communities have been affected by dust, and to identify potential treatment options for mitigating impacts (ABR 2009). The preliminary results of this impact assessment suggested that the primary causes of the observed vegetation impacts were deposition of acid-forming dust, input of iron sulfate and zinc sulfate from fugitive dust, and reduction of soil aluminum to soluble forms.

Based on these preliminary results, treatment blocks were set up in three assessment areas to test treatment using dolomitic lime to promote vegetation recovery in the affected areas. The assessment areas included the Triangle Area north of the tailings dam, Red Dog Creek on the north side of the Red Dog Creek diversion channel, and the tailings areas on the southeast-facing slope on the west side of the tailings pond. The blocks were treated with lime in August 2006 to raise soil pH and decrease aluminum bioavailability to vegetation. In 2007, triple super phosphate was added to one block within each assessment area. This treatment was intended to reduce lead bioavailability to vegetation.

The effectiveness of the two treatments at improving soil conditions and promoting vegetation recovery in dust-affected areas was largely inconclusive. In the plots treated with lime, some increases in pH and reductions in aluminum concentrations were observed, although these changes were not significantly different from those measured in reference plots. Applying triple super phosphate did not significantly reduce vegetation tissue lead levels in treated plots.

Despite the lack of measurable improvements in soil characteristics, the preliminary vegetation response observed in the treatments was encouraging. Although the measured increase in vascular cover was modest, and colonization of mosses and lichens was slight, these small changes suggest that with more time and more extensive treatments, soil surface conditions may continue to become more favorable for vegetation (ABR 2009).

3.1.10 Bearded Seal Study

A study of bearded seals (*Erignathus barbatus*) published in 2009 evaluated concentrations of 19 trace elements in liver tissues of bearded seals harvested near the Red Dog Mine port site and reference sites, to determine whether the seals harvested near the Red Dog Mine port were as safe to eat as those harvested in other locations (Quakenbush and Citta 2009). Liver tissues from 24 bearded seals were analyzed; 9 seals were harvested near the RDM port site, and 15 were harvested from other reference sites. Some statistically significant trends were identified in concentrations of certain elements (mercury, selenium) with the age of the seal, but not with respect to harvest location (port versus elsewhere). Arsenic and copper concentrations were found to be statistically significantly elevated near the Red Dog Mine port site, as compared to reference sites; however, the report indicated that neither element is known to be toxic in the chemical form or at the concentrations found. Also, while arsenic and copper concentrations were elevated above those found in the bearded seal livers from the reference sites, they were not higher than those found elsewhere in Alaska. In addition, arsenic is converted to organic arsenic forms in the liver of mammals and other vertebrates. Thus, most arsenic in the seals would be in the form of organic arsenic, which has much lower toxicity than inorganic arsenic (ATSDR 2007). No evidence was found to suggest that bearded seals harvested near the port are less safe to eat than those harvested in other areas.

3.1.11 Macrolichen Community Survey in Noatak National Preserve

Holt et al. (2009) identified a lack of community-level studies of macrolichen ecology in the Arctic environments of western North America. Therefore, the objective of the Holt et al. (2009) study was to describe lichen community structure in Noatak National Preserve and its relationship to environmental factors such as latitude, vegetation type, habitat rockiness, topography, and substrate that drive lichen community patterns. Holt et al. (2009) identified 201 macrolichen taxa from 88 plots in the Noatak National Preserve. The study indicated that average species richness was 26 species per plot. Lichen species were related to vegetation composition (described by forests, moist tundra, or high alpine communities), and were influenced by soil moisture and exposure. In the Arctic, both protected forests (and densely shrubby sites) and high-elevation alpine sites are relatively dry and well drained, while mesic, lowland tundra habitats are relatively moist. Substrate pH is related to the presence of sphagnum moss, which increases the acidity of its surrounding environment, and is also affected by the presence of limestone and dolomite that underlies much of Noatak National Preserve. Holt et al. (2009) suggested that the combination of vegetation community and substrate pH influences species establishment and species survival.

The significance of the work by Holt et al. (2009) in Noatak National Preserve is that it provides baseline data that may be useful for future comparisons to evaluate possible changes in lichen communities.

3.1.12 Vegetation Monitoring in the Mine Area in 2006

Long-term vegetation monitoring plots were established in 2006 in the mine area by ABR (ABR 2009). The long-term monitoring was initiated to detect recovery of sensitive plant species within the affected area in response to efforts to reduce fugitive dust emissions from mine facilities. A total of 55 monitoring plots were established along nine radial lines surrounding the Red Dog Mine. Vegetation was sampled at distances of 0 m, 500 m, 1,000 m, 2,500 m, and 4,000 m from the mine.

At each monitoring plot, plant cover was measured quantitatively using the point intercept sample method. Vegetation was sampled in each 5×10-m plot using the point intercept method, and 100 points were sampled in each plot. Points were sampled on a 2×0.025-m grid by stretching a 5-m tape measure across the plot at the 1-, 3-, 5-, 7-, and 9-m intervals. Plant cover was measured at 25-cm intervals along the tape within the plot. A small laser pointer mounted on an aluminum rod was used to identify a discrete sample point at each grid location. All plant species were recorded at each point, including multiple layers (canopies). Thus, 100 points were sampled per plot. Vascular plants were identified to the species level, and non-vascular plants (lichens, mosses, and liverworts) were identified to genus, with species identification where possible.

Plots were permanently marked with wooden stakes, photographed, and surveyed with GPS. Data were tabulated and archived for comparison with future monitoring results.

3.1.13 Vegetation Monitoring in the Mine Area in 2010

The long-term vegetation monitoring plots that were established and monitored in 2006 (ABR 2009) were monitored again in 2010 (Cedar Creek Associates 2011). The stated objective of this survey was to provide baseline vegetation, moss, and lichen cover values to facilitate long-term monitoring of representative sites within a 4,000-m radius of the Red Dog Mine. Point intercept vegetation sampling was conducted on 50 of the 55 plots that were established by ABR in 2006 along nine lines radiating from the Red Dog Mine facility areas out into the surrounding environment. Four of the remaining five sampling points were moved due to planned facilities expansion, and the fifth point was relocated because the GPS coordinates were not correct. Similar to the 2006 monitoring, Cedar Creek Associates measured moss and lichen cover and vascular plant cover and composition. Similarly, 5×10 m plots were used. However, the method that was used by Cedar Creek in 2010 to monitor the plots differed from that used by ABR in 2006.

The monitoring conducted in 2010 was implemented using the following approach: at each 1-m interval along each transect, a laser point bar was situated vertically above the ground, and 10 readings were recorded as hits on vegetation (by species), litter, rock, or bare soil. The laser point bar consisted of 10 specialized lasers situated along the bar at 10-cm intervals. Hits were determined at each meter interval, such that 100 first intercepts (first hits) were recorded. This was repeated on each of the five 10-m-long transects for a total of 500 first intercepts per plot. To facilitate assessment of total moss and lichen cover that occurs at ground level, second intercepts (second hits, beyond the initial 100 first hits) were recorded when an overstory vascular plant or standing litter was present. The primary overstory was then moved to the side to allow the laser to penetrate to ground level. The total of first and second hits on lichen and moss provided ground-cover values for those mosses and lichens.

Differences between the 2006 and 2010 study methods may make comparison of monitoring results more difficult. Additional study is needed to enable comparison of monitoring results from the two methods. The differences in methods and the planned comparison study are discussed in Section 4.

3.1.14 Vegetation Monitoring at Port and DMTS in 2010

In 2010, Cedar Creek Associates conducted monitoring at previously established long-term vegetation monitoring plots near the DMTS road and port, and at associated reference areas that were also used as reference areas in the DMTS Risk Assessment (Exponent 2007a). The stated objective of this survey was to provide baseline vegetation, moss, and lichen cover values to facilitate long-term monitoring of the representative sites. The same methods described in Section 3.1.10 were used at these locations, but the layout of the sampling sites differed. The locations of the sampling sites were based on the information outlined in the 2010 Monitoring Plan (Exponent 2011a), which included three sites along the DMTS road and one near the port facilities. At each site, three monitoring transects that parallel the DMTS road were established at distances of 100 m, 1,000 m, and 2,000 m, resulting in a total of 12 stations. Each transect was 100 m long. Points were sampled at 1-m intervals along ten 10-m transects placed end to end, resulting in collection of 1,000 intercepts (first hits) per transect. The same approach was used for reference area monitoring locations.

Differences between the 2006 and 2010 study methods may make comparison of monitoring results more difficult. Additional study may be needed to enable comparison of monitoring results from the two methods.

3.1.15 Study of Metals in Mud and Snow in the Vicinity of the DMTS Road, Red Dog Mine, and Cape Krusenstern National Monument

In 2005 and 2006, USGS collected a small number of mud, road-bed soil, and snow samples to assess metal concentrations and loadings to areas adjacent to the DMTS road (Brumbaugh and May 2008). Mud was collected in the summer of 2005 from wheel-wells of two passenger vehicles used for transport between Red Dog Mine and the port facility, and also from a vehicle stationed in Kotzebue, Alaska, that served as a reference sample. Mud was enriched in cadmium, lead, and zinc by factors of 800, 450, and 220, respectively, as compared to mud collected from the reference site. Aluminum and barium were 2.2- and 5-fold greater, respectively, in the mine-vehicle mud when compared to the reference mud. Enrichment factors in mud from mine vehicles ranged from 10 to 100 for arsenic, antimony, silver, mercury, and thallium.

DMTS road-bed soil samples were collected from the road center and road shoulder. Compared with the Kotzebue reference mud, DMTS road-bed soils were enriched by factors of about 12 for cadmium, 11 for barium, and 6 for lead and zinc. Concentrations for other elements were similar in reference mud and DMTS road-bed soil, with the exception of calcium, probably reflecting periodic applications of calcium chloride to the DMTS road. For temporal comparison, the authors compared road-bed soils to road-dust samples collected in 2000 by Ford and Hasselbach (2001). Concentrations of cadmium, lead, and zinc were about 3- to 4-fold lower than those reported for the 2000 road-dust samples. The authors suggested that improvements in concentrate handling procedures implemented since 2001 might have helped to reduce the metal concentrations.

In April 2006, snow samples were collected near three creeks in CAKR (Straight Creek, Aufeis Creek, and New Heart Creek) that were 15 to 50 m from the DMTS road. In addition, snow was also sampled along a gravel road near Kotzebue, Alaska, that carries little vehicular traffic and is not used by large trucks, to serve as a reference area. Metal loadings were estimated from individual samples and were greater in the creeks by factors of 13 to 316 for cadmium, 28 to 589 for lead, and 8 to 195 for zinc, when compared to the snow samples collected near Kotzebue.

Snow samples collected in full-depth snowpack cores at a distance of 50 m north of the DMTS had an average of 172 mg of particulate; samples from 15 m north of the DMTS had an average of 292 mg of particulate; and samples from 15 m south of the DMTS had an average of 60 mg of particulate. Samples collected on the south side of the road were expected to contain lower amounts of particulates because of prevailing southerly winds.

Paired snow samples were collected 15 m north of the DMTS at the three drainages. There were substantial differences in the amount of particulates in the paired samples. However, cadmium, lead, and zinc concentrations in the particulates were fairly consistent among the three drainages, with loadings greatest at Aufeis Creek and least at Straight Creek. The authors suggested that results of the study indicated that the “port effect”—previously attributed to fugitive metal-enriched dusts stemming from concentrate transfer operations at the port facility—was not necessarily an important factor affecting spatial differences of metals deposition in snow along the road in CAKR during the winter of 2005/2006. Removal of contaminated soil and improvements in concentrate handling procedures at the port facility in 2003, as well as the cessation of port shipping operations between early fall and early summer, might help explain these observations.

Differences in particulate and metal loadings in snow collected from the three drainages were probably a result of localized meteorological conditions, such as snow drift and scouring in windy locations; micro-topography related to vegetation growth in the arctic tussock tundra, which is heterogeneous; and orientation and surface relief, which affects attainable truck speeds. As vehicle speed increases, Brumbaugh and May (2008) suggested that greater amounts of fugitive dust could be dispersed from truck surfaces and the road surface, due to greater wind velocity and vibration.

The authors also reported that the average metal content of particulates in 2005/2006 snow samples was slightly less than that of snow samples collected by USGS in CAKR at three near-road locations in April 2003. They also suggested that total annual metal loadings dispersed to CAKR lands have been reduced in recent years.

Assessment and monitoring of changes in metal concentrations in areas adjacent to the DMTS is ongoing with the vegetation and road-surface monitoring activities that are included in the Monitoring Plan (Exponent 2011a). Vegetation monitoring and dustfall jar monitoring are also conducted under the Monitoring Plan. These programs provide a more integrated view of deposition than snow sampling, which is subject to more variability.

3.2 Potential Future Uncertainty Reduction Actions

A wide variety of possible uncertainty reduction actions were identified and compiled into a complete list of prospective uncertainty reduction actions. Several sources were relied upon to develop the combined list of potential actions, including the following:

- Past and ongoing uncertainty reduction actions described in this section
- Potential actions identified by stakeholders during the Risk Management Workshop (provided in Table 1)[3]
- Potential actions associated with uncertainties or questions identified in the DMTS Fugitive Dust Risk Assessment process, including the associated comment response documents
- Potential actions identified in the Monitoring Plan and Remediation Plan.

These sources of information were used to assemble Table 2, which includes a list of potential uncertainty reduction actions that could be undertaken, and denotes the source of each potential action.

[3] As part of the risk management workshop, stakeholder groups were asked to list and discuss potential actions for each of six risk management action categories, including uncertainty reduction. As described in detail in the RMP, each potential action within a category was then scored based on five criteria: effectiveness, implementability, level of effort, stakeholder preference for the action category, and stakeholder preference for the potential action. The scores for the latter two criteria were calculated using input from stakeholders at the risk management workshop. The scores for the five criteria were summed to a total score, and a priority ranking of 1 to 3 was assigned based on the total score. Eight of the thirteen potential uncertainty reduction-related actions identified during the workshop received a priority ranking of either 1 or 2.

4 Actions to be Implemented

The overall goal of the RMP is to minimize risks associated with fugitive dust emissions from Red Dog Mine operations. Therefore, actions such as implementation of studies that reduce uncertainty and increase knowledge about how to best minimize those risks are an important part of the RMP. Uncertainty reduction involves the use of scientific studies to address areas of uncertainty, to improve our understanding and management of risk to human health and the environment. As such, studies that are selected for implementation will be designed to answer specific questions where further information would inform long-term risk management goals.

As described in the previous section, a wide variety of possible uncertainty reduction actions were identified and evaluated in order to assemble a complete list of potential actions (provided in Table 2). This list is subsequently screened in Table 3 to identify the most effective set of actions for reducing uncertainty. For those items in the list that are not retained for further action, Table 3 includes the rationale for screening them out. Those items that are retained in Table 3 provide a focused list that can be prioritized for development and implementation. Communication and collaboration actions available at each stage of the uncertainty reduction program are summarized in Table 4. Figure 1 illustrates milestones in the development of this plan, and provides specific communication actions to be implemented.

The specific studies selected to accomplish the goals of the Uncertainty Reduction Plan are summarized in Table 5, along with planned timelines for implementation. The following sections describe the studies selected for implementation.

4.1 Umayutsiak Creek Surface Water Sampling Study

Surface water drainages in the vicinity of the DMTS ultimately flow into the Wulik River or into the Chukchi Sea near the port site (south of Kivalina). The Wulik River is a source of drinking water for Kivalina residents. Sampling of Kivalina drinking water has been conducted on an ongoing basis and has not shown elevated metals concentrations in comparison with DEC drinking water maximum contaminant levels and EPA risk-based screening levels (i.e., Region 9 preliminary remediation goals (ADPH 2001). Because some streams crossing the DMTS flow into the Wulik River, which in turn provides drinking water for Kivalina, and because some use of drinking water from streams occurs during subsistence use activities, drinking water consumption from the freshwater environment has been identified as an exposure pathway for residents and was evaluated in both the subsistence use and the combined worker/subsistence use scenarios in the risk assessment. Water data used in the human health risk assessment were for samples from creeks that cross the DMTS road. These data are expected to represent the water quality of surface water that is potentially the most affected by dust or runoff from the DMTS. As a result, use of these data in the assessment is also expected to be protective of subsistence use of other water sources elsewhere in the surrounding area.

Risk assessment findings showed that water provides a relatively small contribution to overall metals exposure for humans and wildlife, relative to other sources such as food. In comments received during the Risk Management Workshop, at public meetings, and in writing, stakeholders have expressed an interest in sampling of Umayutsiak Creek south of the Port, which is used as a water source during subsistence food gathering and hunting activities. Addressing the data gap associated with water used at Umayutsiak Creek would provide increased confidence in the results and protectiveness of the risk assessment.

Thus, Teck plans to sample surface water from Umayutsiak Creek during the summer of 2013 and analyze the samples for the same set of metals that were included in the DMTS Risk Assessment (i.e., aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, copper, fluoride, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, tin, vanadium, and zinc). The Subsistence Committee and other local stakeholders will be consulted in selecting a sampling location and timing.

4.2 Berry Subsistence Foods Study

All site-related berry samples were included in the DMTS risk assessment, including samples collected at a station directly next to the fuel storage tanks. Although areas within the ambient air boundaries are off limits to berry picking because of safety issues associated with the mine's activities, data for samples collected within the port and along the road were included in the assessment to be conservative (health protective) in the evaluation. Exponent also used data from another location just north of the ambient air boundary (from the south end of Ipiavik Lagoon). The risk assessment found that berries provide a low contribution of total metals intake for people, and found that continued harvest and consumption of berries from the site, including from unrestricted and restricted areas near the DMTS, does not pose a public health concern.

Comments received on the risk assessment questioned the temporal and spatial representativeness of berry samples. A tribal representative and community member stated that sample collection occurred during a year identified as having a particularly poor harvest, and that the timing of sample collection did not coincide with optimal gathering times defined by subsistence users. In particular, the commenter indicated that because sampling occurred directly after a rainfall, there may have been less dust on the berries than usual. In order to address community concerns expressed about the timing of berry sampling, additional sampling could be conducted to provide increased confidence in the results and protectiveness of the risk assessment. In addition, both washed and unwashed berries could be analyzed to assess the contributions of external and internal metals to total metals concentrations in berry samples; this will address an uncertainty reduction action item.

Therefore, a berry subsistence foods study will be planned for the summer of 2013. The berry sampling will be planned to occur at the end of a dry period (before a rainfall), and will include harvest locations identified by the subsistence users. The proposed sampling plan will be developed with input from the Subsistence Committee, and will include stakeholder review and input via the Ikayuktit Team to finalize the study design. Also, members of the community, as designated by the Ikayuqtit Technical Review Workgroup, will assist with sampling.

4.3 Caribou Bone Marrow Study

The RMP Monitoring Plan includes periodic monitoring of metals in caribou tissues. The past caribou studies at Red Dog were conducted in 1996, 2002, and 2009. The data collected from those studies were from caribou muscle, liver, and kidney. As described in the risk assessment, caribou metals concentrations used in the risk assessment came from caribou that had over-wintered at the site. If site metals affect caribou metals concentrations, the recent "exposure" would be most likely to be reflected in the highly vascularized soft tissues, such as the liver.

Caribou bone and bone marrow has not been sampled in the Red Dog studies in the past, nor is it included in the Monitoring Plan. However, stakeholders have stated that they consume bone and marrow as part of their diet, and therefore they are concerned about lead and other metals in these parts of the animals.

As described in the risk assessment and previous comment responses, caribou bone marrow is more than 95 percent fat and not a good source of minerals in general. As such, bone marrow would be less likely to store the metals being evaluated at the site than the muscle and organ tissues that are part of the caribou sampling and monitoring efforts. In addition, bone marrow would make up a very small portion of the caribou tissue consumed by people (compared to muscle). Thus, because marrow is not a storage site for metals, and is a relatively small part of dietary intake, bone marrow was considered to have little or no impact on the results of the risk assessment.

The bone itself (not the marrow) is a storage site for lead, and would be more likely to reflect very long-term exposure than soft tissues such as liver, muscle, and kidney. However, as with bone marrow, if bone consumption were included in the risk assessment, it would likely have little impact on overall risk results because bone would comprise a very small portion of the overall amount of caribou consumed by people, compared with muscle tissue.

Nevertheless, addressing the public concern associated with caribou bone and bone marrow consumption would provide increased confidence in the results and protectiveness of the risk assessment. Therefore, to address this concern, Teck plans to analyze caribou bone and bone marrow concentrations during the next caribou sampling period in 2015. Results will be analyzed to evaluate the difference between site-related concentrations and reference/ background concentrations in bone and bone marrow. Study design and planning will be conducted in consultation with the Ikayuqtit Technical Review Workgroup, ensuring stakeholder review and input into the final study design.

4.4 Caribou Site Use Study

Caribou are an integral part of life for native northern Alaskans, for both subsistence and cultural reasons. Because of this, caribou were included in the DMTS human health risk assessment (Exponent 2007a) to evaluate the potential contribution of caribou to dietary intake of DMTS-related metals for people living in the area. Caribou have an extensive home range and spend only a small portion of their lives in contact with the site. To address the issue of less than full-time residence at the site, the DMTS risk assessment used a "fractional intake" to account for the fraction of the animal's life that is spent at the site, and thus the fraction of metal content in the animal that is theoretically attributable to the site.

The fractional intake used in the DMTS risk assessment was derived based on the ratio of the site area to the subsistence harvest areas for residents of Noatak and Kivalina. This would tend to overestimate fractional intake, because the home range of caribou is far larger than the subsistence harvest areas. Thus, the fractional intake used in the risk assessment likely greatly overestimated both the fraction of metals in the animals that is attributable to the site and site-related risks to human health. The DMTS risk assessment incorporated a fractional intake for subsistence use of caribou of 9% based on the harvest-area calculations. In addition, risks were also calculated under an alternative scenario assuming a high-end fractional intake of 20%.

Results from the DMTS risk assessment indicated that metals concentrations detected in caribou harvested at the site were not associated with elevated human health risks from eating caribou. In addition, studies presented in the DMTS risk assessment indicate that metals concentrations in caribou obtained at the DMTS site are similar to metals concentrations in caribou from elsewhere in Alaska and other parts of the world. These results suggest that caribou metals concentrations are more related to background exposures than to site-related metals.

Based on comments received during the Risk Management Workshop, at public meetings, and in written comments, exposure to metals in caribou remains an area of concern for stakeholders. In particular, uncertainty associated with the fractional intake assumption used in the DMTS risk assessment was a significant area of concern identified at the Risk Management Workshop. Acquisition of data to support either the fractional intake used in the DMTS risk assessment or an alternative fractional intake was identified as an important need. Assuming that the true fractional intake falls between zero and 20% (the high-end alternative assumption), the fractional intake assumption could have a 20-fold effect (or more) on risk estimates. The exposure assumptions used in the risk assessment were designed to provide a conservative (i.e., health protective) estimate of hypothetical risk. Addressing the data gap associated with fractional intake for caribou would provide increased confidence in the results and protectiveness of the risk assessment.

The Alaska Department of Fish and Game (ADFG) has been studying the Western Arctic and Teshepuk caribou herd movements using satellite telemetry. Caribou have been tagged with satellite collars from 1988 through the present. These data are typically used to determine seasonal ranges, calving grounds, and movements and distributions of caribou herds for all seasons. The telemetry data could potentially be used to assess how much time caribou of the Western Arctic and Teshepuk herds spend at the DMTS road, port, mine, and surrounding areas. This would allow for a better estimate of fractional intake, thereby reducing uncertainty associated with that aspect of the risk assessment. However, due to the classified nature of the data (to prevent poaching), a MOU will need to be drafted and accepted between Teck and ADFG to ensure that the data are used and managed properly. A proposed plan will be developed in 2012, and will be shared with the appropriate personnel at ADFG involved in caribou satellite telemetry data collection. After refining the draft plan with input from ADFG, it will be shared with the Ikayuqtit Technical Review Workgroup for stakeholder review and input into the final study design. Teck will work with ADFG to try to secure a cooperative agreement to implement this study in 2012–2013.

4.5 Reclamation and Recovery Study

As part of Teck's commitment to conducting progressive reclamation throughout the life of the Red Dog Mine, a mechanism for tracking the success of reclamation efforts is needed. This study will involve development of a comprehensive reclamation and recovery database, and will include periodic review of reclamation and remediation effectiveness at various sites around Red Dog Operations (mine, road, and port). Natural recovery through colonization of native species into previously reclaimed areas will also be evaluated.

Reclamation and Recovery Database. A Reclamation and Recovery Database is already in use at Red Dog. This database will be expanded and used to track the scheduling and implementation of reclamation activities. The expanded database will also facilitate collection of important information regarding the effectiveness of various reclamation strategies, including the types of sites that have been reclaimed, what techniques were used, and details on the progress of reclamation efforts at each site. The following types of sites will be included in the database:

- Previous sites that were studied (and described briefly in Sections 3.1.5 through 3.1.8)
- Spill sites that were treated and/or revegetated following remediation
- Spill sites that were remediated previously and left to recover naturally
- Spill sites where reseeding was done with a mixture of non-native grasses.

The Reclamation and Recovery Database will integrate a variety of data using GIS. The GIS database will include names and locations (coordinates) of remediation and/or reclamation activity, site characteristics, cover material, grading method, seed type/mix used or vegetation type planted (if any), and treatments applied, such as fertilizers used. Additional informational fields will be added to the database as needed to sufficiently document the sites.

Database expansion is scheduled to begin in 2012. The database and its ongoing maintenance will be incorporated into the Remediation Plan (Exponent 2011b).

Reclamation and Vegetation Recovery Monitoring Study. After the Reclamation and Recovery Database is expanded, various sites around the Red Dog Mine, road, and port will be evaluated to assess the effectiveness of past remediation, reclamation, and revegetation activities. Monitoring will likely provide information on species present (including native versus nonnative vegetation species), and vegetation community characteristics at remediated or reclaimed areas. The results of periodic monitoring of previously treated sites will be entered into the Reclamation and Recovery Database. Reference area sites will also be selected and monitored for comparison with the reclaimed sites.

This study will clarify which reclamation and recovery methods are most effective, and evaluate new techniques or plant species in order to promote recovery of reclamation sites. Ongoing evaluation of trends in these data using the Reclamation and Recovery Database will facilitate continuous improvement in reclamation practices. Work is expected to begin in 2013 after the Reclamation and Recovery Database is expanded.

4.6 Reference Area Monitoring

As part of the DMTS Risk Assessment (Exponent 2007a), reference areas were selected so that plant and animal communities could be compared between areas that are influenced by dust deposition and those not so influenced. The terrestrial reference areas were selected after review of existing studies and data, so that areas similar to those along the length of the DMTS in terms of topography and physiography (including slope, aspect, and water features), bedrock geology, and plant and animal communities would serve as appropriate reference areas.[4]

---

[4] Prevailing winds originate from the east, between the northeast and southeast quadrants. Therefore, the most significant dust deposition occurs to the north and west of the DMTS road and mine. Areas to the east were not suitable, because the topography was more mountainous than most of the DMTS area. As a result, the preferred reference areas were located south of the DMTS road and mine. The Evaingiknuk Creek drainage was selected as the best choice, because it contained a variety of topographic conditions (elevations, slopes, aspects), streams and ponds, and plant communities, providing the opportunity to sample environments similar to those along the

There has been some critique of the reference areas that were selected for the risk assessment. Some reviewers of the assessment suggested that reference areas should have been located farther away from the DTMS road, in a geographically separate area. However, selecting an area too far south of the mine and DMTS road would have put the reference area into the Noatak Valley, where the plant community differs significantly from that at the site.

As of 2011, the Monitoring Plan did not incorporate any reference area stations. Given the importance of reference areas to interpretation of results from ongoing monitoring programs, future monitoring events will include the reference areas that were used in the original DMTS risk assessment biota program (Exponent 2007a). This addition will also be incorporated into the next update to the Monitoring Plan. Collection of reference area monitoring data (including both vegetation community and moss tissue concentrations of metals) will allow assessment of trends in the reference areas that may indicate the possible influence of dust deposition or other factors. The reference area vegetation community monitoring results will be used to evaluate whether changes at site-related stations are a result of dust deposition, or may be caused by climate variation or other factors that may be causing regional changes. If reference area monitoring finds an increasing trend in metals tissue concentrations that appears to be related to site sources, then the need for an additional reference site (or sites) will be evaluated. These evaluations will be performed after each vegetation community monitoring event, as scheduled in the Monitoring Plan (Exponent 2011a).

4.7 Communication and Collaboration

In this section, the standard communication guidelines developed in the Communication Plan (Exponent 2009) are applied to uncertainty reduction–related studies. As with other programs, the Uncertainty Reduction Plan and associated activities will have planning, implementation, and reporting stages. At each stage, communication actions have been identified that address the three categories of communication-related actions identified in the Uncertainty Reduction Plan: collaboration, communication, and education and outreach. Table 4 provides a matrix

length of the DMTS road. In addition, it had low base-metal mineralization compared to other possible reference areas.

summarizing the types of actions identified for the Monitoring Plan and related activities to address the three communication categories at each stage.

The communication tools identified in Table 4 are developed further in Table 5 to identify the specific actions expected to be necessary to accomplish the goals of the Uncertainty Reduction Plan. This list of actions draws from each of the three communication-related categories (i.e., communication, collaboration, and education/outreach) and provides a set of actions that meet the goal of effectively communicating ongoing issues and efforts related to uncertainty reduction studies. Figure 1 illustrates key milestones in the reporting of results from the Uncertainty Reduction Plan or associated study plans, and provides the specific communication actions to be implemented.

4.7.1 Technical and Public Review

As described in the Communication Plan, the Ikayuqtit Technical Review Workgroup has been expanded to incorporate other existing stakeholder representatives/groups and to serve as the technical review committee for fugitive dust-related studies and reports. The expanded Ikayuqtit Technical Review Workgroup will provide technical review and input to the Uncertainty Reduction Plan and other related study plans and reports at the planning, review, and reporting stages. Following review by the team, and revisions per comments from the team, the revised document will be posted to the www.RedDogAlaska.com with public notice.

4.7.2 Community Meetings

Teck will continue to provide updates on uncertainty reduction studies during regularly scheduled community meetings. Face-to-face meetings foster a positive working relationship and provide a forum for soliciting local traditional ecological knowledge for incorporation into study planning and design. Strategies for improving adequate and representative participation in community meetings will be incorporated, including: 1) maintaining a regular and predictable schedule of meetings; 2) improving use of community liaisons to identify potential scheduling conflicts; 3) improving awareness of meetings (e.g., use of additional venues for written notices and/or announcements, improved e-mail lists, early advertisement of meetings); 4) facilitating active participation by using appropriate language and terminology, using translators, and providing information and opportunities for input using varied formats (e.g., formal presentations, informal discussions, small workgroups, written materials and questionnaires, etc.); and 5) providing effective, timely follow-up summarizing the input provided and how it will be incorporated and/or addressed.

4.7.3 Web Portal and E-mail Lists

Teck has established an information-sharing portal to provide access and/or links to fugitive dust-related studies, reports, and other information. The purpose of the portal is to facilitate collaborative development, review, and reporting of studies, monitoring programs, and dust control efforts with stakeholders on the expanded Ikayuqtit Technical Review Workgroup. Thus, the web portal will be used to facilitate and coordinate technical review of uncertainty reduction–related studies and reports. When documents are finalized and/or ready for full public review, they will be made available on the open-access Red Dog website (www.RedDogAlaska.com). Teck will work with state agencies to ensure accessibility of uncertainty reduction–related documents for public access and review, and will provide links from the web portal and the Red Dog website where appropriate. Associated with this effort, Teck has expanded and will continue to update e-mail lists and use them to notify stakeholders of additions and/or revisions to the web portal, or when review and input is needed. Overall, this approach builds in several improved information-sharing strategies that were identified as part of the RMP stakeholder workshop process.

4.7.4 Written Technical Communications

In the annual fugitive dust RMP report, Teck will include a brief summary of the prior year's uncertainty reduction study progress and results, and planned studies or continuation of studies for the upcoming year. In addition, where appropriate, relevant studies from other stakeholder groups that address areas of uncertainty will be summarized and/or incorporated into the report. A simplified summary of all of the uncertainty reduction study efforts will be included at the front of the document to facilitate better understanding of technical information. If necessary, one or more separate "fact sheet" summaries may be developed.

4.7.5 Education and Outreach

Education and outreach actions include those activities that are related to, but outside the immediate scope of, uncertainty reduction studies. They are focused toward providing additional opportunities for stakeholders to gain more understanding and participation in Red Dog operations as a whole, and health and environmental efforts in particular. Several education and outreach actions were proposed by stakeholders during the RMP process. The following actions have been identified as potentially viable for use in uncertainty reduction efforts:

- Provide updates and information related to uncertainty reduction efforts in the following venues:
  - Newsletters
  - Newspaper articles
  - KOTZ radio updates.

5 Periodic Review and Reporting

Teck will prepare an annual report (or reports) detailing the progress and results of the uncertainty reduction studies. A summary of these efforts will be included in the annual RMP report. The annual report(s) will be provided to the Ikayuqtit Technical Review Workgroup by the end of the first quarter for review and comment prior to posting on www.RedDogAlaska.com for access by the general public.

In addition, the effectiveness of the Uncertainty Reduction Plan will be reviewed annually, including the following tasks:

1. Review of the effectiveness of plan actions at meeting the stated goal of the plan
2. Review of each individual uncertainty reduction study undertaken to reduce uncertainties in assessment of effects to humans and the environment
3. Review of uncertainty reduction priorities and the ability of the plan to meet any new priorities
4. Review of the effectiveness of communication, collaboration, and education efforts associated with the plan
5. Revision of the Uncertainty Reduction Plan, as appropriate.

6 Milestones

Key milestones for the Uncertainty Reduction Plan include:

- Scope and goal of plan: August 2008 (in draft RMP)
- Stakeholder technical review: March 2012
- Final draft release: October 2012
- Specific uncertainty reduction actions: To be implemented in 2012, 2013, and beyond as indicated in Section 4 and summarized in Table 5
- Annual report and review: Spring 2013 as part of the annual fugitive dust risk management report.

7 Stakeholder Roles

Teck will prepare the draft plan. Review will be invited from all stakeholders as discussed in Section 4.7. Periodic review, revision, and input on this plan or results produced as a result of this plan will be invited from all stakeholders.

Teck will prepare an annual report (or reports) detailing the progress and results of the uncertainty reduction studies. A summary of these efforts will be included in the annual RMP report. The annual report(s) will be provided to the Ikayuqtit Technical Review Workgroup in spring of the following year for review and comment prior to posting on www.RedDogAlaska.com for access by the general public.

8 References

ABR. 2007. Revegetation plan for the Red Dog Mine, Alaska. Final Report. Prepared for Teck Cominco Alaska, Inc. ABR, Inc.-Environmental Research and Services, Fairbanks, AK. Available at: http://dnr.alaska.gov/mlw/mining/largemine/reddog/publicnotice/pdf/sdf3.pdf.

ABR. 2009. Vegetation impact assessment and monitoring studies, Red Dog Mine, Alaska. Prepared for Teck Cominco Alaska, Inc. Third Annual Report. February 2009. ABR, Inc.-Environmental Research and Services, Fairbanks, AK.

ADPH. 2001. Public health evaluation of exposure of Kivalina and Noatak residents to heavy metals from Red Dog Mine. Alaska Division of Public Health, Department of Health and Social Services, Section of Epidemiology, and Environmental Public Health Program, Anchorage, AK.

ATSDR. 2007. Toxicological profile for arsenic. U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry.

Brumbaugh, W.G., and T.W. May. 2008. Elements in mud and snow in the vicinity of the DeLong Mountain Regional Transportation System Road, Red Dog Mine, and Cape Krusenstern National Monument, Alaska, 2005–06. U.S. Geological Survey Scientific Investigations Report 2008–5040, 30 p.

Brumbaugh, W.G., M.A. Mora, and T.W. May. 2008. Assessment of metals exposure and sub-lethal effects in voles and small birds captured near the Delong Mountain Regional Transportation System Road, Cape Krusenstern National Monument, Alaska, 2006. U.S. Geological Survey Scientific Investigations Report 2008–5211, 21 pp.

Brumbaugh, W.G., M.A. Mora, T.W. May, and D.N. Phalen. 2010. Metal exposure and effects in voles and small birds near a mining haul road in Cape Krusenstern National Monument, Alaska. Environ. Monit. Assess. 170:73–86.

Cedar Creek Associates, Inc. 2011. Red Dog Mine 2010 vegetation monitoring, in accordance with the Solid Waste Permit. Prepared for Teck Cominco. February.

DEC. 2007. Memorandum of understanding between the State of Alaska Department of Environmental Conservation and Teck Cominco Alaska Incorporated related to fugitive dust at the Red Dog Mine. Restated and amended effective January 1, 2007 through December 31, 2007. Available at: http://www.dec.state.ak.us/air/doc/RD_FD_MOU_2007.pdf. Alaska Department of Environmental Conservation, Anchorage, AK.

DEC. 2009. Review comments of Teck's "Draft Fugitive Dust Risk Management Plan Red Dog Operations, Alaska" dated August 2008. Letter to Wayne Hall from Rich Sundet. File No. 475.38.010. Dated June 19, 2009.

Exponent. 2005. Draft DMTS fugitive dust risk assessment. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA. April.

Exponent. 2007a. DMTS fugitive dust risk assessment. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA. November.

Exponent. 2007b. Fact sheet: Risk assessment of metals in dust from Red Dog. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA.

Exponent. 2007c. Evaluation of mine area ecological risk. Report prepared for Teck Cominco Alaska Inc., Anchorage, Alaska. Exponent, Bellevue, WA.

Exponent. 2008. Draft fugitive dust risk management plan. Red Dog Operations, Alaska. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA. August 2008.

Exponent. 2009. Draft fugitive dust risk management communication plan. Red Dog Operations, Alaska. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA. April.

Exponent. 2011a. Draft fugitive dust risk management monitoring plan. Red Dog Operations, Alaska. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA. July.

Exponent. 2011b. Draft fugitive dust risk management remediation plan. Red Dog Operations, Alaska. Prepared for Teck Cominco Alaska Incorporated, Anchorage, AK. Exponent, Bellevue, WA. July.

Ford, S., and L. Hasselbach. 2001. Heavy metals in mosses and soils on six transects along the Red Dog Mine haul road, Alaska. NPS/AR/NRTR-2001/38. National Park Service, Western Arctic National Parklands.

Holt, E.A., B. McCune, and P. Neitlich. 2009. Macrolichen communities in relation to soils and vegetation in the Noatak National Preserve, Alaska. Botany 87(3):241–252.

Menzie, C.A., L.M. Ziccardi, Y.W. Lowney, A. Fairbrother, S.S. Shock, J.S. Tsuji, D. Hamai, D. Proctor, E. Henry, S.H. Su, M.W. Kierski, M.E. McArdle, and L.J. Yost. 2009. Importance of considering the framework principles in risk assessment for metals. Environ. Sci. Technol. 43:8478–8482.

Quakenbush, L., and J.J. Citta. 2009. Trace element concentrations in bearded seals (*Erignathus barbatus*) near Red Dog Mine compared to other locations in Alaska. J. Marine Biol. DOI: 10.1155/2009/275040.

Shock, S.S., B.A. Bessinger, Y.W. Lowney, and J.L. Clark. 2007. Assessment of the solubility and bioaccessibility of barium and aluminum in soils affected by mine dust deposition. Environ. Sci. Technol. 41(13):4813–4820.

Teck Cominco. 2007a. Mineral weathering in Red Dog soils: Leaching. Report 2007RR06. Available at: http://www.dec.state.ak.us/air/doc/RD_soil_leach-feb07.pdf). Teck Cominco, Applied Research & Technology.

Teck Cominco. 2007b. Mineral weathering in Red Dog soils. Report 2007RR01. Available at: http://www.dec.state.ak.us/air/doc/RD_min_weather_soils-feb07.pdf). Teck Cominco, Applied Research & Technology.

Teck Cominco. 2008. Summary of the Red Dog Fugitive Dust Risk Management Workshop, March 25–27, 2008, Kotzebue, AK. CD-ROM. Teck Cominco Alaska Incorporated, Red Dog Operations Alaska, Anchorage, AK.

Wright, S.J. 1990. Final report of data and observations obtained from the Red Dog Mine evaluation and demonstration plots. Unpublished report presented to Cominco Alaska by State of Alaska, Department of Natural Resources, Division of Agriculture, Alaska Plant Materials Center. October.

Wright, S.J., W.L. Campbell, N.J. Moore, D.R. Ross, C.I. Wright, and D. Sheaver. 1993. Alaska Plant Materials Center annual report 1992. Alaska Department of Natural Resources – Division of Agriculture, Plant Materials Center, Palmer, AK.

Figure and Tables

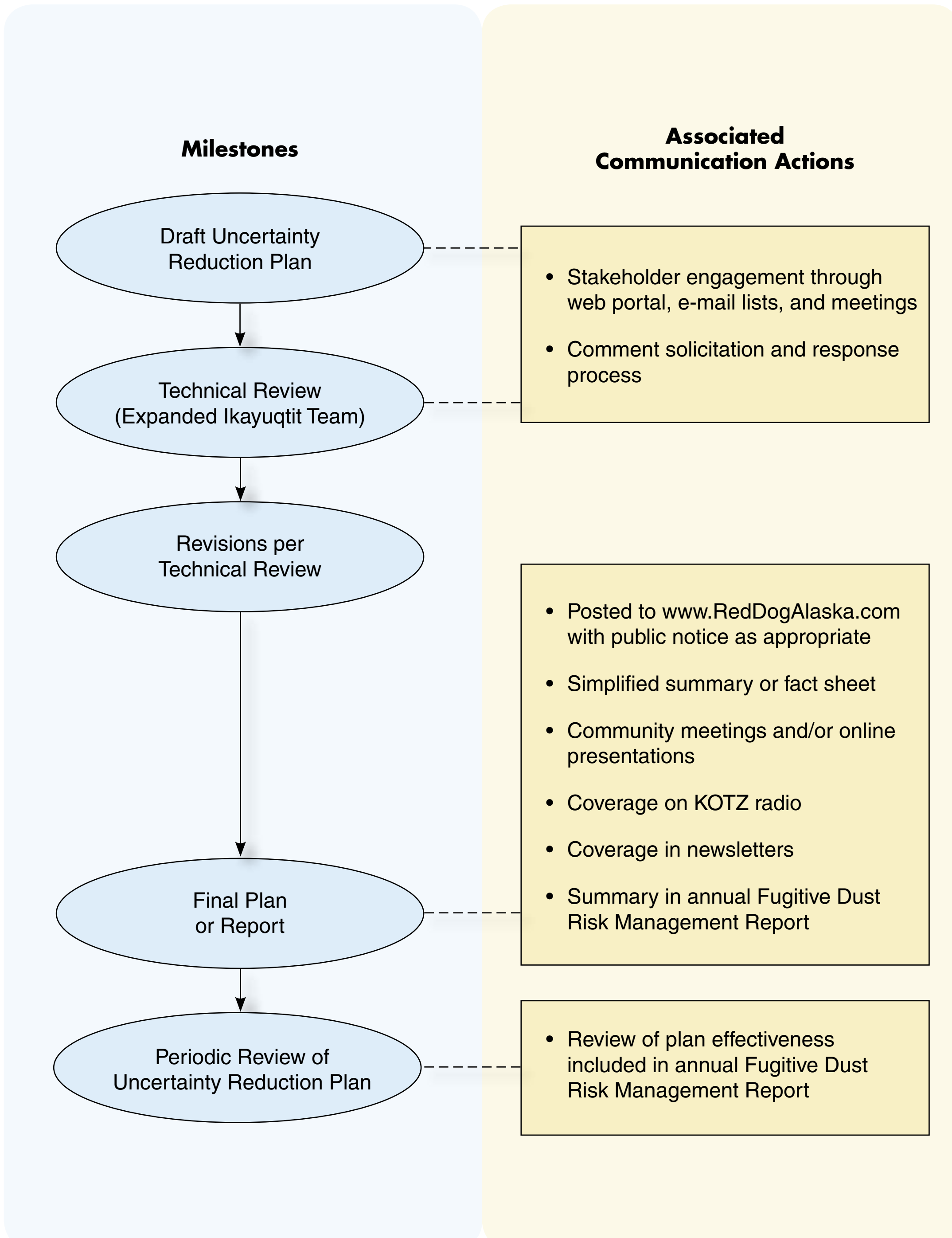

Figure 1. Uncertainty Reduction Plan and report development flowchart illustrating associated communication actions

Table 1. Priority ranking of potential uncertainty reduction actions identified in the Risk Management Workshop

Potential Actions[a]	Priority Ranking
Uncertainty Reduction	
Develop and display information on a spatial and temporal basis for trend identification	1
Determine whether timing of berry and sourdock sampling with respect to weather could have affected the results of risk assessment	1
Determine through additional characterization whether the size of the risk assessment study area was sufficient	1
Develop standard methods for sampling, analysis, and reporting	1
Determine agreed-upon triggers for adjusting monitoring frequency	1
Determine whether changes in tundra and streams are due to natural phenomena (e.g., climate change, natural slumps or seeps) or Red Dog dust or mine discharge	2
Determine safe consumption levels in subsistence foods and water	2
Evaluate potential for changes in mobility and migration of metals from oxidation or other changes in forms of minerals	2
Evaluate the potential effect of cumulative deposition on future exposure levels for humans and ecological receptors	2
Develop tools to predict when and where remediation will be needed	2
Conduct a source contribution evaluation (source apportionment) study	2
Conduct a literature review to determine feasible control measures	2
Develop a better understanding of the factors influencing subsistence animals and fish food sources on the land (near the mine and road) and in the sea (near the port)	3
Develop appropriate action levels to evaluate potential for effects of metals in tundra, plants, fish and other animals, and for people	3
Evaluate potential effects of climate change on mobility of metals	3
Develop a better understanding of the "cocktail effect" of elevated metals associated with the mine	3
Include evaluations of sub-lethal effects to animals or plants; include examination for symptoms of exposure/sickness/organ damage/other effects of exposure	3
Communication	
Provide information on funding commitments and financial assurances for long-term studies and monitoring, given uncertainty of long-term effects	1
Provide stakeholders with opportunities for input during study planning processes, provide updates during studies, and provide results of studies in timely manner to all stakeholders	1

[a] Potential actions identified in the Risk Management Workshop were scored based on effectiveness, implementability, level of effort, stakeholder preference for the action category, and stakeholder preference for the potential action. Scores for the five criteria were summed, and a priority ranking of 1 to 3 was assigned based on total score.

Table 2. Potential uncertainty reduction actions

Potential Actions	Uncertainty Reduction Action	Communi-cation Action	Source
Develop and display information on a spatial and temporal basis for trend identification	X		RMP
Determine through additional characterization whether the size of the risk assessment study area was sufficient	X		RMP
Address uncertainties with regard to potential influence from dust deposition within reference areas	X		RMP
Develop tools to predict when and where remediation will be needed	X		RMP, RP
Develop standard methods for sampling, analysis, and reporting	X		RMP
Determine agreed-upon triggers for adjusting monitoring frequency	X		RMP
Determine safe consumption levels in subsistence foods and water	X		RMP
Conduct a source contribution (source apportionment) study	X		RMP
Conduct a literature review to determine feasible control measures	X		RMP
Develop appropriate action levels to evaluate potential for effects of metals in tundra, plants, fish and other animals, and for people	X		RMP
Determine whether changes in tundra and streams are due to natural phenomena (e.g., climate change, natural slumps or seeps) or Red Dog dust or mine discharge	X		RMP
Study of particle leaching in Red Dog soils	X		RDEO
Evaluate potential for changes in mobility and migration of metals from oxidation or other changes in forms of minerals	X		RDEO/ RMP
Evaluate the potential effect of cumulative deposition on future exposure levels for humans and ecological receptors	X		RMP
Evaluate potential effects of climate change on mobility of metals	X		RMP
Develop a better understanding of the "cocktail effect" of elevated metals associated with the mine; evaluate the compounded effects of dust versus metals	X		RMP
Monitor changes in the vertical distribution of metals in surface tundra and underlying soils	X		MP
Bioaccessibility study for barium and aluminum	X		RDEO
Conduct studies to identify mosses and lichens to species level	X		RA-CR
Assess potential sulfur effects on mosses and lichens	X		RA-CR
Conduct studies on NPS-managed public lands (CAKR), including study of zinc toxicity thresholds in lichen tissue	X		RA-CR
Monitor tissue concentrations in near-facility shrubs or herbaceous plants to track rate of change (1-year frequency)	X		MP
Conduct pilot studies to evaluate tundra rehabilitation methods	X		RP
Study the natural progression of grasslands into tundra to evaluate the potential for natural recovery following reclamation	X		RP
Evaluate phytoremediation for removal of metals from soil	X		RP
Define decision criteria to determine if tundra areas should be remediated or allowed to recover naturally	X		RP
Vegetation impact treatment study to evaluate options for treatments to promote recovery of stressed vegetation	X		RDEO
Develop a better understanding of the factors influencing subsistence animals and fish food sources on the land (near the mine and road) and in the sea (near the port)	X		RMP

Table 2. (cont.)

Potential Actions	Uncertainty Reduction Action	Communi-cation Action	Source
Include evaluations of sub-lethal effects to animals or plants; include examination for symptoms of exposure/sickness/organ damage/other effects of exposure	X		RMP
Conduct studies of caribou site used to evaluate fractional intake assumption used in the risk assessment	X		RDEO
Provide information on funding commitments and financial assurances for long-term studies and monitoring, given uncertainty of long-term effects		X	RMP
Provide stakeholders with opportunities for input during study planning processes, provide updates during studies, and provide results of studies in timely manner to all stakeholders		X	RMP
Consider collecting washed and unwashed plant tissue samples to assess the contributions of external and internal metals to total metals concentrations in plant samples	X		RMP-CR 1
Appropriate reference station locations, sample size requirements, and landcover class designations will be considered in the design of future monitoring studies	X		RMP-CR 2,17
Because hazard indices were above 1 for some ecological receptors, the use of action levels will be evaluated in the RMP	X		RMP-CR 3
The need for future study of plant communities (including lichen and bryophyte species) will be evaluated during development of the RMP	X		RMP-CR 4,5,8
The requirement of the easement agreement will be considered in identifying additional action items	X		RMP-CR 6
Determine whether elevated concentrations occur in snowmelt and whether snowmelt poses acute effects to plant communities, including lichen and bryophyte species	X		RMP-CR 7
The possible need for future studies within NPS-managed lands and within CAKR will be considered during development of the RMP	X		RMP-CR 9,18
Possible need for future studies in the marine environment will be evaluated during development of the RMP	X		RMP-CR 10,11
The appropriate degree of future monitoring of subsistence foods will be evaluated	X		RMP-CR 12
Monitoring of ptarmigan will be considered during development of the RMP	X		RMP-CR 13
The need for future study of vegetation and soil communities, and bioavailability will be evaluated	X		RMP-CR 14,25
The possible need for additional work to evaluate presumed confounding effects of dust versus metals will be considered	X		RMP-CR 16
Further evaluation of wildlife usage patterns associated with the road (as they pertain to wildlife exposure estimates) may be warranted and will be considered during development of the RMP (contaminated sites may attract organisms)	X		RMP-CR 19
Possible actions to further reduce emissions during transport will be considered	X		RMP-CR 20
Possible actions to assess effectiveness of control measures will be considered	X		RMP-CR 20
Determine whether timing of berry and sourdock sampling with respect to weather could have affected the results of risk assessment	X		RMP-CR 21
Modeling of future conditions (predictive tools) will be considered	X		RMP-CR 22
The need for additional study of biological indicators will be evaluated	X		RMP-CR 23
The relative merits of evaluating bone marrow lead will be considered when developing the RMP	X		RMP-CR 24
Sampling of additional creeks will be considered	X		RMP-CR 26

Table 2. (cont.)

Potential Actions	Uncertainty Reduction Action	Communi-cation Action	Source
Draft plans will be reviewed with input from the Subsistence Committee and public meetings will be held in Kivalina and Noatak for additional communication between local communities and Red Dog		X	RMP-CR 27
Ongoing monitoring will be conducted at an appropriate frequency	X		RMP-CR 28
The need for analysis of foxes (animal deformities) will be considered during development of the RMP	X		RMP-CR 29

Note: CAKR - Cape Krusenstern National Monument
MP - Monitoring Plan
NPS - National Park Service
RDEO - Red Dog Environmental Operations
RMP - Fugitive Dust Risk Management Plan
RMP-CR - Risk management plan comments (per DEC 2009); DEC (2009) comment number included
RP - Remediation Plan

Table 3. Actions retained for the Uncertainty Reduction Plan

Potential Actions	Retained?	Rationale/Comments
Develop and display information on a spatial and temporal basis for trend identification	Yes*	Included in Monitoring Plan and associated reporting.
Determine through additional characterization if the size of the risk assessment study area was sufficient	No	Sample collection for the risk assessment focused on areas nearest operational sources of metals, where elevated concentrations occur, to be protective. Concentrations decrease with distance from facilities.
Address uncertainties with regard to potential influence from dust deposition within reference areas	Yes	See actions in Table 5 and Section 4.
Develop predictive tools to identify when and where remediation or preventative measures may be needed	Yes*	Monitoring Plan will be used to identify any potential needs for remediation.
Develop standard methods for sampling, analysis, and reporting	Yes*	Addressed in Monitoring Plan and associated reporting.
Determine agreed-upon triggers for adjusting monitoring frequency	Yes*	Addressed in Monitoring Plan and associated reporting.
Determine safe consumption levels in subsistence foods and water	Yes*	Risk assessment already determined that human health risk is low and subsistence use is safe to continue. Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
Conduct a dust source contribution (source apportionment) study	Yes*	Studies have since been conducted for the mine area to identify key sources for source control. Port area sources are more limited in number and already better understood as to their relative significance. Prior work will be summarized in the Dust Emissions Reduction Plan.
Conduct a literature review to determine feasible control measures	Yes*	To be addressed in the Dust Emissions Reduction Plan.
Develop appropriate action levels to evaluate potential for effects of metals in tundra, plants, fish and other animals, and for people	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
Determine whether changes in tundra and streams are due to natural phenomena (e.g., climate change, natural slumps or seeps) or Red Dog dust or mine discharge	Yes*	To be addressed in Monitoring Plan and associated reporting, based on monitoring results.
Study of particle leaching in Red Dog soils	Yes*	Previously studied. Refer to Section 3 for review.
Evaluate potential for changes in mobility and migration of metals from oxidation or other changes in forms of minerals	Yes*	Previously studied. Refer to Section 3 for review.
Evaluate the potential effect of cumulative deposition on future exposure levels for humans and ecological receptors	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed. Dust Emissions Reduction Plan will minimize future dust deposition.
Evaluate potential effects of climate change on mobility of metals	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed, and site-related effects vs. climate change effects will be evaluated using reference comparisons.
Develop a better understanding of the "cocktail effect" of elevated metals associated with the mine; evaluate the compounded effects of dust versus metals	Yes*	Monitoring Plan will ensure that any changes in exposure levels and effects on receptors will be identified and addressed.

Table 3. (cont.)

Potential Actions	Retained?	Rationale/Comments
Monitor changes in the vertical distribution of metals in surface tundra and underlying soils	Yes*	Previously studied. Refer to Section 3 for review. Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
Bioaccessibility study for barium and aluminum	Yes*	Previously studied. Refer to Section 3 for review.
Conduct studies to identify mosses and lichens to species level	Yes*	Cooperate with NPS studies, evaluate significance, identify whether further studies are needed.
Assess potential sulfur effects on mosses and lichens	Yes*	Monitoring Plan will ensure that any changes in plant communities will be identified and addressed.
Conduct studies on NPS-managed public lands (CAKR), including study of zinc toxicity thresholds in lichen tissue	Yes*	Cooperate with NPS studies, evaluate significance, identify whether further studies are needed.
Monitor tissue concentrations in near-facility shrubs or herbaceous plants to track rate of change (1-year frequency)	No	Expected variability too high relative to other short-term monitoring methods already employed in the Monitoring Plan.
Conduct pilot studies to evaluate tundra rehabilitation methods	Yes*	Previously studied. Refer to Section 3 for review.
Study the natural progression of grasslands into tundra to evaluate the potential for natural recovery following reclamation	Yes	See actions in Table 5 and Section 4.
Evaluate phytoremediation for removal of metals from soil	No	Impractical due to the large scale of the site.
Define decision criteria to determine if tundra areas should be remediated or allowed to recover naturally	Yes*	This will be addressed as part of the reclamation and closure process.
Vegetation impact treatment study to evaluate options for treatments to promote recovery of stressed vegetation	Yes*	Addressed in the Remediation Plan.
Develop a better understanding of the factors influencing subsistence animals and fish food sources on the land (near the mine and road) and in the sea (near the port)	Yes*	Addressed through ongoing discharge permit applications. Monitoring Plan and associated reporting will support ongoing evaluation of this area of uncertainty.
Include evaluations of sub-lethal effects to animals or plants; include examination for symptoms of exposure/sickness/organ damage/other effects of exposure	Yes*	Previously studied. Refer to Section 3 for review.
Conduct studies of caribou site used to evaluate fractional intake assumption used in the risk assessment	Yes	See actions in Table 5 and Section 4.
Provide information on funding commitments and financial assurances for long-term studies and monitoring, given uncertainty of long-term effects	Yes*	Addressed in the closure and reclamation planning process.
Provide stakeholders with opportunities for input during study planning processes, provide updates during studies, and provide results of studies in timely manner to all stakeholders	Yes	See actions in Table 5 and Section 4.
Consider collecting washed and unwashed plant tissue samples to assess the contributions of external and internal metals to total metals concentrations in plant samples	Yes	
Appropriate reference station locations, sample size requirements, and landcover class designations will be considered in the design of future monitoring studies	Yes*	Expanded reference area monitoring is included in this plan, to be incorporated into future monitoring. Land cover types have been considered throughout the risk assessment process. The limitations of small sample size issues have been addressed in the risk assessment uncertainty discussion, and are further addressed as part of the Monitoring Plan.

Table 3. (cont.)

Potential Actions	Retained?	Rationale/Comments
Because hazard indices were above 1 for some ecological receptors, the use of action levels will be evaluated in the RMP	Yes*	Moss tissue monitoring will provide landscape-scale verification that emissions from the road, mine, and port are effectively controlled, and risks to wildlife and vegetation communities are minimized over the life of the mine. Moss concentration data will be compared against target levels. The Monitoring Plan addresses moss monitoring, and the target levels will be incorporated into the final RMP and updated Monitoring Plan.
The need for future study of plant communities (including lichen and bryophyte species) will be evaluated during development of the RMP	Yes*	Cooperate with NPS studies, evaluate significance, identify whether further studies are needed.
The requirement of the easement agreement will be considered in identifying additional action items	Yes*	Addressed by all of the risk management efforts, and in the Reclamation and Closure Plan.
Determine whether elevated concentrations occur in snowmelt and whether snowmelt poses acute effects to plant communities, including lichen and bryophyte species	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
The possible need for future studies within NPS-managed lands and within CAKR will be considered during development of the RMP	Yes*	Cooperate with NPS studies, evaluate significance, identify whether further studies are needed.
Possible need for future studies in the marine environment will be evaluated during development of the RMP	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
The appropriate degree of future monitoring of subsistence foods will be evaluated	Yes	See actions in Table 5 and Section 4.
Monitoring of ptarmigan will be considered during development of the RMP	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
The need for future study of vegetation and soil communities, and bioavailability, will be evaluated	Yes*	Monitoring Plan will ensure that any changes in exposure levels will be identified and addressed.
The possible need for additional work to evaluate presumed confounding effects of dust versus metals will be considered	Yes*	Monitoring Plan will identify changes in ecosystems and communities.
Further evaluation of wildlife usage patterns associated with the road (as they pertain to wildlife exposure estimates) may be warranted and will be considered during development of the RMP (contaminated sites may attract organisms)	Yes	See actions in Table 5 and Section 4.
Possible actions to further reduce emissions during transport will be considered	Yes*	To be addressed in the Dust Emissions Reduction Plan.
Possible actions to assess effectiveness of control measures will be considered	Yes*	Addressed in the Monitoring Plan.
Determine whether timing of berry and sourdock sampling with respect to weather could have affected the results of risk assessment	Yes	See actions in Table 5 and Section 4.
Modeling of future conditions (predictive tools) will be considered	Yes*	The Monitoring Plan is designed to identify trends, and take action to prevent adverse effects from occurring.
The need for additional study of biological indicators will be evaluated	Yes*	The Monitoring Plan includes periodic review of its effectiveness, and will be updated as needed.
The relative merits of evaluating bone marrow lead will be considered when developing the RMP	Yes	See actions in Table 5 and Section 4.
Sampling of additional creeks will be considered	Yes	See actions in Table 5 and Section 4.

Table 3. (cont.)

Potential Actions	Retained?	Rationale/Comments
Draft plans will be reviewed with input from the Subsistence Committee and public meetings will be held in Kivalina and Noatak for additional communication between local communities and Red Dog	Yes	All implementation plans include a stakeholder review component. See actions in Table 5 and Section 4.
Ongoing monitoring will be conducted at an appropriate frequency	Yes*	Included in Monitoring Plan.
The need for analysis of foxes (animal deformities) will be considered during development of the risk management plan	Yes*	Addressed through existing program for reporting abnormal fauna.

Note: * Indicates items retained for uncertainty reduction that are addressed in other plans or were addressed in prior studies.

CAKR - Cape Krusenstern National Monument
NPS - National Park Service
RMP - Fugitive Dust Risk Management Plan

Table 4. Communication elements and potential actions used in uncertainty reduction-related activities

	Options Available at Various Program Stages		
	Planning	Implementation	Review and Reporting
Collaboration (Working together as a team)			
Ikayuqtit technical review	X		X
Community meetings	X		
Web portal and Red Dog website	X		X
E-mail list	X		X
Comment solicitation and response process	X		X
Involve local resident employees in studies	X	X	X
Communication (Providing information)			
Community meetings	X	X	X
Web portal and Red Dog website	X	X	X
E-mail list	X		X
Radio broadcasts and announcements	X		X
Technical reports			X
Annual summary			X
Report summaries and fact sheets			X
Education and Outreach			
Web portal and website	X		X
Involve local resident employees in studies	X	X	X
Newsletter articles			X
Radio broadcasts	X		X

Table 5. Uncertainty Reduction Plan actions

Actions	Planned Timeline for Implementation	Purpose
Uncertainty Reduction		
1) Conduct creek surface water sampling study	Summer 2013	Addresses an area of uncertainty for public health recommendations and, to a lesser degree, health risk assessment.
2) Conduct berry subsistence foods study	Summer 2013	Addresses an area of uncertainty for public health recommendations and, to a lesser degree, health risk assessment.
3) Conduct caribou bone marrow study	2015	Addresses an area of uncertainty for public health recommendations and, to a lesser degree, health risk assessment.
4) Conduct caribou site use study	2012-2013	Addresses an area of uncertainty for public health recommendations and, to a lesser degree, health risk assessment.
5) Conduct reclamation and recovery study	2012-2013 and ongoing beyond that	Addresses uncertainties regarding optimal methods for revegetating reclamation sites; includes evaluation of options for treatments to promote recovery of stressed vegetation as well as natural recovery; includes database for tracking reclamation sites.
6) Conduct reference-area monitoring	2012 and ongoing beyond that	Addresses uncertainties with regard to potential influence from dust deposition within reference areas; provides reference data for comparison with site data.
Communication and Collaboration		
Technical Review		
1) Utilize the expanded Ikayuqtit Technical Review Workgroup for technical review of uncertainty reduction-related plans and reports at the planning, reporting, and review stages.		Creates a clear process for technical review using existing structures.
2) Implement public review process (illustrated in Figure 1)		Provides a means to incorporate local traditional ecological knowledge into study planning and design. Identifies which stakeholder group technical review is appropriate for which activities.
Community Meetings		
1) Provide updates on uncertainty reduction activities during regularly scheduled community meetings.		Forum for soliciting local traditional ecological knowledge for incorporation into study planning and design. Increases trust and positive working relationships.

Table 5. (cont.)

Actions	Planned Timeline for Implementation	Purpose
Web Portal and E-mail Lists		
1) Utilize the e-Project web portal to facilitate and coordinate technical review of uncertainty-reduction related study plans, progress, and reports		Simplifies access to all Red Dog environmental-related documents, work plans, studies, and data.
2) Provide access to uncertainty reduction-related study plans, progress, and reports on the Red Dog website when they are finalized and/or ready for full public review		Increases knowledge of both the existence of new information and access to that information.
3) Provide access to other relevant uncertainty reduction-related information through links on the Red Dog website		
Written Technical Communications		
1) Include a summary of prior-year uncertainty reduction studies and those planned for the upcoming year in the annual report (described in the Communication Plan)		Summarizes in one place yearly accomplishments and activities and plans for the future. Provides sense of continuity and communicates how information gained from past activities is used to develop future actions.
2) Provide a simplified summary or fact sheet for all uncertainty reduction-related reports to facilitate better comprehension of the technical information		Facilitates better understanding of technical information, and thus, more constructive stakeholder involvement.
Education and Outreach		
1) Provide updates and information related to uncertainty reduction as part of KOTZ radio updates and newsletter articles (described in Communication Plan)		Encourages collaboration between stakeholders and use of traditional ecological knowledge as part of uncertainty reduction-related studies.