Alberta Selenium Working Group
Acceptance of the Final Report of the Selenium Science Panel

August 13, 2007

The Alberta Selenium Working Group (SWG) was formed in 1999 to coordinate efforts to assess and manage potential selenium impacts from mountain coal mines in west-central Alberta. Our members include representatives from the provincial and federal governments and the coal industry.

In September 2000, the SWG held a technical workshop to develop, with the help of a panel of invited scientific experts, a work plan that identified the gaps in our understanding of selenium in the environment. The work plan also identified actions to be taken to address those information gaps. This work plan was used to help guide studies undertaken subsequently through to 2005.

In 2005, the SWG commissioned the Selenium Science Panel (SeSP), comprised of scientific experts in the field of selenium, to obtain an independent assessment on effects and approaches to the management of selenium in Alberta mountain coal mines. The following were the main objectives of the SeSP:

1. Review work completed in Alberta and relevant technical reports on surface water quality, the aquatic food web, and monitoring programs on fish and terrestrial wildlife;
2. Assess whether studies conducted to date fulfill recommendations made at the September 2000 selenium technical workshop;
3. Assess the level of any effects occurring and the corresponding level of management measures that may be warranted, considering the level of management effort in terms of changing effects levels;
4. Assess remaining information gaps and priority issues needing to be addressed.

To address the above 4 objectives, the SWG prepared 6 questions for the Science panel:

1. Considering the recommendations from the 2000 workshop in Hinton and the studies completed in response to these recommendations, is the current base of information adequate to determine if selenium effects are, or could be occurring to exposed fish and wildlife populations in West Central Alberta?
2. If effects are occurring, can the magnitude and extent of any such effects be quantified and can the corresponding level of management measures warranted be determined? Considerations should be given to changing level of effects that may occur over time.
3. What information gaps and priority issues need to be addressed to fulfill questions one and two?
4. Is there evidence that any adverse ecological impact(s) have occurred or will occur related to discharges of selenium associated with Alberta mountain coal mining?

5. What are the trends in selenium concentrations in the waters and biota of the watershed and associated terrestrial areas?
6. Are selenium management efforts required, and, if so, what measures would be most appropriate?

The members of the Selenium Science Panel were Dr. Jack F. Klaverkamp, Panel Chair, (Canadian Department of Fisheries and Oceans), Dr. William J. Adams (Rio Tinto Ltd.), Dr. Peter V. Hodson (Queen's University, Canada), Dr. Harry M. Ohlendorf (CH2M HILL Inc.) and Dr. Joseph P. Skorupa (U.S. Fish and Wildlife Service).

A workshop was held June 28 and 29, 2005 in Hinton, Alberta, with the SWG and SeSP. The Panel and SWG reviewed 16 formal presentations in addition to previous written submissions. Some additional information was provided to the Panel over the following several months. After a thorough review of the information presented to them, the Panel submitted their final report on September 30th, 2005 and the chair, Jack F. Klaverkamp, presented those findings at the April 2006 SWG meeting

The Science Panel noted considerable progress in studies proposed in a work plan developed soon after the 2000 Workshop. Presentations at the 2005 workshop demonstrated advances in knowledge in: surface water quality and aquatic food web components; selenium concentrations in aquatic dietary components for fish and birds; selenium concentrations in fish tissues; embryonic deformities associated with selenium accumulation in eggs and fry of rainbow trout; rainbow and brook trout population dynamics in mine-impacted and reference streams; selenium concentrations in American dipper eggs and blood of bighorn sheep; and treatment options for removing selenium from surface waters.

Building upon this foundation of knowledge and other information contained in the scientific literature, the Science Panel noted some knowledge gaps and priority issues. To address these gaps and issues, the Panel's recommendations are presented, along with supporting rationale, in the main body of the Panel Report.

The Alberta Selenium Working Group formally accepts the *Final Report: Scientific Review and Workshop on Selenium at Alberta mountain coal mines held in Hinton, Alberta, Canada, on June 28 and 29,* 2005 by the Selenium Science Panel, including their key findings and recommendations. We thank the members of the Panel for their thorough and timely work and appreciate their efforts to provide clear guidance.

Copies of the Selenium Science Panel Final Report can be downloaded at (http://environment.gov.ab.ca/info/library/7791.pdf).

Sincerely,

Ryan Puhlman
Alberta Environment
Interim Co-Chair, Alberta Selenium Working Group

FINAL REPORT:
Scientific review and workshop on selenium at Alberta mountain coal mines held in Hinton, Alberta, Canada on June 28 and 29, 2005 by the Selenium Science Panel

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September 30, 2005

SUMMARY:

On June 28 and 29, 2005 a scientific review and workshop on selenium (Se) at Alberta mountain coal mines was held in Hinton, Alberta, Canada. The main objectives of this workshop were to review work completed in Alberta (as reflected by relevant technical reports and presentations on surface water quality, the aquatic food web, and monitoring programs on fish and terrestrial wildlife) and to provide assessments of the following topics.

- Considering the recommendations from the 2000 Workshop in Hinton and the studies completed in response to those recommendations, is the current base of information adequate to determine if Se effects are, or could be occurring, to exposed fish and wildlife populations in West Central Alberta?
- If effects are occurring, can the magnitude and extent of any such effects be quantified, and can the corresponding level of management measures warranted be determined? Considerations should be given to changing level of effects that may occur over time.
- What remaining information gaps and priority issues need to be addressed to fulfill the above two questions?

The 2005 Workshop consisted of 16 formal presentations with extensive assessments and evaluations from a five-member Selenium Science Panel. The members of the panel were Drs. Jack Klaverkamp (chair), William Adams, Peter Hodson, Harry Ohlendorf, and Joseph Skorupa. This report presents responses by the Selenium Science Panel to six questions (presented in the main body of this report) provided by members of a Selenium Working Group comprised of representatives from industry and governmental agencies.

The Panel noted considerable success in achieving progress in studies proposed in a Workplan developed soon after the 2000 Workshop. Presentations at the 2005 Workshop demonstrated advances in knowledge in surface water quality and aquatic food web components; Se concentrations in aquatic dietary components for fish and birds; Se concentrations in fish tissues; embryonic deformities associated with Se accumulation in eggs and fry of rainbow trout; rainbow and brook trout population dynamics in mine-impacted and reference streams; Se concentrations in American dipper eggs and blood of bighorn sheep; and, treatment options for removing Se from surface waters.

Building upon this foundation of knowledge and other information contained in the scientific literature, the Science Panel noted some knowledge gaps and priority issues. To address these gaps and issues, the following recommendations are presented, along with supporting rationale, in the main body of this report.

- Although the most convincing piece of evidence that Se effects are occurring is the observation of embryonic deformities in rainbow trout at Se concentrations similar to those reported in the scientific literature, additional research and data are required to strengthen dose-response

relationships between Se concentrations in eggs and deformities in embryos and fry. Work should also continue to include brook trout and bull trout to understand differences in trout species sensitivities to Se toxicity.

- Because Se effects appear to be occurring in some stream invertebrates, there is a need to understand the apparent exceptionally high rates of bioaccumulation of Se from water in some reference streams; the sensitivity of resident invertebrates to Se and other chemical elements in the streams; and terrestrial-aquatic linkages and loadings from terrestrial systems.
- In all biological compartments, Se concentrations should be measured and expressed as dry weight along with the actual percent moisture data. When eggs, liver, muscle, and/or other tissues are analyzed in fish, the remaining carcass should also be analyzed in order to obtain whole-body Se concentration data.
- There is a need to understand the influence of metal interactions and water quality parameters on the availability, accumulation and effects of Se in aquatic biota.
- To address the relatively long-standing and controversial topic of whether Se is producing adverse effects on fish populations, a panel of experts in fish population dynamics and statistics should review presentations made by Sterling, Paul and Schmidt, and should provide their conclusions and make recommendations for additional research, if necessary.
- Additional monitoring of bird eggs for species frequenting the Alberta streams and the aquatic invertebrates in those streams should be performed.
- Small mammals and vegetation on reclaimed areas should be sampled and analyzed to evaluate exposure for those species or for their contribution to exposure of their predators.
- With regard to bighorn sheep, there is a need to better document changes to sheep hooves, unusual fragility of ram horns, and reproductive physiology, and to interpret any findings in relation to blood Se concentrations.
- A panel of experts in the areas of environmental chemistry, mining engineering, hydrogeology, geochemistry, and chemical or waste treatment engineering is needed to provide the best advice on how to determine loading estimates for Se from the various sources. These estimates are required for implementation of Se management approaches, and to provide guidance on best management practices to minimize Se leaching from rock dumps, open cuts, road development, and maintenance of roads and other infrastructure.

Addressing these knowledge gaps and priority issues, and continuing with on-going monitoring programs and plans are essential, but linkages back to management are not clear. The Panel, therefore, recommends that gaps and issues be considered and addressed within a framework of a comprehensive conceptual model. An excerpt from a 1998 USEPA document is provided in the **General Recommendations** section as an example of such a model for consideration by the Selenium Working Group. This section also provides another useful tool, the USEPA Data Quality Objective Process, which could be considered toward assessing what decisions must be made, what information is available toward making those decisions, what additional information is needed, and how that information will be used in making decisions as related to the Alberta coal mines.

I. Introduction:

A. Background/History:

In September 1998, data submitted to Alberta Environment (AENV) by Cardinal River Coals Ltd. (CRC) revealed selenium (Se) concentrations in Lac des Roches, an end pit lake at the Luscar Mine, which were greater than surface water quality guidelines for the protection of aquatic life; i.e. 1 µg/L by the Canadian Council of Environment Ministers (CCME), and 5 µg/L by the United States Environmental Protection Agency (USEPA) (Alberta Environment, 1999). The results indicated an order-of-magnitude increase in Se concentrations in Lac des Roches in 1997 and 1998, compared to 1991 to 1993. In October 1998, AENV initiated additional sampling at Lac des Roches and other streams and rivers close to the Luscar and Gregg River mines and another mountain mine, Smoky River Coals mine near Grande Cache. These results confirmed the industry data for Lac des Roches and showed exceedences of one order-of-magnitude of the CCME guideline for Se in water bodies close to the mines. More recent (2000 and 2001) industry data have shown Se concentrations in water bodies at the Luscar and Gregg River mines up to two orders-of-magnitude greater than water quality guidelines.

An Alberta Selenium Working Group (SWG) was established in October 1999 to produce an adaptive framework and approach for the evaluation and management of Se at the mountain mines. Membership of the SWG includes representatives from provincial and federal governments and from the coal industry. A technical workshop on Se was held in Hinton, Alberta in September 2000. A goal of the workshop was to propose and develop a Work Plan to address data and knowledge gaps. Based on the workshop and subsequent discussions between governmental agencies and industry, biological sampling, off-mine site water quality sampling, on-site water quality monitoring, and investigations of potential sources of Se were undertaken to address components of the Work Plan with review and direction from the SWG.

An overview of the Work Plan, originally developed in early 2001, and descriptions of studies undertaken to address specific projects or items in the Work Plan are available (Alberta Environment, 2005) in "*Selenium Studies in Alberta: Summaries and Status of Projects, 2005*" which was prepared for the SWG in May, 2005. To evaluate progress in achieving the needs and objectives of the Work Plan, a second Workshop was held in Hinton on June 28 and 29, 2005

B. 2005 Workshop

The workshop was chaired by Dr. Jack Klaverkamp, and consisted of 16 formal presentations (see Appendix 1, FINAL AGENDA) with extensive participation on the part of Selenium Science Panel (SeSP) members and the Chair. A short biographical text for members of the SeSP is presented in Appendix 2. Invited presentations from SWG members, and researchers conducting surface water quality, aquatic food web, and studies on fish and terrestrial wildlife in Alberta were given to provide the Chair, panel members, and attending delegates with an overview of the relevant technical reports for each session. Copies of presentations are available in read-only, PDF format at the following Website address: https://extranet.gov.ab.ca/env/seleniumworkshop/ Attending delegates included invited representatives from various provincial and federal government agencies, and the Alberta and British Columbia coal industries, and their respective consultants. A list of attendees and their affiliations is presented in Appendix 3. Input, especially in writing, from attending delegates during the workshop was encouraged.

The overall objective of the 2005 review and workshop was to obtain an assessment from the panel of Se experts on the occurrence of effects and approaches to the management of Se in Alberta. The following were the main objectives:

1) Review work completed in Alberta and relevant technical reports on surface water quality, the aquatic food web, and monitoring programs on fish and terrestrial wildlife.

2) Assess if the studies conducted to date fulfilled the recommendations from the 2000 workshop in Hinton. The SWG provided briefings on the current and historical operation of the mines, and recommendations originating from the 2000 workshop.

3) Assess the level of effects occurring and the corresponding level of management measures that may be warranted, considering the level of management effort in terms of changing effects levels.

4) Assess remaining information gaps and priority issues needing to be addressed.

This Final Report addresses these objectives by SeSP members responding to the following six questions which were provided by the SWG:

1. Considering the recommendations from the 2000 Workshop in Hinton and the studies completed in response to these recommendations, is the current base of information adequate to determine if Se effects are, or could be, occurring to exposed fish and wildlife populations in West Central Alberta?
2. If effects are occurring, can the magnitude and extent of any such effects be quantified and can the corresponding level of management measures warranted be determined? Considerations should be given to changing level of effects that may occur over time.
3. What information gaps and priority issues need to be addressed to fulfill questions 1 and 2?
4. Is there evidence that any adverse ecological impact(s) have occurred or will occur related to discharges of Se associated with Alberta mountain coal mining?

5. What are the trends in Se concentrations in the waters and biota of the watershed and associated terrestrial areas?
6. Are Se management efforts required, and, if so, what measures would be most appropriate?

II. Responses to the six questions:

Question 1: Considering the recommendations from the 2000 Workshop in Hinton and the studies completed in response to these recommendations, is the current base of information adequate to determine if Se effects are, or could be, occurring to exposed fish and wildlife populations in West Central Alberta?

The most convincing evidence that Se effects **are occurring** in exposed fish and wildlife consists of **1)** laboratory studies of developmental toxicity in rainbow trout fry whose parents were collected from contaminated and uncontaminated streams and spawned manually; and **2)** studies indicating impacts on some stream invertebrates. In the laboratory studies, craniofacial deformities were observed in rainbow trout fry at threshold Se concentrations in eggs of 8 to 10 µg/g (wet wt.). At egg Se concentrations of approximately 12 µg/g (wet wt.), skeletal deformities were observed in 30% of fry, craniofacial deformities in 40%, and edema in 70%. While these data are critical to demonstrating effects and to establishing a threshold for effects, improvements in the dose-response curves for relationships between Se concentrations in eggs and effects could be made. For example, more data points on developing embryos from females with the high Se concentrations in their eggs, and the use of a larger number of females from which eggs are collected would improve confidence in establishing thresholds for effects in trout.

Elevated Se concentrations in some invertebrate biota from Luscar Creek corresponded with significant changes in the structure of the macroinvertebrate community with notable losses of many Ephemeroptera, and an increase in abundance of the Tricladida, *Polycelis.* It is important to note, however, that the Ephemeroptera species have not been tested for Se sensitivity in the laboratory. Those tests are required to establish confidence in directly linking the observed losses to Se. There were no notable trends in biomagnification (i.e., successively higher concentrations at higher trophic levels) of Se in the invertebrate food webs from the Alberta streams.

Some evidence was presented by George Sterling at the Workshop that Se was adversely affecting trout at the population level in Luscar Creek. This evidence included: **1)** lower juvenile-to-adult ratios for rainbow trout in recent samples from exposed streams compared to historical values from reference streams; **2)** lower overall density in exposed compared to reference streams; **3)** community shift towards the less-Se-sensitive brook trout in exposed streams; and **4)** density-independent mortality rate increases in exposed streams. A paper authored by Dr. Andrew J. Paul, Dept. of Biological Sciences, University of Calgary, was also provided, but not presented at the Workshop, that gave a review "of the document 'Evaluation of the fish population trends of the Upper McLeod River drainage and their utility for analysis of impacts of elevated Se on the aquatic environment' which appears as Appendix II in the preliminary draft report 'Weight of evidence (WOE) assessment of effects of selenium…" prepared by Golder Associates. Dr. Paul's 4-page paper with 7 literature references provided critical comments directed to the 3 components (effect of Se toxicity on population dynamics; study designs to test for effects of Se toxicity; and, assessment of Se toxicity in western Alberta streams) of the fish populations section of Appendix II of the Golder report. In several instances, Dr. Paul specifically addresses Appendix II and attempts to demonstrate fundamental errors, false and incorrect statements, contradictions, and a need to establish a credible suite of alternate hypotheses with testing to determine whether data supports certain hypotheses over others.

Approximately five weeks after the Workshop, Dr. Dana Schmidt provided a 7-page reply with 10 references to Dr. Paul's review of fish population trends. In this reply, Dr. Schmidt agrees with or supports some comments or recommendations made by Dr. Paul. Dr. Schmidt, however, also soundly disagrees with several issues in Dr. Paul's analyses of Appendix II. For example, Dr. Schmidt finds Dr. Paul's conclusion that increased abundance of adults and eggs can never result in a recruited population that reaches habitat carrying capacity to be "illogical". Further, Dr. Schmidt states that Dr. Paul suggests contentions made by Dr. Schmidt were, in fact, not made; and that Dr. Schmidt "strongly disagrees" with Dr. Paul's interpretation of Dr. Schmidt's comments. Another major area of disagreement concerns the adequacy or sufficiency of the existing data base. Dr. Paul appears to believe that the existing data are sufficient for making conclusions; whereas Dr. Schmidt does not. Finally, Dr. Schmidt also provided an 8-page critique of George Sterling's presentation at the Se Workshop.

It is apparent from the above that the three scientists (Sterling, Paul and Schmidt), who are experts in fish population dynamics as they pertain to potential effects of Se, are not in agreement. It is noteworthy that scientists who served on the expert science panel at the workshop held in 2000 also found the issue to be unresolved and recommended that efforts be made to clarify the uncertainties. The following statements were made by three scientists from that panel, and can be found in Section 2.1.20 in *Selenium Workshop Summary: Development of Monitoring Program* September, 2000:

1. "There is a need to resolve the differences of opinion on fisheries recruitment work."
2. Scientists working on the issue of fish populations "need to review the historic fish population data and agree what it means".
3. Do we know "if effects are observed on fish populations?"

Lines of evidence that give concern that Se effects **could be** occurring in exposed fish and wildlife are:

1. Concentrations of Se in waters from impacted areas exceed the Alberta Se Water Quality Guideline by one to two orders of magnitude. For example, concentrations in streams range from 0.7 to 227 ug/L (Grande Cache report #1); from 1.6 to 635 µg/L in seeps from overburden dumps; from 12.3 to 134 µg/L in settling pond effluents; from 2.6 to 130 µg/L in end pit lakes; and between <0.4

and 123 µg/L in downstream watercourses are being observed (Alberta Environment, 2005).

2. Se concentrations in eggs, liver and muscle of rainbow trout and brook trout from affected streams, especially from waters draining the Luscar and Gregg River mines, are well above threshold concentrations under consideration by the U.S. Environmental Protection Agency (USEPA) for freshwater fish (but see caveats below). Fish from reference sites, however, generally exhibited tissue concentrations below those thresholds.

3. Se concentrations in American dipper eggs average 6.3 µg/g (dry wt.), with a maximum of 9.0 µg/g, both of which are within the range (6 to 13 µg/g) of threshold concentrations for reduced hatchability in sensitive bird species (Ohlendorf, 2003).

4. The above Se concentrations in fish tissues and dipper eggs are frequently associated with elevated Se concentrations in a major component of their food, namely aquatic invertebrates. For example, Se concentrations in aquatic invertebrates often exceed 5 µg/g (dry wt.), a concentration in the diet of birds that is also associated with reduced egg hatchability in sensitive bird species.

5. Ungulate populations are clearly exposed above background as evidenced by elevated Se concentrations in blood of bighorn sheep from the mine sites compared to other areas.

There are several **caveats** which must be considered with regard to the above points.

1. In Canada and the United States, there is strong agreement among scientists and managers that the measurement of Se concentrations in tissues or whole bodies of fish and birds (including their eggs) is more relevant for regulating Se releases than the use of Water Quality Guidelines (Chapman and McPherson, 2004; Hamilton, 2003, 2004). Because Se in water is an important route of entry into dietary components of invertebrates, fish and birds, Se monitoring of water should be continued. Conclusions that Se is producing adverse effects in biota, however, can not be determined from only the concentrations measured in water from Alberta streams. Approaches and decisions for regulating Se releases to affected Alberta waterways need to be developed and implemented by appropriate governmental agencies.

2. It may not be appropriate to use USEPA-derived Se concentrations for thresholds in trout resident to Alberta streams, because a substantial amount of the research in the United States was conducted on warm-water fish species from lentic habitats. For example, the USEPA's proposal of using a whole-body concentration of 7.91 µgSe/g (dry wt.) (or about 5.85 µgSe/g when considering lipid loss during winter conditions) for regulating Se is based on a study using bluegills. Hamilton (2003, 2004) provides evidence that there is little proof for differentiating Se thresholds between warm water and cold water fish. In a recent and thorough review, Simmons and Wallschlager (2005) state that "fundamental considerations suggest that Se ecotoxicity in lotic systems should be reduced compared to lentic systems, but we conclude that this statement is

not substantiated by the existing data". Adams et al. (2000), however, have reported significantly less accumulation of Se in fish from lotic systems in the western U.S. as compared with lentic systems.

3. Se concentrations in invertebrates from Alberta streams associated with American dipper usage and feeding are elevated at both reference and mine-impacted sites with concentrations often exceeding 5 μg/g (dry wt.). As described above, this concentration in the diet of birds is associated with reduced egg hatchability. Elevated Se concentrations in dipper eggs (up to 6.4 μg/g in an individual egg from a reference stream) may be due partly to movement by the birds and exposure outside the reference stream. However, the reasons for elevated concentrations in invertebrates (greater than expected on the basis of waterborne concentrations) are unclear. Nevertheless, differences between reference-affected and mine-affected streams generally were not large, no effects on dippers were observed, and Se concentrations higher than those in Alberta were found in similar studies in British Columbia (mean = 7.4 μg/g), also without adverse effects.

4. The toxicological and ecological significance of the high Se concentrations in blood from ungulates is unknown. There is little evidence of either direct toxicological or population effects, although casual observations of changes to sheep hooves and unusual fragility of ram horns were briefly described. No data were presented relative to these observations.

The SeSP notes the following issues as they pertain to the adequacy of data in relation to responding to Question 1:

1. Adequacy of data is a very important issue in the relatively long-standing and controversial topic of whether Se is producing adverse effects on fish populations. To be effective in resolving this scientific issue, it would be constructive if a panel of scientific experts who are specialists in fish population dynamics and statistics were to review presentations made by Sterling, Paul and Schmidt. The panel of experts could then provide their conclusions and make recommendations for additional research, if necessary. Attention should be directed to determining the extent and importance of fish migrations between impacted and reference streams. Despite the high ecological relevance of determining effects on populations and communities, however, it is critical to acknowledge that population declines are frequently irreversible and can result in extinction. Therefore, actions to implement measures to manage Se releases should not be further delayed until definitive information is available for effects on fish populations. Emphasis is lent to this recommendation by the findings of Dr. Palace indicating Se levels in rainbow trout eggs at some sites are high enough to result in teratogenic effects.

2. Food-web conceptual diagrams (models) have not been developed and integrated for all the habitats, including lakes, rivers, wetlands, and the terrestrial components. An excellent food-web conceptual diagram was prepared by Podemski, also found in other reports for some components of the system. Casey also presented a conceptual food-web that was site-specific for streams near the mine. However, these models have seemingly been prepared

independently for specific studies, and they have not been "harmonized" to develop a generally applicable model for each of the habitats (See also **General Recommendations** section below about integration of food-web models with an overall model for the physical and ecological components of the system.)

3. Limited work has been done (or presented) as related to sources of Se to the environment (e.g., leaching tests and seeps), indicating that prediction of release rates and future Se concentrations are unknown and incomplete in both aquatic and terrestrial ecosystems. (See also **General Recommendations** section below about integration of food-web models with an overall model for the physical and ecological components of the system) It is noted that few data exist on the form of Se in the surface waters where monitoring has been performed. With concentrations exceeding 10 ug/L, the techniques now exist to determine whether the dominant form of Se is selenate or selenite at low levels and whether there are detectable quantities of organic forms of Se.

4. Small mammals have not been sampled on reclaimed areas of the mines, so it is not possible to evaluate exposure for those species (or their contribution to exposure of their predators). Similarly, vegetation sampling is not adequate. Beth MacCallum has sampled vegetation at some sites (information not presented at the workshop or in available reports), but further information is needed to assess Se concentrations in the diet of ungulates feeding on reclaimed lands or nearby areas. Information about Se concentrations in various kinds of plants may be useful for determining the kinds of vegetation to be established during reclamation as well as understanding exposure pathways for mammals. It would also be useful in order to assess potential for transfer via the food chain to upland birds.

5. Although a few comments were made on the apparent lack of effort toward evaluating Se accumulation and effects in other aquatic species (e.g. amphibians, forage fish, and semi-aquatic species), no specific plans were presented to address these gaps. These organisms should be considered in developing the conceptual food-web models described above, and be sampled in future monitoring programs.

Question 2: If effects are occurring, can the magnitude and extent of any such effects be quantified and can the corresponding level of management measures warranted be determined? Consideration should be given to changing level of effects that may occur over time.

Aquatic Effects:

1. Exposure can certainly be quantified. Concentrations of Se are summarized in response to Question 1.

2. Effects on developing rainbow trout embryos have been quantified in the laboratory. That study has strong correspondence to published data (see reviews by Hamilton and by Chapman and McPherson), and, therefore provides confidence in tissue residue approach. Data from laboratory studies by Dr. Palace with rainbow trout appear to allow for the calculation of a Se threshold in eggs for effects on this species. Similar data suggest brook trout are less sensitive. Data for bull trout egg and fry survival are lacking. Direct application of the Palace rainbow trout data to the field to quantify field-related effects would be difficult at this point due to the small number of female fish and eggs collected and hatched to date. However, the approach used by Dr. Palace could be used to set a threshold for effects and to establish a dose-response curve for interpreting field-collected egg residue data. His proposals to investigate emergence of fry from stream-beds and to study the molecular mechanisms of Se-induced embryonic deformities could provide information helpful to determine the ecological significance of those deformities and to understand differences in sensitivities of fish species.

3. Effects on some limited number of benthic invertebrate species appear to be occurring in the field, although there is significant uncertainty related to cause and effect. The available invertebrate data indicate that additional detailed studies are needed including Se toxicity studies with sensitive species.

Terrestrial Effects:

1. There are insufficient data to quantify effects in ungulates (bighorn sheep). The available blood Se data do provide a good monitoring tool for assessing changes over time and could be used to evaluate potential for effects. Several possibilities exist for interpreting these data: first, a comparison with blood Se concentrations that have been developed in laboratory studies for other animals including cattle and sheep; second, a comparison with existing blood Se concentrations for cattle and sheep that were monitored as related to phosphate mines in Idaho; and third, a laboratory study with bighorn sheep could be performed to establish a dietary threshold and Se blood threshold for effects.

2. There are insufficient data to evaluate magnitude or extent of effects on birds. Limited data suggest a low or moderate level of concern, but the number of eggs collected to date is small. It is important to note that invertebrate concentrations in some, but not all, streams exceed 5 µg/g (dry wt.), a dietary concentration that has been found to be associated with reduced hatchability in sensitive bird species. Establishing the trophic transfer at the mine-impacted

streams is necessary to evaluate the significance of the invertebrate concentrations.

Linkages:

1. Linkages between the terrestrial environment and the aquatic system (e.g., inputs from vegetation to streams) and the ecological significance (magnitude) of Se-related effects observed in the aquatic system as well as exposure of bighorn sheep should be better understood before management actions can be determined.

2. Better understanding of physical-chemical processes (release mechanisms and rates, loading estimates, etc.) is needed before the most useful management measures for existing sources can be determined. However, interim measures for best management practices can be implemented to control Se releases as new areas are being developed (e.g., Cheviot, Grande Cache) and can be built into development of the sites, as discussed during the Workshop.

3. Monitoring plans that have been developed are a good start, but linkages of investigative studies back to management are not clear (e.g., Cheviot). (See also **General Recommendations** section below about integration of food-web models with an overall model for the physical and ecological components of the system.)

Question 3: What remaining information gaps and priority issues need to be addressed to fulfill question 1 and 2?

Specific information gaps and priority issues include the following:

1. Loading estimates for Se from the various sources need to be established to determine priority of sources for implementation of Se management approaches. A panel of experts in areas of environmental chemistry, mining engineering, hydrogeology, geochemistry, and chemical or waste treatment engineering would provide the best advice on how to determine those loading estimates. Some specific areas that need to be addressed include characterizing relationships among the chemistry of rock and leaching of Se, chemistry of groundwater, physical structure and size of particles, and water movement through the various dumps. Understanding the hydrogeology of the area is needed to determine ideal frequencies of sampling, considering the variability of flows.

2. There is a need to understand the influence of metal interactions and water quality parameters on the availability, accumulation and effects of Se in aquatic biota. For example, the presence of other metals, such as arsenic and copper (Hamilton, 2004) can antagonize the toxicity of Se in fish and other animals. Further, sulphate and total dissolved solids affect the availability and accumulation of Se (Brix et al., 2001; Simmons and Wallschlager, 2005). Understanding the influence of factors such as these may provide insight on variations observed between reference and impacted streams. Further, it is recommended that an effort be made to understand the form in which Se exists in the surface waters for both the mine-impacted sites and the reference streams.

3. For making more comparisons to the scientific literature and, thereby validating the setting of tissue and whole body thresholds, there are needs to have whole-body Se data in addition to egg, muscle and liver data for fish. Given the high costs of collecting fish, the scarcities of fish in some streams, and the relatively low cost of Se analyses, Se concentrations and % moisture should be measured in those individual tissues and the remaining carcasses for all fish collected. As a matter of consistency and accuracy in reporting Se results, they should be expressed as dry weight (along with the moisture content to facilitate conversions). This rationale and need to express data as dry weight also applies to plants, mammals, birds and all other biological samples.

4. Other gaps and priority issues for individual fish include: **a)** strengthening dose-response relationships between Se concentrations in eggs and deformities in embryos and fry by obtaining additional data on rainbow trout, brook trout and bull trout; **b)** strengthening dose-response relationships between Se in fish muscle (evaluate use of muscle plugs) and eggs by obtaining additional data; **c)** understanding whether temperature stress is an issue for local species, and, if so, whether that stress contributes to Se effects; and **d)** establishing trophic transfer ratios between invertebrates and fish muscle. Addressing these gaps and issues will provide clarification/agreement on effects thresholds/benchmarks, and will result in the development of consistent monitoring tools for evaluating effects on fish. Agreement should be reached by

the SWG on dose-response curves regarding whether an EC5, 10, 20 or other value would be used as the threshold.

5. Comments and recommendations on fish populations were provided above in responses to Question 1. In addition to addressing absence or presence of effects on fish populations, studies on tagging of fish are needed to understand the extent of mixing among exposed and reference sites.

6. With regard to invertebrates, there are needs to understand **a)** the exceptionally high rates of bioaccumulation of Se in some reference streams; **b)** their sensitivity to other chemical elements in the streams; and **c)** terrestrial-aquatic linkages and loadings from terrestrial ecosystems. As in the case of studies on fish, additional confirmatory studies on effects on invertebrates are needed to develop dose-response relationships and strengthen confidence in those relationships.

7. Additional monitoring of bird egg Se for species frequenting the Alberta streams as well as Se concentrations in the aquatic invertebrates in those streams should be performed.

8. With regard to bighorn sheep, there is a need to relate blood Se concentrations to other responses, such as changes to sheep hooves, unusual fragility of ram horns, and reproductive physiology. To do so requires a systematic and concerted effort to collect sufficient data on the prevalence of these conditions, and to move beyond casual observations. There is a need to address and evaluate other risk factors, such as interactions with other environmental stressors. There are also needs to **a)** characterize Se concentrations in vegetation at reference and exposed sites; **b)** describe plant species present to determine presence and absence of hyper-accumulators; **c)** review case studies of poisonings to develop an array of biomarkers for monitoring potential effects; and, **d)** develop mass balances for transfers among soils, vegetation, herbivores, carnivores, air, and water depending on the level of risk that might exist for all species of concern that might, in the future, be found to be exposed to excessive Se concentrations.

Other gaps and issues are described in reponses to Questions 1 and 2.

Rationale for gaps and priority issues is also presented in responses to Questions 1 and 2. Additional information is also provided in those responses on ecosystem components, such as birds, small mammals and vegetation, and is not repeated in the above responses to Question 3. These specific information gaps and priority issues (i.e., considerations of the various pieces of the ecosystem) should be considered and addressed within a framework of a comprehensive conceptual model. Additional information and an example of such a model are presented in the **General Recommendations** section at the end of this report.

Question 4: Is there evidence that any adverse ecological impacts have or will occur related to discharges of Se associated with Alberta mountain coal mining?

Yes. The strongest evidence is the dose-response relationship on rainbow trout eggs and fry developed by Dr. Palace.

Question 5: What are the trends in Se concentrations in the waters and biota of the watershed and associated terrestrial areas?

The SeSP concludes that this question can not be answered at this time. The time periods and the data are not sufficient to establish trends, given the stochastic nature of the stream flows, mining activity, restoration activities, and other physico-chemical environmental factors. The data are also incomplete. For example, data for the terrestrial system are missing so an assessment of soil concentrations over time can not be made, and vegetative monitoring is deficient. The USEPA documents and conceptual models cited in the **General Recommendations** section provide additional guidance for the SWG in addressing data gaps and priorities.

Most available data deal with Se concentrations in water, and to a lesser extent in biota. For example, Se concentrations in waters from reference sites ranged from <0.5 to 2.2 μg/L with most being less than the Water Quality Guideline (WQG) of 1 μg/L. Surface water data for the McLeod River demonstrated that Se concentrations increased slightly in the late 1990s at the river mouth, about 300 km downstream of mines. Data for the headwater creeks intersecting the mines (e.g. Luscar, Falls, Berry's) and Lac des Roches showed that Se concentrations were usually an order of magnitude greater than the WQGs after 1998. Similar concentrations, (i.e. an order of magnitude above the WQG), were observed in Beaverdam Creek, (a stream downstream of the open-pit mine at Grande Cache Coal). Some degree of seasonality was observed with lowest concentrations reported in the spring, compared to summer and fall. A report from AENV on samples from old, closed mines demonstrated no signs of elevated Se concentrations. A report from Grande Cache Coal Corporation established that waterborne Se concentrations at a 20-year old reclaimed mine site were at 2 to 8 μg/L. While these concentrations exceed the WQG, they may provide evidence that waterborne concentrations decrease over time.

Substantial bioaccumulation of Se from surface waters to lower trophic levels in streams was documented. Patterns similar to those for surface waters were observed in that highest Se concentrations in epilithon (stream substrate biofilm) and aquatic insects were observed at exposed sites. As indicated previously, Se concentrations in aquatic insects from exposed sites generally exceeded dietary thresholds for birds and fish (Hamilton, 2003 and 2004; Ohlendorf, 2003). Se biomagnification within the invertebrate food web was not observed to a significant degree, which is consistent with information for other freshwater sites.

Relatively small numbers of samples from fish and birds, often only 2 or 3 per site, were collected and analyzed. Overall, Se concentrations in liver, ovaries and muscle from rainbow trout and brook trout collected from exposed streams, especially waters draining the Luscar and Gregg River mines, were generally elevated above those contained in reference streams and in 2000 and 2001 were greater than toxicity effects thresholds proposed by Lemly (1996). However, as noted earlier, species-specific effects thresholds should be developed to allow for site specific assessment of risk. Tissues from trout residing in reference streams were usually below these thresholds. Smaller sample sizes, a limited number of sampling locations, and influences of spawning migrations prevented similar comparisons for bull trout, mountain whitefish, Arctic grayling and longnose sucker.

Question 6: Are Se management efforts required and, if so, what measures would be most appropriate?

Se management efforts are required. Although there may be considerable debate over specific threshold numbers for specific bird and fish species, the consensus of the SeSP was that the eco-system is beginning to show Se-induced stresses. Much of the data presented demonstrated variability of responses and uncertainty characteristic of an ecosystem at the threshold of effects. Examples concerning fish are described in the previous questions and include: **a)** significant uncertainties regarding community and population analyses with trout species; **b)** interspecies differences in toxicity (which suggest interspecies differences in risk, but management should protect rainbow trout, which is apparently most sensitive species); and, **c)** uncertainty about exposure (e.g. elevated Se concentrations at exposed reference sites; latest fish data from Dr. Peter Chapman presented to Elk Valley Coal, June 23, 2005) and responses which are likely due to fish migrations and the occurrence of co-stressors in highly variable headwater streams. In light of uncertainties, such as these, and the indications of effects, every effort should be made to reduce exposure.

Examples of potentially effective controls were presented by industry during the Workshop. These included source control, limitation of infiltration, access of oxygen, and introduction of reducing equivalents. Challenges, such as issues dealing with terrain, safety, and location of natural springs relative to coal deposits and waste dumps were also presented.

Progress has been made in identifying direction of flows and monitoring points for groundwater and watersheds. The key approach to the management of dumps is one of 'adaptive management' with annual meetings. The course of this management is to be determined by results, new data, and advances described in the literature. Additional evaluation of existing data is needed to determine the potential benefit from waste rock segregation. As indicated in responses to Question 5, however, 'trend' monitoring over 4 years is inadequate. For monitoring of water much longer time periods, (e.g. 10 to 20 years) is required to develop real trends that can be distinguished from interannual 'noise', and to enable identification of factors causing interannual variation (e.g. relationships between Se discharge rates and annual rainfall). The SeSP recommends that sampling frequency be tied to observed variations to create statistical power for improved discrimination of temporal and spatial trends.

Additional specific requirements recommended by the SeSP include:

a. A mass flow accounting is needed by stream and seep to provide an evaluation of the significance of the releases and loadings to the watershed streams. This will also identify where management efforts should be placed.

b. Evaluation of the use of passive treatment is needed to determine the utility of this approach for cost-effectively immobilizing Se in waste rock dumps or at the base of the waste rock dumps.

c. The role of sediment transfer should be evaluated. There is clearly a large transfer of particulates to surface waters, either standing or flowing, near rock dumps and mine operations. If these particulates are derived from rock containing Se, could they be a source of soluble Se in depositional zones?

General Recommendations

Integration and synthesis of existing information would help to determine what is known and what is not known. This applies to identification of sources of Se, release and transport processes, exposure pathways for ecological receptors in all pertinent habitats, and potential adverse effects (endpoints) for evaluation. The summary report provided by Alberta Environment (Selenium Studies in Alberta: Summaries and Status of Projects, 2005) and the weight-of-evidence assessment by Chapman (as well as results of the specific studies), provide a large amount of information, but they focus mostly on evaluating various pieces of the systems (such as sediment and invertebrates, water and fish, or invertebrates and fish or birds) without considering the inter-relationships of the information. Because there has not been an overall integration of the information as might be achieved through the development of a comprehensive conceptual model showing inter-relationships of the various media and receptors as well as primary sources, release mechanisms, secondary sources and exposure pathways, overall understanding/context of the various components is limited. It is recommended that such a model be developed. Guidance by USEPA (1998) may be helpful to the Alberta Selenium Working Group in that effort. An excerpt from the USEPA document is provided (Appendix 4) with this report. The comprehensive and integrated approach described above could be useful to identify at this stage where the highest concerns exist, both in terms of ecosystem components and specific streams or sites. This would allow for focused studies and identification of areas of concern and non-concern.

The USEPA Data Quality Objective (DQO) process (USEPA 2000) provides another useful tool toward assessing what decisions must be made, what information is available toward making those decisions, what additional information is needed, and how that information will be used in making decisions as related to the Alberta coal mines. Using the DQO process along with developing an overall conceptual model (Appendix 4 gives example) would help show how the physical/chemical and ecological components of the environment are related, as well as providing context to the work that is being done. It is recommended that the Alberta Selenium Working Group consider using the DQO process along with development of an overall conceptual model to help focus their activities. An excerpt from the DQO guidance document is included with this report (Appendix 5) to highlight the steps of the DQO process.

Using the DQO process along with developing an overall conceptual model would contribute to understanding of area-wide risks, such as was done for the phosphate-mine area in Idaho. Then, more specific assessments could be tiered under that overall umbrella to focus on issues that are specific to an individual mine. This may seem overly complicated, but it is our experience that it helps “get everyone on the same page” and provides focus for what is being done, as well as knowing when enough information has been developed.

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Appendix 1
FINAL AGENDA
of
SELENIUM SCIENCE WORKSHOP
Hinton, Alberta

June 28, 2005: (07:30 – 18:00)

07:30 – 08:00 **Registration**

08:00 – 08:30 **Introductions and Purpose of the Workshop**

a. Presentation of the Five Workshop Objectives and summary of Recommendations from 2000 Workshop; Andy Lamb, Chair, Selenium Working Group;
b. Introduction of Selenium Science Panel (SeSP) members, Dr. Jack Klaverkamp, Chair, Selenium Science Panel.

08:30 – 9:30 **SESSION 1- Selenium Sources and Monitoring**

- **a.** « Development of a Selenium Monitoring Program for the #12 and #9 Mines, Grande Cache Coal Mine ». Daniel Andrews, Western Resource Solutions.
- **b.** "Cheviot and Cardinal River Coal Mines – Selenium Sourcing and Monitoring Report, 2004", Curtis Brinker, Silkstone Environmental.

9:30 – 10:00 **Discussion** (Panel first, then questions from the Selenium Working Group and the floor)

10:00 – 10:30 **Coffee**

10:30 – 11:30 **SESSION 2 - Water Quality and Aquatic Food Webs**

- **a.** **"**Results of Alberta Environment Aquatic Selenium Studies in the McLeod and upper Smoky Rivers", Richard Casey, Alberta Environment
- **b.** "Selenium in Aquatic Insects from upper McLeod River by Environment Canada", Richard Casey, Alberta Environment.
- **c.** **"**Selenium in Northern Stream Food-Webs", Dr. Cheryl Podemski, Fisheries and Oceans Canada.

11:30 – 12:00 **Discussion**

12:00 – 13:00 **Lunch**

13:00– 14:30 **SESSION 3 - Fisheries**

- **a.** **"**Selenium Concentrations in the Tissues of Fish from the Upper Mcleod and Upper Smoky River Systems", Dr. Bill MacKay, W. C. MacKay and Associates
- **b.** "Developmental effects of bioaccumulated selenium in eggs and larvae of trout species", Dr. Vince Palace, Fisheries and Oceans Canada.
- **c.** "Fish community changes in the Luscar Creek watershed downstream from an open pit coal mine", George Sterling, Alberta Sustainable Resource Development

14:30 – 15:00 **Discussion**

15:00 – 15:30 **Coffee**

15:30 – 16:30 **SESSION 4 - Studies on birds and mammals**

- **a.** "Selenium Scoping in Ungulates, Mammalian Predators, and American Dipper in Alberta", Jeff Kneteman, Alberta Sustainable Resource Development.
- **b.** Cheviot Creek Pit – Selenium Monitoring and Management Plan – Local Terrestrial Monitoring Programs". Beth McCallum, Bighorn Environmental.

16:30 – 17:00 **Discussion**

18:00 **Dinner**

June 29, 2005: (08:00 – 17:00)

08:00 – 10:00 **SESSION 5 - Approaches to Se management – Toxicological Approaches and Regulatory Applications.**

a. Overview presentation on history of Se criteria development in the United States, Dr. Joe Skorupa, US Fish and Wildlife Service
b. Alberta Environmental Approvals Process, Ryan Puhlmann, Alberta Environment
c. "Weight of Evidence (WOE) Assessment for Effects of Selenium Released From Coal Mines in Alberta to Resident Fish and Waterfowl" Dr. Peter Chapman, Golder Associates.

10:00 – 10:30 **Coffee**

10:30 – 12:00 **SESSION 6 – Approaches to Se Management – Remediation approaches and available technologies**

- **a.** "Treatment Options for Water-Borne Selenium at Coal Mines in West-Central Alberta", Andre Sobolewski, Microbial Technologies Inc.
- **b.** "Selenium Management - The Idaho Experience", Bruce Winegar, J. R. Simplot Company.

c. Summary of Se management proposals to meet AENV Approval conditions, Bernd Martens, Grande Cache Coal Corporation, and Curtis Brinker, Elk Valley Coal

12:00 – 12:30 **Discussion**

12:30 – 13:30 **Lunch**

13:30 – 15:00 Meeting of SeSP members only to prepare preliminary presentations for SESSION 7

15:00 – 15:30 **Coffee**

15:30 – 17:00 **SESSION 7: Preliminary Presentations from Panel and wrap-up**

SeSP members present their individual preliminary responses to the six questions presented in the Final Report document.

Appendix 2
Brief Biographical Sketches of SeSP Members

William J. Adams, Ph.D.
Dr. Adams is currently Principal Environmental Scientist for Rio Tinto. His responsibilities include managing product stewardship programs, environmental research, ecological risk assessments and interface with regulators on science-based issues. Recent interests include developing ecotoxicology risk assessment methods for metals, site-specific methodologies for water quality criteria for metals, and development of an alternative strategy for metals to replace the existing Practical Best Technology (PBT) approach for metals. Dr. Adams was a member of the US EPA Science Advisory Board (SAB) for 10 years and recently served on the OPA Superfund National Advisory Committee for Environmental Policy and Technology. Additionally, Bill chairs several technical workgroups for the metals industry. Dr. Adams received his Ph.D.degree from Michigan State University in 1976. He conducted his PhD dissertation research on the toxicity and residue dynamics of selenium on fish and aquatic invertebrates. Since then Dr. Adams has published 16 papers on selenium related to effects and exposure for birds and fish including work in the Great Lakes and Utah. Recent publications have dealt with approaches for setting site specific water quality standards for selenium.

Peter V. Hodson, Ph.D.
Dr. Hodson is a Professor in the Department of Biology of Queen's University, Kingston, Ontario, and the Director of Queen's School of Environmental Studies. Dr. Hodson received a B.Sc. (Physiology) from McGill University (1968), and M.Sc. (Biology) from the University of New Brunswick (1970), and a Ph.D. (Zoology – fish toxicology) from the University of Guelph (1974). He joined the Public Service of Canada in January, 1974 and spent 18 years a s a scientist with the Department of Fisheries and Oceans. He joined Environment Canada in 1992, where he was Project Chief of Ecosystem Health Assessment at the National Water Research Institute, Burlington, Ontario, until he joined Queen's University in September, 1995. Dr. Hodson is currently a member of the World Council of the Society of Environmental Toxicology and Chemistry (SETAC). He is also a Past President of SETAC North America and served twice on its Board of Directors and on the Board of the North East North American Chapter. He was the Program Chair of SETAC 89, SETAC's 10th Annual Meeting in Toronto, 1989, a member of the Steering Committee of Canada's Aquatic Toxicity Workshop, and is currently a member of the International Association for Great Lakes Research. Dr. Hodson is a past Editor of the journal *Environmental Toxicology and Chemistry* and a member of the Editorial Board of *Fish Physiology and Biochemistry* and the *Canadian Journal of Fisheries and Aquatic Sciences.* He has contributed to many technical panels, committees, and workshops, including the Science Panel for the Se Workshop held in 2000 at Hinton when he presented a paper entitled *"Se toxicity to freshwater fish."* Dr. Hodson's most recent publication on selenium was entitled, *"Indicators of ecosystem health at the species level and the example of selenium effects of fish."*

Jack F. Klaverkamp, Ph.D.
Dr. Jack Klaverkamp received his Ph.D. in Pharmacology from the medical school at the University of Washington in 1971. He then received a post-doctoral fellowship in the Washington State Toxicology Department; and in 1973 accepted a position as a research scientist at the Freshwater Institute (FWI) on the University of Manitoba campus. For 30 years, Dr. Klaverkamp held positions as research scientist and research manager at the FWI. For 25 of those years, he was also appointed as an adjunct professor of Zoology at the University of Manitoba where he taught a forth-year course in Environmental Toxicology; and served as advisor and supervisor for graduate students. During his career he served on numerous national and international advisory committees on issues pertaining to organic contaminants and metals. During the mid-to late-90's he served as DFO representative on multi-stakeholder exercises entitled *"Assessment of Aquatic Effects of Mining in Canada"* and *"Aquatic Effects Technology Evaluation"* as related to the Canadian mining industry. Last year Dr. Klaverkamp completed a five-year term, three as

Chairman, on the International Expert Advisory Panel for the *"Metals in the Environment – Research Network."* Dr. Klaverkamp has published peer-reviewed manuscripts on laboratory studies addressing the toxicity of selenium to fertilized salmonid eggs and juvenile freshwater fishes; on the accumulation and distribution of Se in fish from a north western Ontario lake; and in fish from lakes exposed to Se from the smelter in Flin Flon, Manitoba and effluents from a uranium mine in northern Saskatchewan.

Harry M. Ohlendorf, Ph.D.
Dr. Ohlendorf received his Ph.D. degree in Wildlife Science from Texas A&M University in 1971. His present position is Principal Environmental Scientist, Ecological Risk Management with CH2M HILL, Inc., Sacramento, California. Dr. Ohlendorf has been employed at CH2M HILL since 1990. As an environmental scientist, he manages or provides technical oversight for a wide variety of environmental projects, including the planning, implementation, and reporting of site ecological characterizations and surveys, contaminant exposure and effect analyses, risk characterization, and project impact evaluations. He provides firm-wide technical guidance in the area of ecological risk assessment and risk management. Dr. Ohlendorf began his career with the U.S. Fish and Wildlife Service's Patuxent Wildlife Research Center in Laurel, Maryland, where he served for 7 years as assistant director of the Research Center and was actively involved in pollution ecology research. Subsequently, he was leader of the Pacific Coast Research Station in Davis, California, and studied the pollution ecology of wildlife. For 18 years, Dr. Ohlendorf's research focused on the occurrence and impacts of contaminants in aquatic and terrestrial ecosystems. Dr. Ohlendorf conducted the studies of aquatic birds at Kesterson Reservoir (California) in the early 1980's that first documented reproductive effects of selenium in the wild. He completed numerous subsequent studies and evaluations of selenium exposure and effects in fish and wildlife, and also some for domestic livestock. Dr. Ohlendorf completed a comprehensive study of selenium and arsenic concentrations and their fate and potential effects on human and ecological receptors, including livestock grazing on areas affected by mining activities. He is currently serving as technical lead for evaluation of selenium-related issues pertinent to future management of Salton Sea, CA. He is recognized as one of the "Pioneers of Selenium Research" in a book, *Environmental Chemistry of Selenium,* edited by W.T. Frankenberger, Jr., and R.A. Engberg and published by Marcel Dekker, Inc., 1998. He also served on the Science Panel for the Se Workshop held in 2000 at Hinton, Alberta.

Joseph Skorupa, Ph.D.
Dr. Skorupa earned a Ph.D. in Biological Ecology from the University of California (Davis Campus) in 1988. He served as a National Science Foundation student fellow at the Savannah River Ecology Laboratory, University of Georgia (1975-77); as a research technician at the Denver Wildlife Research Center, Division of Bird Damage Control, of the U.S. Fish and Wildlife Service (1978-80); as a research fellow for the New York Zoological Society (Bronx Zoo) at the Kibale Forest Research Station in central Africa (1980-82); as a research biologist for the Patuxent Wildlife Research Center of U.S. Fish and Wildlife Service (1988-91); as a senior biologist in the Environmental Contaminants Division of the U.S. Fish and Wildlife Service's Sacramento, CA, field office (1992-2003); and is currently the Clean Water Act Biologist in the U.S. Fish and Wildlife Service's Washington, DC, national office (2004-present). Dr. Skorupa also served as a part-time faculty member in the Environmental Studies Departments of U.C. Davis and California State University Sacramento (1997-2003). Since 1987, Dr. Skorupa's research has focused on the ecotoxicology of selenium and a field research program aimed at documenting exposure-response relationships for selenium in avian eggs, primarily focusing on various species of water birds. His field research program has included over a decade of work at terminal basin water bodies in the San Joaquin Valley of California. Dr. Skorupa has also conducted field work at the Salton Sea in Southern California, in the San Francisco Bay Estuary, at Las Vegas Wash, Nevada, and in Wyoming and Idaho. Dr. Skorupa served as the U.S. Fish and Wildlife Service's technical lead on a federal multi-agency Data Synthesis Team for the National Irrigation Water Quality Program (NIWQP). The NIWQP surveyed more than 150 sampling sites in the 17 westernmost United States for selenium and other inorganic and organic constituents in water, bottom sediment, and biota. Presently, Dr. Skorupa is assisting with a

federal multi-agency research team planning studies of selenium dynamics in Appalachian aquatic ecosystems influenced by mountain-top removal/valley-fill coal mining. Dr. Skorupa's core contribution to the selenium literature has been the publication of statistically rigorous exposure-response curves relating Se concentrations in avian eggs to incidence of embryo teratogenesis.

APPENDIX 3

Alberta Selenium Science Panel

Jack Klaverkamp	DFO (Research Scientist – Emeritus) – ***Chair***
William (Bill) Adams	Rio Tinto Ltd.
Peter Hodson	Queen's University
Harry Ohlendorf	CH2M HILL
Joseph Skorupa	U.S. Fish and Wildlife Service – ***Presenter***

Attending Delegates

Alice Hontela	University of Lethbridge
Andre Sobolewski	Microbial Technologies – ***Presenter***
Andy Lamb	AENV – ***Presenter and Chair, SWG***
Arden Rosaasen	COGEMA Resources Inc.
Bernd Martens	Grande Cache Coal Corp. – ***Member, SWG***
Beth MacCallum	Bighorn Environmental Design Inc. – ***Presenter***
Bill Mackay	W.C. Mackay & Associates – ***Presenter***
Brenda McFadyen-Landry	Grande Cache Coal Corp.
Bruce Greenfield	EUB
Bruce McCullouch	DFO – ***Member, SWG***
Bruce Winegar	J.R. SIMPLOT Co. – ***Presenter***
Cheryl Podemski	DFO – ***Presenter***
Curtis Brinker	Silkstone Environmental Ltd. – ***Presenter***
Dale Kirkland	Environment Canada
Dani Walker	DFO
Daniel Andrews	Western Resource Solutions – ***Presenter***
David Janz	University of Saskatchewan
Dermot Lane	Elk Valley Coal Corp. – ***Member, SWG***
Elan Gluckie	AENV
Gene Leskiw	AENV
George Sterling	ASRD – ***Presenter and Member, SWG***
Jeff Kneteman	ASRD – ***Presenter***
Jenny Earle	Mainstream Aquatics Ltd.
Jody Frenette	Elk Valley Coal Corp.
Jolene Raggett	BC Ministry of Environment
Ken Banister	EUB
Kim Bellefontaine	BC Ministry of Energy and Mines
Lana Miller	University of Lethbridge
Leanne Zrum	AENV
Marc Symbaluk	Elk Valley Coal Corp.
Mark Strosher	BC Ministry of Environment
Mike Zemanek	AENV
Patrick Shaw	Environment Canada
Paul Gregoire	Environment Canada
Peter Chapman	Golder Associates Ltd. – ***Presenter***
Richard Casey	AENV – ***Presenter***
Richard (Rick) Nutbrown	AENV
Ron Jones	Elk Valley Coal Corp.
Rudy Hawryluk	ASRD
Ryan Puhlmann	AENV – ***Presenter***
Scott Johnson	Luscar Ltd.
Tom Gates	Saskatchewan Environment
Vince Palace	DFO – ***Presenter***

Appendix 4
ERA Conceptual Models

ERA Conceptual Models (excerpted from U.S. Environmental Protection Agency (USEPA). 1998. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F. Risk Assessment Forum. Washington DC. April.)

CONCEPTUAL MODELS

A conceptual model in problem formulation is a written description and visual representation of predicted relationships between ecological entities and the stressors to which they may be exposed. Conceptual models represent many relationships. They may include ecosystem processes that influence receptor responses or exposure scenarios that qualitatively link land-use activities to stressors. They may describe primary, secondary, and tertiary exposure pathways (see section 4.2) or co-occurrence among exposure pathways, ecological effects, and ecological receptors. Multiple conceptual models may be generated to address several issues in a given risk assessment. Some of the benefits gained by developing conceptual models are described below.

What Are the Benefits of Developing Conceptual Models?

-The process of creating a conceptual model is a powerful learning tool.

-Conceptual models are easily modified as knowledge increases.

-Conceptual models highlight what is known and not known and can be used to plan future work.

-Conceptual models can be a powerful communication tool. They provide an explicit expression of the assumptions and understanding of a system for others to evaluate.

-Conceptual models provide a framework for prediction and are the template for generating more risk hypotheses.

Conceptual models for ecological risk assessments are developed from information about stressors, potential exposure, and predicted effects on an ecological entity (the assessment endpoint). Depending on why a risk assessment is initiated, one or more of these categories of information are known at the outset (refer to section 3.2). The process of creating conceptual models helps identify the unknown elements.

The complexity of the conceptual model depends on the complexity of the problem: the number of stressors, number of assessment endpoints, nature of effects, and characteristics of the ecosystem. For single stressors and single assessment endpoints, conceptual models may be simple. In some cases, the same basic conceptual model may be used repeatedly (e.g., in EPA's new chemical risk assessments). However, when conceptual models are used to describe pathways of individual stressors and assessment endpoints and the interaction of multiple and diverse stressors and assessment endpoints (e.g., assessments initiated to protect ecological values), more complex models and several submodels will often be needed. In this case, it can be helpful to create models that also represent expected ecosystem characteristics and function when stressors are not present.

Conceptual models consist of two principal components:

- A set of risk hypotheses that describe predicted relationships among stressor, exposure, and assessment endpoint response, along with the rationale for their selection
- A diagram that illustrates the relationships presented in the risk hypotheses.

Risk Hypotheses

Hypotheses are assumptions made in order to evaluate logical or empirical consequences, or suppositions tentatively accepted to provide a basis for evaluation. Risk hypotheses are specific assumptions about potential risk to assessment endpoints and may be based on theory and logic, empirical data, mathematical models, or probability models. They are formulated using a combination of professional judgment and available information on the ecosystem at risk, potential sources of stressors, stressor characteristics, and observed or predicted ecological effects on selected or potential assessment endpoints. These hypotheses may predict the effects of a stressor before they occur, or they may postulate why observed ecological effects occurred and ultimately what caused the effect. Depending on the scope of the risk assessment, risk hypotheses may be very simple, predicting the potential effect of one stressor on one receptor, or extremely complex, as is typical in value-initiated risk assessments that often include prospective and retrospective hypotheses about the effects of multiple complexes of stressors on diverse ecological receptors. Risk hypotheses represent relationships in the conceptual model and are not designed for statistically testing null and alternative hypotheses. However, they can be used to generate questions appropriate for research.

What Are Risk Hypotheses, and Why Are They Important?

Risk hypotheses are proposed answers to questions risk assessors have about what responses assessment endpoints will show when they are exposed to stressors and how exposure will occur. Risk hypotheses clarify and articulate relationships that are posited through the consideration of available data, information from scientific literature, and the best professional judgment of risk assessors developing the conceptual models. This explicit process opens the risk assessment to peer review and evaluation to ensure the scientific validity of the work. Risk hypotheses are not equivalent to statistical testing of null and alternative hypotheses. However, predictions generated from risk hypotheses can be tested in a variety of ways, including standard statistical approaches.

Although risk hypotheses are valuable even when information is limited, the amount and quality of data and information will affect the specificity and level of uncertainty associated with risk hypotheses and the conceptual models they form. When preliminary information is conflicting, risk hypotheses can be constructed specifically to differentiate between competing predictions. The predictions can then be evaluated systematically either by using available data during the analysis phase or by collecting new data before proceeding with the risk assessment. Hypotheses and predictions set a framework for using data to evaluate functional relationships (e.g., stressor-response curves).

Early conceptual models are normally broad, identifying as many potential relationships as possible. As more information is incorporated, the plausibility of specific hypotheses helps risk assessors sort through potentially large numbers of stressor-effect relationships, and the ecosystem processes that influence them, to identify those risk hypotheses most appropriate for the analysis phase. It is then that justifications for selecting and omitting hypotheses are documented. Examples of risk hypotheses are provided below.

Examples of Risk Hypotheses

-Hypotheses include known information that sets the problem in perspective and the proposed relationships that need evaluation.

Stressor-initiated: Chemicals with a high Kow tend to bioaccumulate. PMN chemical A has a Kow of 5.5 and molecular structure similar to known chemical stressor B.

Hypotheses: Based on the Kow of chemical A, the mode of action of chemical B, and the food web of the target ecosystem, when the PMN chemical is released at a specified rate, it will bioaccumulate sufficiently in 5 years to cause developmental problems in wildlife and fish.

Effects-initiated: Bird kills were repeatedly observed on golf courses following the application of the pesticide carbofuran, which is highly toxic.

Hypotheses: Birds die when they consume recently applied granulated carbofuran; as the level of application increases, the number of dead birds increases. Exposure occurs when dead and dying birds are consumed by other animals. Birds of prey and scavenger species will die from eating contaminated birds.

Ecological value-initiated: Waquoit Bay, Massachusetts, supports recreational boating and commercial and recreational shellfishing and is a significant nursery for finfish. Large mats of macroalgae clog the estuary, most of the eelgrass has died, and the scallops are gone.

Hypotheses: Nutrient loading from septic systems, air pollution, and lawn fertilizers causes eelgrass loss by shading from algal growth and direct toxicity from nitrogen compounds. Fish and shellfish populations are decreasing because of loss of eelgrass habitat and periodic hypoxia from excess algal growth and low dissolved oxygen.

Conceptual Model Diagrams

Conceptual model diagrams are a visual representation of risk hypotheses. They are useful tools for communicating important pathways clearly and concisely and can be used to generate new questions about relationships that help formulate plausible risk hypotheses.

Typical conceptual model diagrams are flow diagrams containing boxes and arrows to illustrate relationships (see Appendix C). When this approach is used, it is helpful to use distinct and consistent shapes to distinguish stressors, assessment endpoints, responses, exposure routes, and ecosystem processes. Although flow diagrams are often used to illustrate conceptual models, there is no set configuration. Pictorial representations can be very effective (e.g., Bradley and Smith, 1989). Regardless of the configuration, a diagram’s usefulness is linked to the detailed written descriptions and justifications for the relationships shown. Without this, diagrams can misrepresent the processes they are intended to illustrate.

When developing conceptual model diagrams, factors to consider include the number of relationships depicted, the comprehensiveness of the information, the certainty surrounding a linkage, and the potential for measurement. The number of relationships that can be depicted in one flow diagram depends on their complexity. Several models that increasingly show more detail for smaller portions can be more effective than trying to create one model that shows everything at the finest detail. Flow diagrams that highlight data abundance or scarcity can provide insights on how the analyses should be approached and can be used to show the risk assessor's confidence in the relationship. They can also show why certain pathways were pursued and others were not.

Diagrams provide a working and dynamic representation of relationships. They should be used to explore different ways of looking at a problem before selecting one or several to guide analysis. Once the risk hypotheses are selected and flow diagrams drawn, they set the framework for final planning for the analysis phase.

Appendix 5
The US EPA Data Quality Objective (DQO) Process (USEPA, 2000)

DQO Steps (excerpted from U.S. Environmental Protection Agency (USEPA). 2000. Guidance for the Data Quality Objectives Process. EPA QA/G-4. EPA/600/R-96/055. Office of Environmental Information, Washington, DC. August.)

1. State the Problem
- Identify the planning team members including decision makers.
- Describe the problem; develop a conceptual model of the environmental hazard to be investigated.
- Determine resources - budget, personnel, and schedule.

2. Identify the Decision
- Identify the principal study question.
- Define alternative actions.
- Develop a decision statement.
- Organize multiple decisions.

3. Identify the Inputs to the Decision
- Identify the information needed.
- Determine sources for this information.
- Determine the basis for determining the Action Level.
- Identify sampling and analysis methods that can meet the data requirements.

4. Define the Boundaries of the Study
- Define the target population of interest.
- Specify the spatial boundaries that clarify what the data must represent.
- Determine the time frame for collecting data and making the decision.
- Determine the practical constraints on collecting data.
- Determine the smallest subpopulation, area, volume, or time for which separate decisions must be made.

5. Develop a Decision Rule
- Specify an appropriate population parameter (mean, median, percentile).
- Confirm the Action Level exceeds measurement detection limits.
- Develop a decision rule (*If...then...*statement).

6. Specify Tolerable Limits on Decision Errors
- Determine the range of the parameter of interest.
- Choose a null hypothesis.
- Examine consequences of making an incorrect decision.
- Specify a range of values where consequences are minor (gray region).
- Assign probability values to points above and below the Action Level that reflect tolerable probability for potential decision errors.

7. Optimize the Design for Obtaining Data
- Review the DQO outputs.
- Develop data collection design alternatives.
- Formulate mathematical expressions for each design.
- Select the sample size that satisfies the DQOs.
- Decide on the most resource-effective design, or agreed alternative.
- Document details in the QA Project Plan.