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

February 2010

The Alberta Selenium Working Group (ABSWG) was established in 1999 to coordinate efforts to assess and manage potential selenium impacts from mountain coal mines in west-central Alberta. ABSWG members include representatives from the provincial and federal governments, and the coal industry. The ABSWG is co-chaired by one representative from government and one from industry.

In September 2000, the ABSWG held a technical workshop with a panel of invited scientific experts aimed at the development of a work plan that identified the gaps in our understanding of fate and effects 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 ABSWG commissioned the Selenium Science Panel (SeSP), comprising scientific experts in the field of selenium research, to obtain an independent assessment on the effects of selenium in Alberta mountain coal mines. A SeSP workshop was held in June of 2005 in Hinton, Alberta with ABSWG members and the Panel; several formal presentations were given and written documents were submitted. The Panel's final report was submitted in September 2005. The Panel noted advances in knowledge in many areas since the 2000 workshop, and also noted some knowledge gaps and priority issues. One of these was whether Se is resulting in adverse effects on local fish populations. The Panel recommended that another panel of experts focusing on the topics of fish population dynamics and ecological statistics be brought together to address this issue.

In response to this latter recommendation, the ABSWG commissioned the Selenium Fish Science Panel (SeFSP). This Panel comprised four fisheries populations and statistics experts, specifically:

- Joseph Rasmussen (Professor of Biology & CRC Chair, University of Lethbridge), Panel Chair;
- Spencer Peterson (USEPA, Corvallis, OR);
- Subhash Lele (Professor of Mathematics, University of Alberta); and
- Jordan Rosenfeld (BC Ministry of Environment, Vancouver, BC)

The workshop was held October 9-11, 2007, in Hinton, Alberta. The panel heard 3 formal presentations, received several written submissions before and after the workshop, and entertained productive discussions.

The ABSWG asked the Panel to answer four specific questions:

1. Are fish populations altered in mountain water bodies affected by coal mining including elevated levels of selenium compared with reference streams?
2. If so, are these alterations detrimental to the function and productivity of those fish populations?
3. What are the reason(s) for any alterations? (including, but not restricted to, selenium; all possible natural and anthropogenic factors [e.g., physical habitat changes] need to be considered)

4. If causation cannot be conclusively determined based on available data, what additional studies are required to establish causation?

Five objectives were set forth to the SeFSP in order to provide the Panel with the necessary background information and framework required to answer the four questions posed.

These were as follows:

1. Review historical and current data pertaining to fish populations in lotic and lentic water bodies associated with mountain coal mining – including but not restricted to Luscar Creek – and appropriate reference water bodies.
2. Determine whether or not existing data are sufficient for describing recruitment, population and community trends in these water bodies.
3. If data rigor supports analysis, assess recruitment, population and community changes for water bodies affected by coal mining, including elevated selenium, compared with appropriate reference water bodies.
4. As possible and appropriate, based on the analyses in Objective 3, above, attempt to determine potential causative factors and the overall environmental significance of any differences.
5. If available data are not definitive, provide recommendations in sufficient detail for study design regarding the key information gaps and priority issues that need to be addressed, such that potential causative factors can be determined.

The Panel presented discussions, conclusions and recommendations in their final report, *Report to the Selenium Working Group Workshop, October 9-11, 2007, Hinton Alberta*, along with supporting rationale. The SeFSP thoroughly addressed the objectives and questions established by the ABSWG. The ABSWG accepts the final version of this report and the Panel's key findings. We thank the members of the Panel for their thorough and timely work, and appreciate their efforts in considering subsequent information and comments, and providing clear guidance. Copies of the SeSP Final Report can be downloaded at the following URL: http://environment.gov.ab.ca/info/library/8257.pdf

Sincerely,

Chiadih Chang

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Alberta Selenium Working Group – Coal Industry
Acceptance of the Final Report of the Selenium Fish Science Panel Workshop

October 2009

RE: Additional Comment on SeFSP Report from Coal Industry Co-Chair:

The coal industry members of the ABSWG are unanimous in their support of the Panel report and believe that the findings and recommendations of the report provide constructive guidance for our management and research/monitoring programs. We understand and appreciate the Panel's difficulty in trying to answer the question of whether selenium was impacting local fisheries populations, and note that the uncertainty and ambiguity of certain comments and conclusions in the report will lead to difficulties in interpreting some of the conclusions made.

In the Coal Industry's view, the Panel chose to extend their commentary into two specific issues that are beyond the realm of fisheries science, to which we provide the following comments:

- The Panel report raises concern about potential human impacts related to fish consumption (page 20). The report does not take into consideration a peer-reviewed scientific publication submitted to the Panel (i.e., Lawrence & Chapman, 2007) nor other reports (Cantox Environmental, 2000; ETL, 2000). These reports concluded that negative human health effects are unlikely to occur by consuming fish from Lac des Roches, the water body with the highest selenium fish tissue concentrations in the region; and
- The Panel concluded that, based on preliminary data from Alberta Environment (AENV) made available after the Workshop, selenium concentrations in receiving streams will increase in the future (page 19). AENV's trend data were limited to two sites and were limited in sample size. Neither AENV nor the Panel attempted to understand the reasons for trends in historic selenium concentrations or loadings. We believe that trends must be developed using the full set of data rather than selected subsets, and that the causes of historic trends must be understood before predictions of future trends are made. We therefore believe it was misleading for the Panel to make such statements without substantial qualification.

The coal industry provides the foregoing comments to give broader context on these two issues. Industry membership restates our support and respect for the Panel, their findings and their report.

Sincerely,

Bernd Martens
Manager Environment, Grande Cache Coal Corporation
Co-Chair, Alberta Selenium Working Group

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Experts Workshop on Selenium Fish Science In the Athabasca River, Alberta:

Workshop Summary Report

Workshop Convened:

Oct 9 -11, 2007
Hinton Training Centre
1176 Switzer Drive, Hinton, Alberta

Report Submitted To:

Alberta Environment
Central Region
250 Diamond Avenue
Spruce Grove, Alberta T7X 4C7

Report Submitted – July2008 (revised Jan and Mar 2009) - By:

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Experts Workshop on Selenium Fish Science In the Athabasca River, Alberta:
Workshop Summary Report

July 2008 (revised Jan & Mar 2009)

We, the undersigned, have prepared this Workshop Summary Report on Selenium Impacts on Fish populations in the Athabasca River

June 28, 2009
July 14, 2009
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Date

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07/14/09
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Date

July 3/2009
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July 2, 2008
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Date

** This report was developed as part of a workshop sponsored by the Government of Alberta. It was written by the authors signed above, but not reviewed and/or approved by their respective organizations. Therefore, the opinions and conclusions expressed in this report are solely those of the authors and do not represent the position of their various organizational affiliations. Likewise the mention of trade names or commercial products does not constitute endorsement or recommendation for use by the authors or their respective organizational affiliations.*

REPORT TO THE SELENIUM WORKING GROUP ON THE SELENIUM FISH SCIENCE PANEL (SeFSP) WORKSHOP

Oct 9-11, 2007, Hinton, AB

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EXECUTIVE SUMMARY

The Selenium Fish Science Panel reviewed evidence from monitoring studies carried out in mountain water bodies affected by coal mining activities compared with reference streams. There is evidence that a number of changes in the fish populations affected by coal mining have occurred. Rainbow trout densities in Luscar Creek are lower than in reference streams and low juvenile/adult ratios in this stream suggest that recruitment may be impaired, relative to the levels seen in reference streams. In addition, Brook trout have become the most abundant species in the Luscar Creeks system. While populations in reference streams have fluctuated over time, and brook trout occur in these streams as well, no significant changes in community make-up were noted. Luscar Creek, which receives Se-rich inputs, has had elevated Se levels (6-32 µg/L), relative to reference headwater streams (<1 µg/L) and has exceeded the CCME PAL guideline since at least the late 1990's. Spawning rainbow and brook trout from Luscar Creek also have elevated Se levels in their eggs (9.9±1.4µg/g ww) compared to 0.5±0.2 µg/g ww in reference streams.

It is difficult to establish that the reported trends in fish population parameters are statistically reliable, and it is even more difficult for monitoring surveys to establish the causal basis for changes. The trends however, if real, are considered to be detrimental to function and productivity of native Athabasca Rainbow trout. While not all studies agree as regard to time trends, the differences between the fish communities of Se elevated streams and reference streams were consistent with what would be expected on the basis of the elevated Se levels in the system. Firstly, the low juvenile/adult ratios in Rainbow trout would be expected if the elevated levels of Se were leading to reduced recruitment. The average concentration of Se in rainbow trout eggs from Luscar Creek was 9.9 µg g ww and these are in the same range as published egg Se thresholds for teratogenic defects (developmental abnormalities) in newly hatched larvae (8.8-10.5 µg/g ww) (Holm et al. (2005). In fact, rainbow trout larvae hatched from eggs obtained from Luscar Creek exhibited high teratogenicity levels relative to reference streams. Secondly, the apparent increases in brook trout abundance in Luscar Creek are also consistent with what we would expect if Se toxicity were affecting rainbow trout, since the two species have similar feeding and habitat requirements, and Holm et al. (2005) detected only slightly higher teratogenicity in brook trout from Luscar Creek relative to Cold Cr (reference stream), and were

not able to detect a relationship between egg Se concentration and teratogenicity in this species. Thus it is possible that Se toxicity may contributing to a community shift in Luscar Creek and enhancing the spread of brook trout, an introduced species.

There are of course, other possible explanations for low abundance and recruitment of rainbow trout in Luscar Creek. For example, juveniles may be migrating out of the creek into the McLeod R. Palace et al. (2007) in their Laser ablation study of Se in rainbow trout otoliths showed that many of the trout spawning in Luscar Creek had not been reared in the creek, and were recent immigrants; consequently, it would be reasonable to expect that many of the rainbow trout born in the creek from these migrant parents, would migrate back out as juveniles. Even if these effects were a reflection of adverse rearing conditions in Luscar Creek for juvenile rainbow trout, they may result from channel alterations that could have degraded the quality of the stream's nursery habitat for rainbow trout. There are also alternative explanations for increased brook trout abundance, since this introduced species has expanded their numbers in many eastern slope streams from Utah to B.C. without any 'help' from mining activities.

The SeFSP discussed the limitations of population monitoring data for drawing inferences about fish population responses, and their causes. The high level of 'noise' resulting from 'natural' environmental factors such as extreme flooding, and other anthropogenic activities such as logging, make it difficult to determine how much of what we see are mine-related effects. In addition, the open-ended and multi-stock structure of stream salmonid populations makes population level effects difficult to detect, and failure to detect such impacts at small scales, can expose systems to the risk of large-scale cumulative impacts. A range of alternative approaches to monitoring that might prove more effective in teasing apart causal influences were discussed. These included mathematical modeling of salmonid populations on large spatial scales, involving the simulation of scenarios of expansion of mining within the watershed, and the testing of management options pertaining to salmonid communities as well as Se management. There is also a need for more laboratory analysis of Se effects on fish involving whole-life-cycle experiments, in order to better understand how Se toxicity affects fish and to establish more reliable Se toxicity guidelines for environmental management. The panel also discussed the possibility of field experiments on a variety of spatial scales. Experimental manipulations could possibly overcome the problem of open-ended fish population structure because they could be applied on a spatially restricted scale to populations of fish that are constrained to flumes, experimental side-channels, or on a larger scale within sections of the stream closed to migrants from outside.

The inference that native rainbow trout populations in Luscar Creek, and any other stream that were to receive discharge water from Se rich drainage, are potentially at risk, is strongly contingent on the validity of the Holm et al (2005) study, and there was much criticism leveled at the analytical component of this study. The panel was asked to review this study, and through the co-operation of Vince Palace, obtained the original data set and subjected it to a weighted logistic regression analysis that was designed to address the statistical concerns being raised. After a thorough re-analysis of the data set, using both single species, and two-species models containing interaction terms to test for the significance of species differences in Se sensitivity, the findings reported by Holm et al were confirmed in most respects. Thus, for both single species models, and two species models with an interaction term, there is very strong evidence that rainbow trout suffer an elevated teratogenicity rate from the Se exposure regime they encounter in Luscar Creek; but that brook trout do not. Indeed the models generated in our reanalysis places the Se toxicity threshold for a 20% increase in teratogenicity in newly hatched rainbow trout at 7.5±0.8 µg egg Se/g ww, and most of the fish from Luscar Creek matched or exceeded this threshold. Moreover, the analysis indicates that egg Se exposures up to 18µg Se/g ww produced no increased teratogenicity in brook trout. The threshold value of 7.5 µg egg Se/g ww corresponds to a value of 30 µg egg Se/g dw (assuming egg moisture content = 75%).

The SeFSP concludes that while the state of our knowledge concerning the population impacts on native rainbow trout is incomplete, the weight of the scientific evidence at our disposal indicates that Se-rich inputs that raise Se levels in streams to the point where egg Se concentrations exceed 7.5 µg egg Se/g ww, pose a serious teratogenicity risk for rainbow trout. Moreover, this risk will likely adversely affect recruitment and reduce the species ability to compete with introduced brook trout, for which this level of Se exposure is not toxic. Indeed eggs from spawning rainbow trout in Luscar Creek have been shown to have elevated teratogenicity rates compared to reference streams (Holm et al. 2005) whereas brook trout eggs from this stream do not. While monitoring results indicate that some changes in fish populations consistent with this perceived risk have occurred, they are not of a level where they can be regarded as statistically certain, nor can other plausible explanations for the changes be ruled out. Therefore while monitoring data cannot conclusively confirm that the teratogenicity risk has adverse effects on the level of populations and communities, *they cannot rule it out either*, since such data are inherently ‘noisy’ and large-scale effects on fish populations can easily escape detection. While our knowledge base is incomplete, we recognize that the risk posed by Se-rich inputs to headwater streams is likely to increase with time due to a combination of progressive weathering and the expanding scope of mining activities.

Because the risk to fish posed by Se-rich discharges is likely to grow as more end-pit lakes begin to discharge into headwater streams, we recommend that in addition to continued research at many levels, we begin to experiment with all available technologies with the aim of reducing Se loading to tributary streams. This should include both technologies aimed at preventing Se loading from Se rich rock, Se removal from water, as well as biogeochemical experiments aimed at developing technologies to reduce the Se concentrations in end-pit lakes. The panel recommends that the mining companies be major participants in this research, both intellectually and financially. Economic instruments aimed at providing incentive to reduce Se releases to surface waters, involving both market-based and regulatory components eg. trading of Se emission permits, should also be actively investigated. The “*Stewardship and Conservation*” section of the recent Government of Alberta report entitled *Land-Use Framework* stresses the need for innovative market-based approaches to stewardship. The wide range of mining and agricultural activities that enhance Se weathering on the Canadian landscape suggests that such initiatives may have a broad theatre of applicability. Similar market-based mechanisms, involving the trading of Se release permits, have been developed to regulate Se releases from agriculture in California.

BACKGROUND INFORMATION –ecotoxicology and environmental chemistry of Se

Selenium is a trace element whose chemistry, both in the inorganic and organic form, strongly parallels sulfur, in that these elements share the same oxidation states and are released by similar weathering processes as the mineral forms are oxidized. Mining activities and other geospheric disturbances can greatly accelerate weathering and increase the loading of selenium to surface waters. Oxidized (soluble) forms are assimilated by primary producers and reduced to the organic (Se-H) form which is incorporated into a variety of amino acids which can be transferred efficiently through the food chain to invertebrates and fish. While some of the Se-containing proteins perform essential functions, organoselenium can be highly toxic and interfere with cellular functions; moreover, the margin between nutritional requirements and toxic concentrations in fish and many other organisms is narrow. In fish, organoselenium is transferred to eggs as ovaries ripen, and newly hatched larvae can experience developmental abnormalities such as craniofacial and skeletal deformities as they ultilize the yolk sac. Species vary considerably in regard to their Se toxicity thresholds. Teratogenicity can reduce fitness and survival of young and thus interfere with population recruitment.

QUESTIONS AND OBJECTIVES POSED TO THE SeFSP BY THE SWG:

1. Are fish populations altered in mountain water bodies affected by coal mining including elevated levels of selenium compared with reference streams?
2. If so, are these alterations detrimental to the function and productivity of those fish populations?

3. What are the reason(s) for any alterations? (including but not restricted to selenium; all possible natural and anthropogenic factors [e.g., physical habitat changes] need to be considered)
4. If causation cannot be conclusively determined based on available data, what additional studies are required to establish causation?

Five objectives were set forth to the SeFSP in order to provide the panel the necessary background information and framework required to answer the four questions posed. These were:

1. Review historical and current data pertaining to fish populations in lotic and lentic water bodies associated with mountain coal mining – including but not restricted to Luscar Creek – and appropriate reference water bodies.
2. Determine whether or not existing data are sufficient for describing recruitment, population and community trends in these water bodies.
3. If data rigor supports analysis, assess recruitment, population and community changes for water bodies affected by coal mining, including elevated selenium, compared with appropriate reference water bodies.
4. As possible and appropriate, based on the analyses in Objective 3, above, attempt to determine potential causative factors and the overall environmental significance of any differences.
5. If available data are not definitive, provide recommendations in sufficient detail for study design regarding the key information gaps and priority issues that need to be addressed, such that potential causative factors can be determined.

PRESENTATIONS TO THE SeFSP:

The panel first heard the presentation by Jim Allen (Pisces Environmental Consulting Services Ltd), who provided a presentation entitled:

Cardinal River Coals / Cardinal River Operations Stream Fish Population Monitoring Program for the Luscar Mine: An Overview and Summary. A report had been previously provided and distributed to the Panel and the SWG. Key points made were:

- The time series analysis (approximately 14 years of data) is not long enough for meaningful analysis.
- There appear to have been reductions in numbers of rainbow trout in Luscar Creek; however, causation is unknown – there are a number of possible causes, not just increased concentrations of Se (e.g., habitat changes, inter-specific competition, extensive electro-fishing, fish movements).
- Similarly, reasons for declines in bull trout in Sphinx Creek are unknown.
- There is a need to establish longer-term trends, then to attempt to identify causal links between those trends.

The second presentation was by Dana Schmidt (Golder Associates Ltd) entitled:

Evaluation of Fish Population Trends in the Upper McLeod Drainage and Their Utility for Analysis of Possible Impacts of Elevated Selenium in the Aquatic Environment. A report had been previously provided and distributed to the Panel and the SWG. A number of key points were made, of which a few are:

- Temporal trends are highly variable among adjacent drainages.
- Multiple causes are likely and are inherent to the specific area.

- Order of magnitude abundance changes occur throughout the system over the time series available.

Recommendations and possible adaptive management approaches were suggested. Final comments included: ensure studies are cost-effective; the bottom-line goal is more fish; habitat improvement is likely to have the greatest positive effect on fish numbers.

The third presentation was by George Sterling (ASRD) who provided a presentation entitled: *Fish Community Changes in West-Central Alberta Foothill Streams Affected by Open-Pit Coal Mining*. No report was provided ahead of the workshop; however, a handout of the presentation was provided to attendees. A number of key points were made, including:

- Since 2000 rainbow trout densities in Luscar Creek have declined in comparison to Jarvis and Sphinx Creeks (increases).
- Brook trout have increased in Jarvis and Luscar Creeks and now dominate the trout communities in these water bodies.
- The low juvenile to adult rainbow trout ratio in conjunction with low overall densities in Jarvis and Luscar Creeks suggest that these populations are collapsed and at significant risk. Several other streams exhibit similar ‘collapsed’ conditions.

Each of these reports was followed by a lengthy discussion wherein questions raised by the SeFSP, followed by other participants, were addressed. The SeFSP’s answers to the questions posed by the SWG, consider both the material presented in the three presentations, material available in the literature, as well as the points raised in follow-up discussions.

ANSWERS TO QUESTIONS POSED BY THE SWG

1. ***Are fish populations altered in mountain water bodies affected by coal mining including elevated levels of selenium compared with reference streams?***

Several streams with coal mines in their watersheds, including Luscar Cr and its tributaries, East and West Jarvis Creeks, plus the Gregg River have exhibited elevated Se levels relative to reference streams over the last few decades, most notably since the late 1990's (Casey and Siwik 2000; Holm et al. 2005). In association with increased Se in stream water, tissue levels in rainbow trout and brook trout from these streams are also elevated. Elevated egg Se concentrations in rainbow trout are associated with elevated levels of craniofacial, edema and skeletal defects, and Luscar Cr has elevated levels of such larval defects relative to reference streams (Holm et al. 2005). Brook trout in Luscar Cr exhibited somewhat elevated levels of craniofacial defects, however neither the frequencies of edema nor skeletal defects differed from the reference stream, and no relationship between elevated defect levels and egg Se levels was detected for brook trout. Thus the development of rainbow trout but not brook trout, in Luscar Cr, (and possibly to some extent the Gregg R) was affected by Se released from the mined watershed.

There are indications that a number of changes in the fish populations affected by coal mining have occurred. Rainbow trout densities in Luscar Cr are low relative to reference streams, and according to the Sterling presentation appear to have declined. In addition the juvenile/adult ratios in this stream are low relative to the levels seen in reference streams. In addition, Brook trout have increased in Jarvis and Luscar Creeks, and now dominate the trout communities in these streams. While populations in reference streams also exhibit such large and dramatic fluctuations in numbers, these appear to be related to environmental disturbances such as major flood events that can dramatically influence fish densities in these streams. Brook trout occur in these streams as well, but no significant changes in community composition similar to those observed in Luscar Ck. were noted in recent years. While Sterling reports a decline in Luscar Cr rainbow trout, and an overall increase in brook trout abundance, Allen reports no significant time trend in rainbow trout, and a sharp decline in brook trout abundance since 2003. Although the reports disagree on the time trend over the last decade, there is good agreement in regards to the overall low rainbow trout abundance in Luscar Creek (much lower than densities reported by Sterling in reference streams), and in regard to brook trout abundance being generally higher than rainbow trout abundance, which stands in sharp contrast to the low densities reported by Sterling in the 1980's. As Schmidt points out the high level of uncertainty associated with quantitative fish surveys makes the establishment of time trends very difficult especially when the time interval under consideration is fairly short.

Recently, the development of concretion-like deposits on the substrate has been noted in Luscar Creek downstream of the outflow of a settling pond, and concern has been expressed over the possible effect that these deposits might have on feeding and spawning habitat for fish.

Answer to Q1:

Se levels in water and fish tissues are elevated in streams affected by mining, and rainbow trout developmental abnormalities are also elevated, and the fish communities is these streams differ from reference streams in regard to their low rainbow trout densities, low

juvenile/adult ratios, and high brook trout densities, although studies fail to agree on time trends for both species.

2. **If so, are these alterations detrimental to the function and productivity of those fish populations?**

Rainbow trout densities in Luscar Cr appear to have declined and in addition the low juvenile/adult ratios in this stream in recent years suggest that recruitment may be impaired, at least relative to the levels seen in reference streams. In addition, the increases in brook trout in Jarvis and Luscar Creeks may pose a bottleneck to rainbow trout recovery, since brook trout have similar food and habitat requirements to rainbow trout, and in addition, grow more rapidly and reproduce at an earlier age. The spread of introduced brook trout can pose a potential risk to native salmonid populations throughout the eastern slopes of Alberta, British Columbia, Montana and other U.S. states, and is therefore not an issue that is unique to the Athabasca region. However, differential Se mortality on larval rainbow trout where mines are operating may facilitate a switch to dominance by brook trout.

Answer to Q2:

While the trends reported are only marginally reliable from the statistical perspective, if the trends reported are real, then they are of a nature that should be considered detrimental to function and productivity, at least with respect to the native Athabasca Rainbow trout.

3. **What are the reason(s) for any alterations? (including but not restricted to selenium; all possible natural and anthropogenic factors [e.g., physical habitat changes] need to be considered).**

Some of the reasons for this variability were suggested in the presentations: in particular temporal trends are highly variable among adjacent drainages and temporal fluctuations are very erratic, and cannot be correlated with any simple measures of coal mining impact.

The changes in the fish community in Luscar Creek since 2000 that the Sterling report documents are, however, consistent with what would be expected on the basis of the elevated Se levels in the system. Firstly, the low juvenile/adult ratios in Rainbow trout would be expected if the elevated levels of Se were leading to reduced levels of recruitment in Luscar Cr. The average concentration of Se in rainbow trout eggs from Luscar Creek was 9.9 µg g ww, and these must be regarded as elevated levels since the egg Se thresholds for teratogenic defects in newly hatched larvae are in the range of 8.8-10.5 µg/g ww (Holm et al. 2005). In fact, rainbow trout larvae hatched from eggs obtained from Luscar Cr exhibited high levels of craniofacial, skeletal, as well as edematous defects (~30% in Luscar compared to < 15% in reference streams). If we were to assume that larvae with teratogenic defects have reduced viability, the apparent low abundance and low recruitment levels of rainbow trout in Luscar Creek are consistent with what we would expect on the basis of Se toxicity. Although the Sterling results are consistent with the explanation based on selenium toxicity, the statistical reliability of the time trends can be questioned, and in addition, there are plausible alternative explanations for the observations. As Schmidt points out the high level of uncertainty associated with quantitative fish surveys makes the establishment of time trends very difficult especially when the time interval under consideration is fairly short. Thus while Sterling reports a decline in Luscar Cr RT, and an overall increase in brook trout abundance, Allen reports no significant time trend in RT, and a sharp decline in brook trout abundance since 2003. Although the reports disagree on the time trend over the last decade, there is good agreement in regards to the overall low rainbow trout abundance in Luscar Creek (much lower than densities reported by Sterling in reference streams), and in regard to brook trout abundance being generally higher than rainbow trout abundance, which stands in sharp contrast to the low densities reported by Sterling in the 1980's. In addition to the problem of statistical uncertainty associated with the time trends, there are other plausible explanations that could account for low abundance and recruitment of rainbow trout in Luscar Creek. For example the washout of the large beaver dams from the lower reaches of the creek may have allowed many juvenile rainbow trout to migrate out of Luscar Cr into the McLeod R. Palace et al (2007) in their Laser ablation study of Se in rainbow trout otoliths showed that many of the trout spawning in Luscar Creek had not been reared in the creek, and were recent immigrants; consequently, it would be reasonable to expect that many of the rainbow trout born in the creek from these migrant parents, would migrate back out as juveniles. While the high proportion of immigrant rainbow trout observed spawning in Luscar Creek is consistent with the low juvenile/adult ratios, and this may be a reflection of demographic impairment resulting from Se toxicity, it must be kept in mind that many small stream populations that are linked to large rivers, depend on immigration of spawners that spend most of their adult lives in the main river.

Even if these effects were a reflection of adverse rearing conditions in Luscar Creek for juvenile rainbow trout, the adverse conditions may result from factors other than high Se exposure.

Luscar Creek has a long history of channel alterations resulting from past mining activities, together with the fact that it shares its channel with a railroad track. These channel alterations, although not recent, could easily have degraded the quality of the stream's nursery habitat for rainbow trout. As such, since the stream appears to have good spawning gravels in its lower reaches, such physical habitat alterations may have contributed to Luscar Creek having a weak resident rainbow trout population, while providing good spawning conditions for immigrant spawners from the McLeod River.

The report by George Sterling that brook trout have increased in Jarvis and Luscar Creeks and now dominate the community in these streams, may also be a reflection of the elevated Se exposure in these creeks since Holm et al. (2005) found no adverse effects of egg Se concentration on newly hatched brook trout larvae. Thus, if we assume that the dietary and habitat overlap between rainbow and brook trout are sufficient to make them competitors, then the more Se resistant brook trout might well be expected to increase in abundance while their Se sensitive competitor suffers impaired recruitment. While this explanation is consistent with the idea that Se exposure may be the driving factor, there are again alternative explanations. Firstly, brook trout have expanded their numbers in many eastern slope streams from Utah to B.C., and while the factors that contribute to this are not well known, it often occurs in streams that have low densities of native trout. Moreover, the rapid growth of brook trout, coupled to their rapid maturation, make them an excellent competitor that has displaced native salmonids from many western streams, without any 'help' from Se exposure or other mining related influences.

Answer to Q3:

Elevated levels of larval defects in rainbow trout from the Luscar Cr system are according to the analysis of Holm et al.(2005) directly attributable to the elevated Se levels in this stream. Many of the patterns reported in fish surveys, notably low rainbow trout densities, low ratios of juveniles/adults, and high brook trout densities are all consistent with the hypothesis that they result from selenium impairment of rainbow trout recruitment. However, since other plausible explanations cannot be ruled out, we cannot be sure that Se is behind these differences. Moreover the results of the stream fish surveys do not allow us to conclude with confidence that the elevated larval deformities in rainbow trout caused by Selenium are resulting in impacts on fish populations.

4. **If causation cannot be conclusively determined based on available data, what additional studies are required to establish causation?**

Answer to Q4.

The failure to definitively detect population level changes that can be causally linked to selenium, may not mean that such effects are not present, since the use of surveys on open streams to detect population level effects has inherent weaknesses. The SeFSP discussed the limitations of population monitoring data for drawing inferences about fish population responses, and their causes. A range of alternative approaches to monitoring that might prove more effective in teasing apart causal influences were discussed. These included mathematical modeling of salmonid populations on large spatial scales, involving the simulation of scenarios of expansion of mining within the watershed, and the testing of management options pertaining to salmonid communities as well as Se management.

There is also a need for more laboratory analysis of Se effects on fish involving whole-life-cycle experiments, in order to better understand how Se toxicity affects fish and to establish more reliable Se toxicity guidelines for environmental management. The panel also discussed the possibility of field experiments on a variety of spatial scales. Experimental manipulations could possibly overcome the problem of open-ended fish population structure because they could be applied on a spatially restricted scale to populations of fish that are constrained in flumes suitable for larval development experiments, in experimental channels suitable for juvenile rearing constructed next to Luscar creek (with a reference water source for a low Se concentration treatment), or on a larger scale, within sections of the stream closed to migrants from outside.

We expand on these topics below:

The statistical uncertainties inherent in fish surveys.

The first issue discussed was the statistical uncertainties associated with the survey data, a point raised both in the Allen report and in the Schmidt report, but while there are methods that can improve precision of estimates from individual sites, they are much more laborious and would generally reduce the spatial extent of the surveys, which would likely reduce precision overall. Habitat variables, e.g. depth, velocity, substrate characteristics can greatly affect the local distribution of fish, and while such data might be useful in interpreting fish survey data and the effects of habitat condition and quality on abundance, they were generally not consistently collected.

Thus it is virtually impossible to discern whether the patterns reported in monitoring studies are related to natural causes, or result from Se, other effects of mining, or from other unrelated anthropogenic influences. There was a general consensus that more information was required before any conclusions about causation could be definitively drawn; yet at the same time, there was also a strong feeling that too much effort was being allocated to monitoring owing to the uncertainties inherent in such data. The high level of ‘noise’ makes the ability to detect mine-related effects relatively low. Present monitoring does not have the power to detect possible Se-related effects to resident fish populations. The general consensus was that while changes can possibly be identified in monitoring surveys, causation cannot; moreover, perhaps that is all that we can really expect monitoring to accomplish, given the size and complexity of the systems involved. Indeed, Ham and Pearsons (2000) demonstrated that the statistical power of most stream fisheries surveys are too low to allow effects to be detected in time to limit potential impacts.

The open-ended spatial structure of river salmonid populations makes interpretation of stream survey data difficult.

In addition, to the problem of “noisy” data in monitoring surveys, another problem with the monitoring approach taken here is that it is focused on individual streams whereas fish life-histories are often not. Salmonid populations in unfragmented river systems generally consist of a complex of genetically distinct stocks (breeding units), that differ widely in their spatial scale of movement and life-history traits, but are generally morphologically indistinguishable (Hilborn et al. 2003). Each of these stocks is a valued ecosystem component and helps buffer the overall population against extinction (Allendorf et al. 2008). Many streams support both resident stocks that complete their life-cycle within the stream as well as migrant fish that move among streams and the river mainstem as well. Environmental changes that adversely affect one stream but not neighboring streams will therefore first impact resident fish much more than migrant fish that only use the stream part of the time. However, such impacts may go undetected in the stream population surveys since they may be compensated for or at least obscured by changes in numbers of migrants. Thus the inability to resolve stocks poses the same problem for the ecotoxicologist attempting to assess environmental impacts as it has long posed for fisheries managers, who have come to realize that harvesting of mixed stocks often puts individual stocks at risk in an undetectable way. Moreover, migrant stocks will not exhibit impacts until the spatial scale of the environmental effect approaches that of the stock, making such stocks too insensitive to provide the impact information on small scales in space and time that are required for appropriate management decisions. Thus the spatial structure of river salmonid populations makes small-scale impacts difficult to detect, exposing the population to the risk of large-scale cumulative impacts.

This population structure problem is particularly pertinent to Luscar Creek. The Laser ablation study of Palace et al. (2007) that traced the Se history in fish otoliths, showed that many of the trout that spawned in Luscar Creek had not been reared there, but were recent immigrants. The juvenile offspring of such migrant spawners usually migrate back out of the spawning stream at an early age. Thus the low juvenile/adult ratios in Luscar Creek might simply mean that juveniles migrate out early in their lives. Thus while it might be interesting to compare what is going on in Luscar or Jarvis Cr to “reference” streams such as Wampus or Deerlick Creeks, such a comparison may not shed much light on the impacts of mining. It cannot be assumed that

Luscar or Jarvis ever had “stable” resident rainbow trout populations comparable to these reference streams, and thus it is difficult to know what one can conclude from the changes that the monitoring studies have revealed. It is also possible that a significant fraction of the resident Luscar Cr fish population has already been sharply reduced as a result of the effect of Se on their reproduction, and that the influx of migrant fish to Luscar Cr makes impacts undetectable.

It is difficult to devise a monitoring program that reflects this type of open-ended spatial structure, especially as is usually the case, when the spatial and genetic structure of the population is not known. Moreover by the time such impacts are detected, it may be the whole McLeod R rainbow trout population that is impacted. Thus failure to detect potential population level impacts immediately and at small spatial scales, which with our present monitoring methods is likely, could ultimately prove very costly if the absence of evidence for population-level effects were interpreted as evidence of their absence.

The pertinent large-scale question is “How many streams can suffer Se related effects before the whole McLeod River rainbow trout population is impacted?” This large-scale question is very pertinent given the rapidly expanding area impacted by mining, and will require a multi-scale monitoring and modeling approach to address. Such an approach could be useful in modeling the costs and efficacy of implementing different management methods. In addition, such a model can be applied to a wide range of other resource management problems including logging effects and fish management problems related to species interactions between native introduced species such as brook trout, and to frame hypotheses concerning the types of changes we expect to see in space and time.

Failure to detect population level effects at small spatial and temporal scales can lead to large-scale cumulative impacts.

Ecological impacts on biological communities have usually been most readily detected using survey approaches where the scale of the impact is large, and are more difficult to detect with certainty at small scales. Conversely, failure to detect key impacts when their scale is small and amenable to management has sometimes allowed industrial operations to expand, ultimately leading to large-scale ecological catastrophes where the health of fish, wildlife, and even humans have been compromised, and massive restoration efforts are required. There are two aspects of the present situation that heighten our concern about a possible cumulative effects scenario. The mining footprint in the McLeod R watershed has increased dramatically over the last decade, and there is every reason to think that this might continue and even escalate. This means that more and more disturbed watersheds and end-pit lakes could be expected to begin discharging selenium-enriched water to headwater streams. Moreover, the present monitoring approach will make it difficult to detect and react to this growing footprint, for the reasons outlined above. The second reason for concern, which is closely tied in to the first, is the long time scale, associated with weathering induced disturbances to the selenium geochemical cycle, and the difficulty of controlling these processes once a disturbance has been initiated. Indeed selenium concentrations from a mined landscape are increasing gradually over time in both the Gregg R (0.5µg/L/yr) and in Luscar Cr (1.3 µg/L/yr) (Alberta Environment data 2009) and it may take many more years before loadings reach their peak. Therefore, as more and more mines are opened the scale of the process can have expanded from a few small streams to a significant portion of a drainage system before the loadings from initially disturbed areas have reached their peak and begun to subside.

Evidence of this time-delayed loading effect leading to a large-scale concentration increase can be seen in Elk River, which supports a highly valued recreational fish resource. While the Selenium Status Report (Golder Associates 2007) stresses the low overall level of impact of selenium loadings to the Elk River biota, there is the nagging reality (Figure 11 of the Golder Report) that selenium concentrations (and annual loading rates) to the river from the five mines in its watershed, have increased gradually by 1µg/L per decade (Golder Associates 2007). While at present selenium levels in cutthroat trout and other aquatic biota have not reached critical levels, if this long-term increase continues, and we have no reason to think that it will stop, the impact on the fish would likely span the entire Elk R and possibly the lower Kootenay River as well. Meanwhile, the low level of present impacts are being used to justify an expansion of mining, both within Elk system and to neighboring systems such as the Flathead R, which drains south into Montana near Glacier National Park, where highly valued fish resources are present. Therefore given the broad spectrum of biotic impacts that Se can have, and the difficulty of detecting effects on small scales of space and time, there is every reason to consider the possibility of large-scale health impacts on a broad range of fish and aquatic wildlife, with potential human impacts arising both from exceedance of health based drinking water quality quidelines (0.01 mg/L, Health Canada 2006) as well as fish consumption (Health Surveillance, Alberta Health and Wellness Report). At the very least, the potential for these impacts argues for the development of a large-scale spatially explicit modeling tool that can evaluate the downstream and cumulative impacts of different mining scenarios throughout a watershed at decadal time scales.

The potential role of field experiments

While laboratory studies have always played a large role in environmental science even though they have limited realism, they can compensate for this with high precision and control of variables. The discussion focused on field experiments and how they could be applied on a variety of spatial scales. The advantage that such approaches presented was that they could be applied on a spatially restricted scale to populations of fish that are constrained to enclosure flumes or experimental side-channels, or on a larger scale, within sections of the stream closed to migrants from outside. As such this approach would in principle overcome the problems of spatial open-endedness that plague stream monitoring studies as discussed earlier. Questions such as "How much do teratogenic defects, such as the craniofacial defects, skeletal defects and edema that are linked to Se toxicitiy, reduce the viability of rainbow trout fry?" could be addressed within stream channel enclosures. Such experiments, regardless of the scale on which they are attempted, will of course present many technical and methodological challenges, both pertaining to the control of treatment variables (eg Se concentration in water and food organisms utilized by fish within enclosed stream sections). Besides the fact that they are very labour intensive and must be monitored intensively, there is also the problem of interpreting the data that they yield. While swim-up and early fry stage growth and development, and interactions with other species can be studied in braided experimentally manipulated flumes, how does one deal with the later fry or parr stages? These fish need to select habitats over larger scales, and containment would likely generate behavioural artifacts, collectively known to experimental ecologists as "container effects". Such artifacts become even more pronounced as fish grow to adulthood and express habitat selection on larger spatial scales, and spawning sites and mates as well. It is possible that such studies could be carried on in streams that are entirely fenced; however, the time scales of such experiments are likely to be limited by flood events.

As a result it would appear that field experimental approaches will likely be limited to a few months duration, and as such, will never be able to encompass the whole life-cycle of any salmonid fishes. Nonetheless, it was thought by most members of the SeFSP that, for a modest investiture of funds and resources, some meaningful results pertaining to effects of Se on fish populations, and also effects of species interactions between rainbow and brook trout, could be obtained. Moreover, it was thought that such field experiments, could help fill in the spectrum between field monitoring and laboratory studies, and provide an intermediate scale where reasonable control over variables is possible, and a reasonably high degree of field relevance is obtained. In addition to the experimental flume studies, it was thought that brook trout removal from sections to see how rainbow trout respond would be useful.

Thus the panel and the workshop participants discussed a variety of options surrounding the general topic of monitoring, whether to do more monitoring or less, or how to modify the approaches to address some of the problems that prevent us from obtaining useful information from the monitoring program. In general, however, the SeFSP felt that the present monitoring, while not really capable of providing much conclusive evidence of causation, did detect some changes in populations that could be useful. While population monitoring studies were not capable of conclusively confirming that Se impacts on populations in Luscar Creek were present, it could not conclusively refute them either. The panel felt that while it might be possible to carry out more definitive studies that produce clearer results, that this would take years, and that there was an immediate need to proceed on the basis of the weight of evidence (WOE) already in hand.

DISCUSSION OF POTENTIAL MANAGEMENT APPROACHES

While the main focus of this panel was not on management or removal technologies there was a great deal of interest in this topic both among the panel members, several of which have limnological expertise, and among the workshop participants. There was also a general feeling among both panel members and participants that important population level effects were going undetected in stream fish surveys, and that the risk of a cumulative effects scenario was significant. Because of this the panel focused attention in an evening session on selenium removal technologies. While the discussion was mostly exploratory, a broad range of chemical and biological techniques for selenium removal were discussed, in particular their relative applicability to Se removal from end-pit lake drainage. While AENV participants put forward a variety of ideas relating to Se removal based on reduction techniques citing results of a report by Sobolewski (Microbial Technologies Inc, 2004) which favoured microbial bioreactor technologies, industry participants expressed most interest in techniques involving direct source control involving capping of waste rock and water diversion from rock dumps. Many participants felt that research on the implementation of such technologies should be pushed forward as rapidly as possible using an adaptive management approach to evaluating mitigation techniques, with the rationale that any reasonable course of action that might mitigate such risks, and at the same time, contribute to the growth of our knowledge about how to identify and deal with these types of mining impacts, should be pursued. Others felt that there were insufficient data showing Se impacts on populations to support the level of expenditure that this would involve.

There were very divergent opinions among the participants as to whether or not it was necessary to consider the implementation of technologies to remove Selenium from surface drainage entering streams, and in many ways the viewpoints expressed in regard to the necessity for mitigation crystallized the debate. Much of this difference of opinion was centered on where actually the "Weight of Evidence" was pointing. We will paraphrase two extreme viewpoints that reflect the divergent views. The first of these can be represented as follows:

"We know from published field/laboratory studies that have already been done on streams in this area, that Se exposure is high enough in some of the streams to cause substantially elevated levels of larval defects in rainbow trout and thus we should consider these populations to be at risk. We also have evidence that suggests that the Se exposure regime in affected creeks might be enhancing the spread of an exotic competitor, the brook trout, which has had adverse effects on native salmonids in many Alberta streams. We have some observations from our monitoring surveys that indicate that such adverse effects might be occurring; however, we cannot rule out plausible alternative explanations. Neither can we conclude from the data that there are no effects, since we are aware that such data are noisy and "effects" can easily go undetected. Since our field/laboratory studies give us reasons to suspect that populations may be at risk, and our field monitoring can't conclusively show that they are not, it would be prudent to go forward as though there is a problem, and one that may grow in scope in the future, and try to initiate measures that can reduce Se loading to streams where potentially hazardous exposure exists"

The counter-view to this can be paraphrased as follows:

The studies that have been done, though peer-reviewed and published, do not provide us with sufficiently well established guidelines to make sound judgments about levels of Se exposure that would be required to place fish in our streams at risk of teratogenic defects. There are particular weaknesses in the analysis of the Holm et al (2005) study that compromise the results and make it unwise to conclude that the elevated Se exposures seen in creeks like Luscar that receive Se-rich drainage are sufficient to place the rainbow trout at risk. This can be seen from the fact that rainbow trout, brook trout and bull trout succeeded in establishing populations in Lac Des Roche, and established a spawning run in the outflow stream (West Jarvis Creek, during 1991-98 (Schwartz and Allan 1999). In addition to this, the idea that brook trout might be enhanced through Se impacts on rainbow trout, is also not well supported by the data in this study, even though many have drawn that conclusion, and moreover, brook trout become established to the detriment of native species in many eastern slope streams where no mining impacts have occurred. Other studies on cold-water fish have published much higher teratogenicity thresholds than those published by Holm et al. and, in the light of the uncertain picture that these studies present, we have no basis for considering fish to be at risk at the Se exposure regimes we see in the study area. We have also seen that the monitoring results cannot establish any firm causal links between reductions in population density or recruitment indices and mining related elevations in Se levels. For this reason there is no basis for suggesting that money and resources be allocated to measures aimed at reducing Se loading to streams from surface drainages”.

These two views are clearly very divergent and any attempt to discuss the possible need for management approaches would not likely find much common ground between these two views. The “cleavage point” between these two views is clearly the validity of the Holm et al (2005) Se exposure guidelines for teratogenic effects, which indicated that rainbow trout are a very Se sensitive species, and that that brook trout are much less so. Peter Chapman indicated that several people on the Golder Associates staff (See the Learned Discourse of McDonald and deBruyn, 2008) who had scrutinized this study closely had found weaknesses in the analysis. Because of this, he requested that the panel devote some effort to examining this study, and if possible, to reanalyzing the data in the light of some of the weaknesses he suggested might be present. The SeFSP agreed that this study was indeed pivotal and we were able to obtain the data set through the co-operation of Dr.Vince Pallace (DFO Winnipeg) we re-analyzed it in such a way as to deal with some of the potential issues in the make-up of the data set. We present this analysis in the following section of the report in the hope that we could either confirm the validity of the Holm et al (2005) analysis or reject it as a basis for making management decisions concerning the risks of Se exposure in this area.

REANALYSIS OF THE HOLM ET AL. (2005) DATA SET

Review of some selenium toxicity studies and the debate over implementation of toxic effect guidelines.

Studies have revealed considerable variation in toxicity thresholds—usually among species but sometimes even within species, and hence there is thus considerable controversy over toxicity guidelines. The first teratogenic deformity index based on tissue Se residues was that of Lemly (1997), which were based on bluegill sunfish, channel catfish and fat-head minnows, and based on subsequent studies by Lemly the USEPA established a tissue Se criterion (7.9 µg/g dw, which corresponds to ~17µg/g dw in eggs). Most studies carried out in more northerly locations on salmonids, pike and suckers did not show deformations at this level of exposure, and there is a general sense that "cold-water" fish are more selenium tolerant than "warm-water" fish. While Se tolerance has not been studied in very many species, and thus we cannot really say how true this generalization is, even a relatively low deformation thresholds identified in a salmonid such as that of Holm et al (2005) for rainbow trout (EC_{15}= 9µg egg Se/g ww~36 µg egg Se/g dw) is significantly higher than those reported by Lemly. A very similar value was reported for northern pike (EC_{20}= 34µg egg Se/g dw and 22 µg muscle Se/g dw, Muscatello et al. 2005) whereas still other studies on salmonids failed to detect any deformation thresholds over similar Se exposure regimes (Holm et al (2005) on brook trout, and Kennedy et al (2000) on westslope cutthroat trout, and deRosemond et al (2005) on white suckers). Thus while there is a general consensus that the criteria developed by Lemly and advocated by the USEPA are very conservative for salmonids, pike and suckers, the high level of variability in Se sensitivity seen in these studies leave a great deal of room for debate on exactly what the toxic threshold level for Se should be in a given situation, and also, whether site-specific environmental factors may affect Se toxicity.

With respect to the Athabasca rainbow trout, the study of Holm et al 2005 indicate that the average egg Se concentrations in rainbow trout obtained from Luscar Cr (where Se levels are elevated) were significantly higher than those from reference streams, and moreover, that larval rainbow trout that hatched from eggs with elevated Se levels (mostly from Luscar Cr) had significantly higher frequencies of teratogenic defects. Using probit models, Holm et al (2005) reported statistically significant residue (µg/g ww Se in eggs) –response relationships in rainbow trout for three different types of abnormalities (craniofacial defects, skeletal defects and edema). The study reported threshold values for a 15% teratogenicity response ranging from 8.8-10.5 µg Se/g ww in eggs. These analyses were carried out on egg clutches (~90-300; this number was not stated in the Holm et al (2005) paper, but is based on a personal communication from Vince Palace) stripped from spawning females in the field, from streams with different concentrations of Se in their water and biota and subsequently fertilized and reared in the laboratory until hatching, at which time all larvae from each clutch were scored for 4 different types of teratogenic defects. A sample of eggs from each clutch were measured (ICPMS) to determine the egg Se concentration for each clutch, and this value was related to the percentage of larvae expressing each of the four different defects. In contrast to the results for rainbow trout, the study reported no significant residue-response relationships for brook trout from the same creeks, in spite of the fact that these fish had similar selenium exposure regimes, although the range of egg Se residues were slightly lower for brook trout than for rainbow trout. The brook trout were analyzed using the same probit analysis procedures, and their egg clutches were handled and the larvae scored with the same procedures as the rainbow trout. While some differences between Luscar Cr and reference streams were reported for brook trout (craniofacial defects were significantly elevated in Luscar Cr relative to Cold Cr), these differences are much lower in magnitude than those reported for rainbow trout, and were not statistically significant for % edema, finfold, or skeletal defects.

The greater sensitivity of native rainbow trout to Se raises the concern that Se may be contributing to low rainbow trout recruitment and indirectly to a gradual increase in brook trout abundance, which were the trends that George Sterling‘s monitoring results had identified. See Holm et al (2005) for details pertaining to collection, sampling and analytical procedures used in the study.

McDonald and deBruyn (2008) argue that the Holm et al study is flawed because the rainbow trout data set included values from 3 clutches whose Se concentrations (>20 µg Se/g ww) were beyond the range represented in the brook trout data set. They assert that the dose-response relationship obtained for the rainbow trout was “defined” by these extreme values, and that if these values were omitted from the analysis the response thresholds obtained would have been “much less convincing”. While they did not assert that the rainbow trout residue-response relationship obtained in the Holm et al. (2005) probit analysis were “spurious”, they did assert that the failure to detect a significant residue-response for brook trout may have been due to the narrower selenium range tested (no brook trout clutches exceeded 18 µg Se/g ww). Thus McDonald and deBruyn (2008) assert that the data do not allow us to conclude that brook trout are less sensitive to Se in their eggs than rainbow trout.

Since the panel considered the Holm et al. study to be pivotal to our discussion, and since these issues had been raised concerning its methodology we undertook a re-analysis of the Holm et al data set based on a weighted logistic regression method designed to overcome possible leverage and skewing effects of extreme values, in order to determine whether the concerns voiced by McDonald and deBruyn have merit, and thus weaken the conclusions that can be drawn from the study. The logistic regression method minimized the following optimal estimating function based on the weighted least squares criterion:

$$\sum_{i=1}^{n} \hat{p}_i (1-\hat{p}_i) \left\{ \log \frac{\hat{p}_i}{(1-\hat{p}_i)} - X_i \beta \right\}^2$$

where $\hat{p}$ = the proportion of larvae with a given type of defect, and $X_i\beta = \beta_{0j} + \beta_1 S_i + \beta_2 SP_i$ or any other model that we considered. This weighted criterion ensures that values of $\hat{p}$ close to 1 or 0, will have negligible weights, which removes the skewing effects caused by values with $\hat{p}$ near 0 or 1 and ensures that the residuals from this model will be approximately normally distributed. This weighted optimality criterion also satisfactorily dealt with the issue of egg Se values > 20 ng/g in the rainbow trout data set, since all had $\hat{p}$ =1, and therefore received a weighting of 0 in the analysis. In addition to this, we performed analyses where only clutches with Se values < 20 ng/g were retained (that is, the three high rainbow trout values queried by McDonald and deBruyn were excluded), and in these analyses the statistical parameters for the rainbow trout and brook trout egg Se concentrations were very similar. Since these high Se clutches received 0 weighting, models obtained with and without these values, were essentially identical, and below we report only on the analyses from which they were excluded.

The dependent variables in the Holm et al. (2005) data set were the $\hat{p}$ = the proportion of larvae with a given type of defect, and does not include the raw numbers of larvae. Since the authors have assured us that all estimates were based on full egg clutches (90->300 eggs) we estimated based on binomial probabilities that the precision levels associated with these $\hat{p}$ estimates would have been >95%. That is, their coefficients of variation would range from 2-5% of the $\hat{p}$ estimate, and for this reason, to have included a weighting factor for the precision of each estimate into the logistic regression would have had a negligible effect on the coefficients obtained. For this reason we carried out our logistic regressions using $\hat{p}$ estimates supplied to us by Vince Palace, and saw no reason to request the raw larval numbers from the authors.

Notation:

Y_{ij} : Number of Type j defective eggs for the i-th individual (j=1,2,3,4; i=1,2,…,I)

N_i : Number of eggs laid by the *i*-th individual

S_i : Amount of selenium found in the tissue sample of the *i*-th individual

SP_i : Species indicator for the *i*-th individual (1=Rainbow trout, 0=Brook Trout)

Assume that $Y_{ij} \sim Binomial(N_i, p_{ij})$ where p_{ij} denotes the probability that an egg from the *i*-th individual will have defect type j. That is, $\hat{p}_{ij} = Y_{ij} / N_i$.

Statistical analysis:

We consider following models for p_{ij} in order to assess the extent to which different types of defects are affected by exposure to selenium.

Model 1: We start with a simple model to see if the amount of selenium exposure affects the probability of defective larvae. We fit a different model for each of the species, Rainbow trout and Brook trout.

$$\log\frac{p_{ij,BT}}{(1-p_{ij,BT})}=\beta_{0,BT}+\beta_{1,BT}S_i$$

$$\log\frac{p_{ij,RT}}{(1-p_{ij,RT})}=\beta_{0,RT}+\beta_{1,RT}S_i$$

If the coefficients related to Se exposure are significant, it implies that Selenium exposure affect the proportion of defects.

Model 2: Next we would like to address the Se effects and species effects within the same model; for this we need to fit both a species effect (SP_i=1 for brook trout and 0 for rainbow trout) to estimate the differences in intercept between rainbow trout and brook trout, and an S_i*SP_i (interaction term) to estimate the differences among rainbow trout and brook trout in response to Se. Both these terms are necessary since the single species models indicated that rainbow trout and brook trout differed both in their intercepts and in their slopes. The model fitted was

$$\log\frac{p_{ij}}{(1-p_{ij})}=\beta_{0j}+\beta_1 S_i+\beta_2 SP_i+\beta_3(S_i * SP_i)$$

The interaction coefficient tells us if the selenium response of brook trout and rainbow trout are different.

Fitting procedure:

We fitted the models in JMP 5.1 ® by minimizing the weighted least squares criterion:

$$\sum_{i=1}^{n}\hat{p}_i(1-\hat{p}_i)\left\{\log\frac{\hat{p}_i}{(1-\hat{p}_i)}-X_i\beta\right\}^2$$

where $X_i\beta=\beta_{0j}+\beta_1 S_i+\beta_2 SP_i$ or any other model that we considered.

These analyses were conducted both with the complete data set, as well as after removing the three high selenium exposure points for the rainbow trout. The results of the analysis presented in the following tables are those with the three high rainbow trout Se values removed. Tables 1-4 correspond to four defects in Brook trout, tables 5-8 correspond to four defects in Rainbow trout and Tables 9-12 correspond to four defects and model without interaction.

Table 1a: Brook trout-Craniofacial defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.27	0.34	-6.74	<0.0001
EggSe	0.018	0.04	0.36	0.722

Table 1b: Brook trout-Skeletal defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.23	0.34	-9.45	<0.0001
EggSe	-0.01	0.05	-0.24	0.811

Table 1c: Brook trout-Finfold defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.34	0.47	-7.02	<0.0001
EggSe	0.10	0.07	1.32	0.190

Table 1d: Brook trout-Edema

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.94	0.41	-7.03	<0.0001
EggSe	-0.10	0.07	-1.39	0.175

Table 2a: Rainbow trout- Craniofacial defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.76	0.27	-10.20	<0.0001
EggSe	0.20	0.04	5.21	<0.0001

Table 2b: Rainbow trout- Skeletal defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.45	0.29	-8.81	<0.0001
EggSe	0.17	0.04	4.30	<0.0001

Table 2c: Rainbow trout-Finfold defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-1.51	0.47	-3.22	<0.0001
EggSe	0.034	0.06	0.55	0.586

Table 2d: Rainbow trout- Edema

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.99	0.30	-10.1	<0.0001
EggSe	0.25	0.04	6.09	<0.0001

Comparison of brook trout and rainbow trout models:

(1) Selenium has significant effects on the proportion of defects in Rainbow trout, with the exception of finfold defects, but no significant effects on the proportion of any of the four types of defects in brook trout.

(2) The standard errors of both the intercepts (0.34-0.47 for brook trout & 0.27-0.47 for rainbow trout) and the regression coefficients (0.04-0.07 for brook trout & 0.04-0.06 for rainbow trout), and therefore the detection limits for the two species analyses, are very similar. Thus the non-significant regression coefficients for craniofacial defects, skeletal defects and edema in brook trout are significantly different from those obtained for rainbow trout (t=3.8, 3.6 and 4.4 respectively), which means that the absence of Se effects in brook trout were **not due to the inability of the analysis to detect them.**

(3) For two of the defects, the intercepts were significantly lower for brook trout than for rainbow trout. For skeletal defects the brook trout intercept was -3.23 vs -2.45 for rainbow trout (t=--2.9), and for finfold defects the brook trout intercept was -3.34 vs -1.51 for rainbow trout (t=-4.1). Thus for two types of defects, **rainbow trout exhibited a higher background deformity rate than brook trout**.

Interaction effect models:

Table 3a: Interaction effect models – Craniofacial defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.51	0.22	-11.5	0.0000
Selenium	0.11	0.03	3.47	0.0008
BT	-0.31	0.10	-2.79	0.0064
(Se -5.96)*BT	-0.093	0.03	-2.92	0.0043

Table 3b: Rainbow trout- Craniofacial defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.72	0.22	-12.36	0.0000
Selenium	0.203	0.03	5.97	0.0000

Table 3c: Brook trout- Craniofacial defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.23	0.258	-10.558	0.00
Selenium	0.017	0.03	0.566	0.55

Table 4a: Interaction effect models – Skeletal defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.97	0.25	-12.08	0.0000
Selenium	0.052	0.034	1.51	0.1348
BT	-1.19	0.12	-9.00	0.0000
(Se-6.14)*BT	-0.14	0.034	-4.10	0.0001

Table 4b: Rainbow trout- Skeletal defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.75	0.25	-11.0	0.0000
Selenium	0.19	0.034	5.58	0.0000

Table 4c: Rainbow trout- Skeletal defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.20	0.258	-12.4	0.0000
Selenium	-0.08	0.045	-1.77	0.21

Table 5a: Interaction effect models – Finfold defects

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.97	0.44	-6.82	0.0000
Selenium	0.006	0.066	0.09	0.93
BT	-0.94	0.22	-4.38	0.0001
(Se-5.88)*BT	-0.052	0.066	0.79	0.53

Table 5b: Rainbow trout- Finfold defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-2.33	0.44	-5.29	0.0000
Selenium	0.057	0.066	0.86	0.91

Table 5c: Brook trout- Finfold defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.61	0.258	-12.4	0.0000
Selenium	-0.04	0.06	-0.66	0.45

Table 6a: Interaction effect models – Edema

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.69	0.31	-11.98	0.0000
Selenium	0.10	0.044	2.26	0.0269
BT	-1.41	0.15	-9.53	0.0000
(Se-6.00)*BT	-0.22	0.044	-4.95	0.0000

Table 6b: Rainbow trout- Edema defects based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.58	0.44	-8.13	0.0000
Selenium	0.32	0.05	7.27	0.0000

Table 6c: Brook trout- Edema based on Interaction model

Parameter	Estimated value	Standard error	t-statistics	p-value
Intercept	-3.80	0.44	-8.63	0.0000
Selenium	-0.10	0.05	-1.81	0.24

Conclusions regarding Interaction effect models:

(1) Selenium effects and background deformity rates from models with interaction terms essentially replicate those obtained from single species models.

(2) The selenium effects in these models are usually not statistically significant, however the Se*SP interaction term was always highly significant (-) with SP as the categorical variate. Thus the rainbow trout selenium effect was highly significant for craniofacial defects, skeletal defects and edema, but not for finfold defects, and for brook trout the selenium effect was not statistically significant in any of the models..

(3) The strongly negative Se*SP interaction effects for craniofacial defects, skeletal defects and edema in brook trout were all highly significant which reinforces the point that the absence of Se effects in brook trout are real, and **not due to the inability of the analysis to detect them.**

(4) For skeletal defects, finfold defects and edema (but not for craniofacial defects) the brook trout intercept was significantly more negative than the rainbow trout intercept. Thus the interaction effect models support the conclusion drawn from the comparison of the

rainbow trout and brook trout models, namely that **rainbow trout exhibited a higher background deformity rate than brook trout** for skeletal and finfold defects.

Discussion and Conclusions from the Re-analysis of Holm et al (2005)

The weighted logistic regression analysis revealed patterns that were largely consistent with the Probit analysis of Holm et al. 2005 and shows that the relationship between larval defects in rainbow trout and their egg Se concentrations are very strong, whether or not the three highest rainbow trout clutches were included. The weighting algorithm assigned 0 weights to proportions at 0 or 1 (and very low weights to proportions near 1 or 0) and as such prevents many of the problems normally associated with fitting logistic or probit models. Values near 0 or 1 will have skewed residuals, which will bias regression slopes, and violate normality assumptions of linear regression analysis, and none of these problems occurred with our weighted algorithm. The EC_{20} threshold obtained from inverse prediction of our rainbow trout models were 7.5±0.7 µg Se/g ww for craniofacial defects, 7.3±0.8 for skeletal defects, and 7.6±0.7 for edema. Thus our weighted logistic regressions returned Se toxicity thresholds that were somewhat lower than those reported by Holm et al. (2005); they reported EC_{15} values of 8.8-10 µg Se/g ww. This analysis clearly demonstrates that the models obtained by Holm et al. demonstrating toxic effects of egg Se were not in fact being driven by a few extreme values (rainbow trout values > 20 ug Se/g ww). Not only are these points not driving the models, the slopes obtained in our weighted models, which assigned zero weights to these values, returned steeper slope estimates leading to lower estimates of toxicity thresholds. The fact that estimates near 0 tend to have positively biased residuals, whereas those near 1 tend to have negatively biased residuals leads to a downward slope bias, and a somewhat higher threshold estimate.

Although a wide range of environmental factors are known to be contributing factors to larval deformities such as those dealt with in the Holm et al (2005) study (e.g. Kruse and Webb 2006), our re-analysis of their data indicate that three different kinds of larval deformation had effects thresholds at 7.3-7.6 (μg/g). While the data do suggest that some amongstream differences in baseline deformation rates may exist, a larger data set would be necessary in order to adequately explore these effects. The analysis however clearly indicates that Se contamination is the major contributing factor to the the high incidence of deformations seen in rainbow trout from the Luscar Cr system. While this would suggest that rainbow trout recruitment should be impaired in this system, the observation that Lac Des Roches became colonized by a population of several hundred rainbow trout that spawned in the lake outflow stream, was purported by some as evidence that rainbow trout could establish a self-sustaining population (at least in lakes) in spite of elevated Se concentrations. The data however do not support the contention that rainbow trout populations were being maintained by their own spawning; in fact, egg hatching success rates were very low due to fungal infections, very few newly hatched young were caught in fry traps, and the size and age structure in the population indicates that the young of the year age class of rainbow trout was missing. The absence of young-of-the-year rainbow trout suggests, instead, that that the population was being sustained by immigration from downstream, although this aspect was never investigated. Brook trout, on the other hand did appear to be spawning successfully since young of the year were generally present, and more fry were captured in fry traps, thereby supporting the inference of differential Se impacts on larval survival.

This analysis also demonstrates clearly that the absence of a relationship between the same larval defects in brook trout and the concentrations of Se in their eggs was not due to a narrower range of egg Se concentrations. The weighting algorithm lead to very similar parameters of egg Se concentration for rainbow trout and brook trout; for brook trout the mean egg Se concentration was 5.98, with st dev 0.8, and values ranged from 0.4-18.9, for rainbow trout the mean egg Se concentration was 5.94, with st dev 1.0 and values ranged from 0.1-18.3, and thus their distributions were virtually identical. Moreover, the standard errors for the slope and intercept parameters for brook trout were very similar to those obtained for rainbow trout in both the single species and the two species interaction model, which means that the power of the analysis to detect a Se effect for brook trout was the same as that for rainbow trout. Another way of saying this is that the brook trout data were no more “noisy” than the rainbow trout data, and as such, had a relationship between defects and egg Se existed for brook trout it would have been just as easy to detect in the analysis as the effect for rainbow trout.

By testing the data for the two species together within the same model (two species interaction model, Tables 3-6), we were able to test for the significance of the species differences in both intercepts and slopes within the same model. The analyses for craniofacial, skeletal and edema defects all revealed strongly significant egg Se effects for rainbow trout, and no effect for brook trout. The interaction term and the brook trout effect in the two species interaction model were highly significant (negative) which would not have been the case had the species differences been obscured by noisy data. We can thus safely conclude that under the Se exposure regimes occurring in Luscar Creek, there is a statistically significant elevation of teratogenic defects in newly hatched rainbow trout larvae, and that for the same egg Se exposure, brook trout experienced no increase in the frequency of teratogenic defects. Although the analysis cannot produce an estimate of the egg Se exposure threshold for brook trout, we can safely conclude that brook trout are significantly less sensitive to egg residues of Se than rainbow trout, as Holm et al. (2005) suggested. While this species difference in sensitivity would support the idea that Se toxicity could be a contributing factor to the spread of brook trout in the McLeod system, it should be noted that species invasions and replacements are often influenced by many factors operating simultaneously. Thus the fact that brook trout have been successful in establishing themselves in several streams of the McLeod R system (e.g. Cold Cr) and many other river systems as well, where no mining influences are present, does not in any way reduce the potential importance of Se as a contributing factor to the spread of this exotic.

The analysis also raises a point not brought out in the Holm et al. (2005) analysis, and that is that in addition to being more sensitive to egg Se residues than brook trout, for two of the four types of larval defects, rainbow trout have a significantly higher background deformity rate than brook trout (as judged by their zero Se intercepts). This raises the possibility that the greater sensitivity of rainbow trout to egg Se residues, may be linked to an overall weaker level of developmental homeostasis.

How the SeFSP weighed evidence to arrive at our conclusions.

In arriving at its conclusions the SeFSP weighed evidence from all available sources, and considered the evidence for elevated Se exposure, Se effects, population level impact, both at present and potential impact. At each level we attached weight to evidence on the basis of both its level of certainty, and in relation to the scale of any potential ecological cost, that we perceived to be present.

Thus we are confident that Se concentrations in the McLeod R and the tributaries whose watershed are exposed to mining activities have risen, and as well we are very confident that there is a high likelihood that that they will continue to increase in the future if no remedial measures are taken. Based on our re-analysis of Holm et al (2005) we are very confident that this exposure regime is presently having effects (elevated frequency of larval deformities) on rainbow trout in the Luscar Cr system, likely in the Gregg R. system as well, and that the scale of these effects will likely expand with time given the likelihood that Se exposure is increasing.

We cannot definitively assess whether this effect is translating into a population level impact. While monitoring studies have presented some evidence that is consistent with the idea that Se induced effects may be having adverse effects on populations of rainbow trout, the level of certainty associated with all of these observations is quite low, given the difficulties associated with these type of monitoring surveys. There are also several plausible alternative explanations for such observations that cannot be ruled out. Surveys tend to agree that over the last two decades brook trout has become the most abundant species in the Luscar Cr system, and while this would be consistent with the lower sensitivity of this species to Se induced deformities, there are again other plausible explanations.

While we cannot accurately determine whether there is a population level impact, there is nothing in the monitoring data that can make us certain that there is no population level impact.

We have a high degree of confidence that rainbow trout densities in Luscar Cr are much lower than in some of the reference streams, and even if they are stable at such a low level (as one monitoring survey suggests), this provides no basis for dismissing the possibility of population impacts. The observations that a “self-sustaining “ population of rainbow trout existed for several years in Lac Des Roche and its outflow stream West Jarvis Creek is not convincing in that there is no solid evidence that it was being maintained by successful spawning (as opposed to recruitment of immigrants from downstream). Moreover, even if the recent reduction in brook trout abundance in Luscar Cr reported by the Allen study is in fact true, brook trout still remain more abundant than rainbow trout in Luscar Cr. and its tributaries, and as such this evidence cannot be used to rule out a significant brook trout impact on rainbow trout.

Thus while we are not confident that the Se effects on rainbow trout reproduction translate into a population level impact, it is consistent with observed changes in rainbow and brook trout abundance, and we are even less confident that we can rule this out since failing to detect such effects when they are actually or potentially present can entail significant potential risks for future large-scale impact on the whole river system.

1) **SeFSP CONCLUSIONS:**Holm et al. (2005) showed that Se exposure in Luscar Creek is high enough to cause elevated levels of teratogenic defects in rainbow trout, and our re-analysis of their data confirms, and in fact strengthens, this assertion. Notwithstanding the large variability in published Se toxicity guidelines for cold-water fish, and the debates about whether guidelines should be based on egg Se residues, muscle, or whole body residues, or whether they should be standardized to dw or ww or total protein, the

analysis demonstrates that in Luscar Creek rainbow trout teratogenic defects are occurring at significantly elevated rates relative to reference streams, and that the Se exposure regime is the causative agent. As such, this population should be considered to be *at risk* from elevated Se exposure resulting from endpit lake drainage into Luscar Creek.

2) Our assertion that the rainbow trout population in Luscar Creek is at risk does not mean that we can definitively conclude that there is a demonstrable impact at the population level. While we have some observations from our monitoring surveys that indicate that such adverse effects might be occurring, we cannot rule out other plausible explanations. We can however, assert that we would expect that significantly elevated rates of larval deformities should have an adverse effect on population recruitment and ultimately abundance, and while monitoring data cannot conclusively confirm this, they cannot deny it either, since we are aware that such data are noisy and that biologically meaningful "effects" can easily go undetected.

3) Most of the spawning rainbow trout that spent their life in Luscar Creek have elevated levels of larval deformities. The average rate observed in the Holm et al study was 33% and this includes a significant fraction of egg clutches from fish that were recent immigrants to the creek. While this defect rate should be expected to reduce recruitment to the fry population of rainbow trout in this creek, this could potentially be counteracted by a compensatory increase in survivorship of healthy fish. Given however, that brook trout (a competitor with rainbow trout for resources in the creek) will preferentially

benefit from any compensatory effects of lower density since they are significantly less sensitive to Se, it is very likely that brook trout will exacerbate the effect negative of Se on rainbow trout recruitment and that Se is in fact contributing to the spread of this exotic species in the McLeod River system.

SeFSP RECOMMENDATIONS:

Because the risk to fish posed by Se-rich discharges is likely to grow as more end-pit lakes begin to discharge into headwater streams, the panel recommends:

I. Research be initiated on population level effects of Se involving a multi-scale modeling/monitoring approach. This would involve simulation of scenarios of the expansion of mining into the watershed, and help to answer the cumulative impacts question “How many creeks need to suffer impacts of Se before the entire McLeod River rainbow trout population is at risk. The approach would also allow the simulated implementation of a variety of management options pertaining to the salmonid communities in the river including rainbow, brook and bull trout. Such models can tell us a lot about the types of changes that we might expect to see, the landscape thresholds where cumulative impacts will be triggered, and the time and spatial scale on which we might expect to see them. They will also be effective management tools to help guide development decisions so as to keep Se levels below impact thresholds at a landscape scale.

II. Laboratory experiments aimed at rearing both rainbow trout and brook trout in the laboratory through the gonadal recrudescence cycle under chronic exposure to Se contaminated food. Such experiments would yield more information on the mechanisms involved in Se toxicity and help to understand why species differences exist, and help to define more precise Se toxicity thresholds useful for environmental management.

III. Field experiments to examine the effect of Se induced defects on swim-up and subsequent viability of rainbow trout fry. The advantage that such approaches presented was that they could be applied on a spatially restricted scale to populations of fish that are constrained in enclosure flumes, or on a larger scale in constructed side-channels or within sections of the stream closed to migrants from outside. As such this approach would in principle overcome the problems of spatial open-endedness that plague stream monitoring studies.

IV. Experimentation with all available technologies with the aim of reducing Se loading to tributary streams. This should include both technologies aimed at Se removal from water, as well as biogeochemical experiments aimed at developing technologies to reduce the Se concentrations in end-pit lakes, and that mining companies be major participants in this research, both intellectually and financially.

V. Instruments aimed at providing economic incentive to reduce Se releases to surface waters, involving both market-based and regulatory components eg. trading of Se emission permits, should be actively pursued. The wide range of mining and agricultural activities that enhance Se weathering on the Canadian landscape suggests that such initiatives may have a broad theatre of applicability. Similar market-based mechanisms, involving the trading of Se release permits, have been developed to regulate Se releases from agricultural watersheds in California, (Woodward et al. 2002). The "*Stewardship and Conservation*" section of recent Government of Alberta report entitled *Land-Use Framwork* stresses the need to pursue innovative market-based approaches to stewardship..

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