Then back to CZN P Reg.

Indian and Northern Affairs Canada
www.inac.gc.ca

Affaires indiennes et du Nord Canada
www.ainc.gc.ca

P.O. Box 1500
Yellowknife, NT
X1A 2R3

Telephone: (867) 669-2661
Facsimile: (867) 669-2716

Your file - Votre référence

Our file - Notre référence

RECEIVED
FEB 05 2003
MACKENZIE VALLEY ENVIRONMENTAL IMPACT REVIEW BOARD

January 30, 2003

Mackenzie Valley Environmental Impact Review Board
200 Scotia Center
Yellowknife, NT
X1A 2N7

ATTENTION: Mr. Vern Christensen
Executive Director

Dear Mr. Christensen:

Re: Historical Water Quality of the Prairie Creek Project Area – Additional Information

In October, 2002, the Water Resources Division of the Department of Indian Affairs and Northern Development (DIAND) provided the MVEIRB with a copy of the "Historical Water Quality of the Prairie Creek Project Area" report. As a follow-up to this report, DIAND contracted Gartner Lee Limited to complete a peer review and statistical analysis of the "Historical Water Quality of the Prairie Creek Project Area" report. The reports detailing the peer review and statistical analysis are enclosed to provide the Board with the additional information for the public registry.

Sincerely,

Robert J Reid

Bob Reid
Head, Water Management and Planning

Encl. Peer Review Comments – Prairie Creek Water Quality Report, October 2002
Statistical Analysis – Prairie Creek Water Quality Report, January 2003

245

Canada

Gartner
Lee
Limited

140 Renfrew Drive
Suite 102
Markham, Ontario
L3R 6B3

Tel: (905) 477-8400
Fax: (905) 477-1456
www.gartnerlee.com

Environmental Services
Since 1973

Office Locations

- Vancouver
- Whitehorse
- Yellowknife
- Calgary
- Toronto
- St. Catharines
- Bracebridge
- Montreal
- Halifax

A Member Of
Environmental Strategies
ALLIANCE

October 30, 2002 GLL 22-594

Ms. Paula Spencer
Water Resources Division
Indian and Northern Affairs Canada
3rd Floor Bellanca Building
P.O. Box 1500
Yellowknife, NT
X1A 2R3

Dear Ms. Spencer:

Re: Peer Review Comments – Prairie Creek Water Quality Report

The following letter contains our review comments of the Prairie Creek report. The report was prepared by Bernie Neary and reviewed by Neil Hutchinson.

Introduction

"Historical Water Quality of the Prairie Creek Project Area" (Beavers, 2002), summarizes available water quality data from monitoring in the vicinity of a mine site adjacent to Prairie Creek and Harrison Creek. The author has assembled water quality analytical data from available sources and has statistically analyzed all available data, with the aim of determining whether drainage from the mine site is impacting Prairie Creek.

Gartner Lee Limited was retained by Water Resources Division of INAC to provide a technical peer review of the report. Our review focussed on the methods used to gather the data, statistical interpretation and technical interpretation. We have attempted to provide a balance between comments on technical validity and an assessment of the overall conclusions and interpretations of water quality.

1. Technical Review

Overall, the report is well and clearly written. There is a good description of the site, its history, sources of data and the receiving environment. The report clearly acknowledges the shortcomings of the data. Any shortcomings of the report are related to the quality of the data and interpretations that are influenced by data availability and quality concerns as discussed below.

1.1 Discussion of Analytical Methodology

One of the obvious problems with the assessment of the Prairie Creek site is the dearth of sampling data. The earliest data available is from 1980, taken by inspectors from the

Department of Indian Affairs and Northern Development (DIAND). In order to increase the number of samples from the earliest sampling period, the author has pooled samples taken by Beak Consultants, Hardy and Associates, and Chemex from this period. It may be appropriate to include these data, but the report should justify inclusion with a discussion of similarities or differences in analytical methodology (Beavers, 2002, page 6). The laboratory procedures for those samples taken by DIAND inspectors are described (page 7), but the methods used by the consultants are not.

Pooling data assumes that the data are being included from separate observations on the same population. This may be the case if there are no significant differences in analytical methods, or sampling sites. The justification should be made in the report.

The author does discuss changes in laboratory methods and analytical detection limits (page 8), and alludes to difficulties in determining methods used in the early 1980s. However, as is pointed out, given the paucity of data, there was little flexibility available for the exclusion of data and the report instead focuses on what data are available.

1.2 Pooling Data

In addition to concerns about pooling data from different analytical laboratories, it is mentioned (page 4) that it was the practice in the early 1980s to add lime to the settling pond prior to discharge to Harrison Creek. The lime (soda ash) addition was manual from 1982 to 1984, then automatic from September 1984 through mid-1985. As the author notes, lime addition can raise the pH and precipitate metals, yet this effect is not dealt with in the statistics or the discussion of parameters that could be affected by lime addition.

1.3 Statistical Methods

One of the biggest problems with summarizing water chemistry data are how to deal with detection limits. Most data sets have at least some points where the only available information is that the results were below the method detection limit (< MDL). The statistical term for data sets with <MDL qualifiers in place of data points is "censored" data. For some of the data sets described in this report, the majority of the data are reported as <MDL. There is no single, widely accepted way of dealing with data below detection limits. In this report, the author has adopted a 'heuristic set' approach

The heuristic set approach may include replacing the <MDL qualifier with a value equal to the detection limit, half the detection limit, or zero. There is not a strong statistical basis for heuristic approaches to the analysis of water chemistry data, but they are commonly applied. How this set of methods performs across a wide set of circumstances is unknown. They will all behave differently depending upon the distribution and upon the percent of the data that are <MDL. In the Prairie Creek report, the author has elected to replace the <MDL or 'not detected' with the numeric value of the detection limit. This causes problems in cases where the MDL has changed over the time course of the data set and confounds interpretation.

There are more appropriate statistical methods for calculating descriptive statistics such as means and standard deviations when faced with <MDL values. Maximum likelihood estimators (MLE) are one such example. There are maximum likelihood estimators for censored data for many distributions such as normal, lognormal, exponential, and others. The MLE's are more complicated but the long-term results will be better. Non-parametric methods may also be used in dealing with censored data (Clarke, 1998). One commonly used method is that of Helsel, (Helsel, 1990, Helsel and Hirsch, 1992). Despite this shortcoming in statistical approach, many of the author's conclusions appear to be valid, as will be discussed below.

The author also alludes to significant differences in analytical methodology (page 8), but does not attempt to address the issue in the section on statistical analysis. Again, there have been some attempts to deal with differences in analytical methods (see for example Smith and McCann, 2000), but usually in a more data-rich environment.

The report properly uses non-parametric estimators for mean and for hypothesis testing, but the estimates of the mean are likely incorrect, due to the 'heuristic set' approach taken. This criticism does not apply to those parameters where most of the results are above detection limit. The 'box and whisker' approach for the graphical representation of the data are reasonable, but only for those parameters where a significant number of the results are above the detection limit.

1.4 Sampling Site Location

Conclusions about the impact of the Prairie Creek mine site are, as correctly noted in the report, difficult because of the inconsistency in the locations, frequency, and parameters being measured. There are five locations relevant to the assessment of impact of water from the site:

Site Number	Description
932-9	870 m portal drainage
932-4	Final discharge point from the settling pond
932-7	Prairie Creek upstream of the airstrip (upstream of the site)
932-6	Prairie Creek at the confluence of Galena Creek (downstream of the site)
	Prairie Creek at the mouth

As the author observes, these stations are not ideally sited to allow an analysis of the impact of the mine site drainage on the water quality of Prairie Creek. Since these are the only data available, there is little that can be done to address the deficiency. Given this notable shortcoming in the data associated with the site, I feel the author should make some recommendations on the location of more appropriate monitoring locations for any future surveys.

It is not clear from the report if samples taken at "Prairie Creek at the confluence with Galena Creek" were taken immediately upstream of the confluence or within the influence of Galena Creek waters. Logically, one would expect that a program designed to detect mine-related effects would use a site in Prairie Creek upstream, of Galena Creek, but this is not clarified.

1.5 Water Volumes

The only station for which water volume estimates are presented is 932-9 (870 m portal drainage). These volume estimates are derived from a number of people and data sources, and are appropriately described as being approximate. There was no attempt to estimate the volume of water at most of the other stations. Some estimates of flow for Harrison Creek are given in the description of the study area (page 1), but no attempt was made to use watershed areas to estimate flows at the other sites. The flow estimates for Harrison Creek should be included in the 'Hydrometric data' section of the report (page 10).

This becomes problematic when attempting to interpret the results. There are watershed area estimates for Prairie Creek (880 km^2), Prairie Creek above the mine site (495 km^2), and for the ephemeral Harrison Creek (7.5 km^2). Another useful watershed estimate would be for Galena Creek. The first sampling site on Prairie Creek downstream of the mine site is at station 932-6. It would be useful to know (even from a watershed area) how much dilution of the mine site drainage occurs due to the confluence of Galena Creek. The report correctly notes the need to include flow measurements in future surveys (page 33).

1.6 Water Quality Results

The report discusses each water quality parameter in turn, describes the significance of the parameter, and comments on the results of the statistical analysis. As noted above, for many parameters the statistics are skewed by the selection of the 'heuristic set' approach to the data. Nevertheless, the section provides a detailed and methodical elaboration of results. This section of the review will address some minor concerns with the description of the results as presented.

It should be noted that because the associated spreadsheet containing the analytical data contained no indication of which values were below detection limit, and what the detection limit for the analyte was at the time of sampling, it was impossible to check the statistics or to carry out an independent analysis.

1.6.1 pH, Conductivity, Turbidity, Solids

For the most part, the results of these parameters were above the MDL for the methods so the graphical representation of the data, descriptive statistics, and hypothesis testing are appropriate. We would recommend a discussion of alkalinity results. The report mentions acid drainage at one point as a possible explanation of high sulphate levels. Our review of the alkalinity data in Appendix B shows average values above 200 mg/L and minimum values above 100 mg/L for all mine water sites. Consumption of alkalinity would indicate acid drainage before pH was depressed and so the data support a conclusion of no acid drainage.

1.6.2 Sulphate and Ammonia

It is stated that sulphate is an essential plant nutrient, and that reduced concentrations of sulphate have a detrimental effect on algal growth. We are not aware of any situations in Canadian freshwater where low sulphate levels represent any limit to plant growth. If the author has a reference to such a case, the reference should be stated.

In the discussion on ammonia, the author states 'Nutrients in bio-available form like ortho-phosphorus…'. Phosphorus is an element (and is spelled phosphorus, not phosphorus) and the appropriate reference here is to orthophosphate.

The ammonia results presented are somewhat puzzling. Ammonia is not an unusual component of mine discharge, because of its presence in blasting compounds. One would expect that the ammonia concentration would decline with time in an inoperative mine. Since this parameter was one of the ones that frequently exceeded the CFPAL guideline, it would be useful to address the potential sources of ammonia at the site and discuss whether any trend was discernible in the time series from the portal drainage.

1.6.3 Cadmium

The current CPFAL guideline for cadmium is 0.063 µg/L. The author notes that the detection limit for cadmium for samples taken in the 1980s was 10 to 20 µg/L. The 'heuristic set' approach to statistical evaluation of these results is inappropriate. The discussion of the exceedance of the Water Licence limits should discuss the detection limit of the methods being used at the time of the exceedances. Nonetheless, the author appropriately observes that a number of licensed limits were exceeded and raises concerns about this contaminant.

1.6.4 Chromium

In the discussion on Chromium, it is stated "62% of the results at Prairie Creek upstream of the airstrip (932-7) exceeded the CPFAL guideline (n=13), with 17 further results being below detection". This is confusing. The author states earlier that the detection limits for chromium ranged from 100 µg/L to 0.2 µg/L, and only those results that were detectable were compared to the guideline. These qualifications must be carried through to the statements. An appropriate qualification would be: "62% of results **where chromium was detected…**" Otherwise, the numbers simply don't add up.

Similar criticisms can be levelled at most of the other statements about chromium. The last statement is "Of the 6 detectable results at *Prairie Creek at the Mouth,* none exceeded the CPFAL guideline. The median value for chromium was 0.2 µg/L (n=13)." It is stated earlier that the detection limit for chromium ranged down to 0.2 µg/L. Were all these samples 'not detected'? Were they all **at** the detection limit? In either case, quoting a median is inappropriate.

1.6.5 Copper

The detection limit for copper is not stated, but can be assumed to be 0.5 µg/L. The author can properly draw conclusions about guideline exceedances, but stating that the median value of copper at the *Prairie Creek at the Mouth* station is 0.5 µg/L would be better expressed as saying that most of the samples were below detection limit.

1.6.6 Lead

The author correctly states that lead toxicity is dependent on the hardness of the water, and selects a guideline of 7 µg/L as being appropriate for the hardness of the Prairie Creek area. The analysis presented by the author focuses mainly on the exceedance of guidelines and licence limits, and convincingly documents concern about the levels of lead emanating from the site.

1.6.7 Mercury

As noted, mercury concentrations in water are usually extremely low. Early methods for the analysis of water were notoriously unreliable, and most modern methods yield results in the ng/L range (Mierle, 1990). Although some of these sites represent water draining from an ore body, the levels of mercury quoted strain credibility. A more detailed discussion of the history of mercury analytical chemistry is warranted to put these conclusions in a more appropriate context.

1.6.8 Zinc

Along with lead, zinc releases from the site are probably the most significant in terms of potential effects. The comparison of zinc concentrations upstream and downstream of the site is most likely valid, since most of the analytical results appear to be above analytical detection limit. The discussion of exceedances of licensed limits and various guidelines is appropriate and convincing.

1.6.9 Comparison of Upstream Station to Prairie Creek at the Mouth

It is not clear why this comparison was made. The start of the section on p. 30 states that these two sites are the least likely to be influenced by mine drainage. If so why would one wish to compare them ? If they were influenced the downstream site, even if 48 km away, is likely to be influenced by mine drainage. If one is looking to assess the effect of the mine on surface water, then the first comparison should be the upstream site against Prairie Creek at Galena Creek, and then against Prairie Creek at the mouth. This would show initial impact and then any recovery or assimilation with distance downstream (providing there is enough data to do this).

This discussion addresses some of the concerns about differences in periods of record for the two sites and some of the problems with differences in analytical methodology over the time period of data collection. The author acknowledges that the statistical treatment selected contributes to some of the conclusions drawn, but concludes "Those values below detection could either be removed from the dataset or analyzed at half their detection limit." Both of these recommendations are statistically invalid and INAC may require a valid statistical approach if these data are to be used for regulatory means. If the purpose of the report is to illustrate trends for information only then additional analyses may not be needed.

Removing values below detection limit is entirely inappropriate. The resulting dataset would be highly skewed and would disproportionately include samples with "Type II" analytical errors (samples where a parameter is being reported as being greater than detection limit, where the sample really had non-detectable concentrations). As discussed above in the commentary on statistical methods, setting 'non-detects' to half the detection limit is also inappropriate.

If the author wishes to draw conclusions about the relative concentrations of various parameters at these two stations, other statistical techniques should be considered. Some of the references cited in our review of statistical methods may be appropriate.

1.6.10 Summary

The author acknowledges the limitations of the dataset, and addresses some of the problems with the analysis of the data. This is an important qualifier and the overall approach is sound. If all data that are suspect due to changes in analytical methodology are excluded from the dataset, there is very little data left that would allow for an assessment of the impact of the Prairie Creek mine site. One must start somewhere.

The conclusions drawn by the author in terms of exceedances of guidelines or licensed limits are appropriate. However, the author should be more cautious about the conclusions regarding relative concentrations of analytes where significant numbers of the results are below detection limits.

The author is correct in stating that increased sulphate concentrations appear in the sampling sites associated with mine drainage, but characterizing it as 'acid rock drainage' is difficult to support when the pH of the samples is usually well above 7 and no alkalinity has been consumed.

The data presented indicate that discharge of ammonia, lead, and zinc are the most likely to result in adverse biological impacts. A more thorough discussion of these impacts would be welcome in the conclusions. The author states "… the minewater is a significant source of metals…". Metal toxicity varies widely. The metals of apparent concern from the Prairie Creek site are lead and zinc, and should be identified specifically.

2. Conclusions

The author was presented a difficult task: the interpretation of water quality monitoring results spanning close to twenty years. The sample locations were not designed to allow an unequivocal assessment of the impact of drainage from the mine site on Prairie Creek, and there were inconsistencies in parameters sampled, sampling frequency, and sampling agency.

The author selected an inappropriate statistical approach to justify conclusions about the relative concentrations of metals and other water quality parameters at different sites. The 'heuristic set' approach yields invalid statistics and cannot be used to support conclusions about parameters where a significant proportion of the results are below detection limits. The non-parametric statistics were appropriate for those parameters where the results were above detection limits. This shortcoming may present problems if the data or report are to be used for regulatory purposes as they could be challenged on a statistical basis.

Nonetheless, the data do support the observations about exceedances of Water Licence limits and other guidelines and limits (MMLER and CPFAL). Some of these conclusions should be qualified by a more thorough discussion of early analytical results, their detection limits, and the possibility of some of the exceedances being associated with "Type II" analytical errors.

Although there is evidence of mine impact, the impacts could be more clearly assessed through additional surveys that included:

a) consistency in the water quality parameters measured;

b) consistency in analytical procedures and laboratories used;

c) more frequent and consistent sampling strategy;

d) well-designed QA/QC procedures for both sampling and analysis;

e) an additional sampling station downstream of the mine site, but upstream of the confluence of major tributaries (the existing sites are not adequately located) in order to assess impacts to receiving waters; and

f) given that water quality in the creek has been impacted, any follow-up surveys should include benthic community assessments and trace metals in fish tissue to assess the significance of the water quality reported here.

Despite these comments, there appears to be evidence that drainage from the mine site contains elevated levels of lead, zinc, sulphate, TSS and ammonia. The author correctly infers that there is contaminated water being discharged to Prairie Creek. These conclusions are weakened, however, by the use of inappropriate statistics to support the conclusions.

Please review these comments and do not hesitate to contact me at (905) 477-8400 ext. 227 if you have any questions, concerns or needs for further clarification. In closing, I thank you for the opportunity to assist Water Resources Division with this review.

Yours very truly,
GARTNER LEE LIMITED

Bernie P. Neary, B.Sc.
Senior Water Quality Scientist

Neil J. Hutchinson, Ph.D.
Senior Surface Water Specialist
Principal

BPN:mm

References

Beavers, R., 2002:
'Historical Water Quality of the Prairie Creek Project Area'. Water Resources Division. Department of Indian Affairs and Northern Development. 34 pp + appendices.

Clarke, J.U., 1998:
Evaluation of censored data methods to allow statistical comparisons among very small samples with below detection limit observations: Environmental Sciences and Technology, v. 32, no. 1, p. 177–183.

Helsel , D.R. and R.M. Hirsch, 1992:
'Statistical Methods in Water Resources' Elseiver, 1992

Helsel, D.R., 1990:
Less than obvious: Statistical treatment of data below the detection limit. Environ. Sci. Technol. 24(12): 1766-1774.

Mierle, G., 1990:
Aqueous inputs of mercury to Precambrian Shield Lakes in Ontario. Envir. Tox. and Chem., 9: 843-851

Smith, D.G. and P.B. McCann, 2000:
'Water quality trend detection in the presence of changes in analytical laboratory protocols'. Proceedings of the National Water Quality Monitoring Council.
http://www.nwqmc.org/2000proceeding/table_of_contents.htm#TRACK%20A. 13pp.

Gartner
Lee
Limited

140 Renfrew Drive
Suite 102
Markham, Ontario
L3R 6B3

Tel: (905) 477-8400
Fax: (905) 477-1456
www.gartnerlee.com

Environmental Services
Since 1973

Office Locations

- Vancouver
- Whitehorse
- Yellowknife
- Calgary
- Toronto
- St. Catharines
- Bracebridge
- Montreal
- Halifax

January 14, 2003 GLL 22-594

Ms. Paula Spencer
Water Resources Division
Indian and Northern Affairs Canada
3rd Floor Bellanca Building
P.O. Box 1500
Yellowknife, NT
X1A 2R3

Dear Ms. Spencer:

Re: Statistical Analysis – Prairie Creek Water Quality Report

The following letter contains our analysis of the original data that went into the technical report entitled "Historical Water Quality of the Prairie Creek Project Area" which was prepared by DIAND (Beavers, 2002). In November of 2002, Water Resources Division of DIAND requested that Gartner Lee Limited undertake a re-analysis of the raw data used by INAC to produce that report. Our analysis was to address the impacts of mine discharge on Prairie Creek using the long-term data set used by INAC, but incorporate the correct statistical procedures to address concerns with water quality data which were reported as below the Method Detection Limit (<MDL) in the original report. The following report contains that analysis, plus technical commentary on the results, and comparison with the results in the original report, for which we provided a technical review on November 1, 2002.

1. Introduction

"Historical Water Quality of the Prairie Creek Project Area" (Beavers, 2002), summarizes available water quality data from monitoring in the vicinity of a mine site adjacent to Prairie Creek and Harrison Creek. In a peer review of the report (Gartner Lee 2002), some of the statistical methods used to interpret the data were questioned.

Gartner Lee Limited was retained by Water Resource's Division of INAC to provide further statistical interpretation of the analytical data to try and determine whether drainage from the mine site was having an impact on the water quality of the receiving water.

As described by Beavers (2002), the data available for evaluation of the impact of the Prairie Creek site suffers from a number of deficiencies – irregular sampling intervals, different analytical laboratories, changes in analytical methods and reporting, and inconsistent sample sites. In common with many water quality data sets relating to trace metal analysis, there were also frequent occasions when the concentration of a metal was below the method detection limit (< MDL). The statistical term for these data sets is 'censored' sets.

Despite the fact that these types of data are frequently encountered in environmental assessments, there are surprisingly few generally recognized methods for analyzing them, and even fewer software tools available to assist in the analysis and interpretation of the data.

2. Statistical Methods

A review of acceptable statistical methods for analyzing data sets with frequent occurrence of 'non-detects' was carried out. Despite the common occurrence of these types of data in environmental assessment, there is a surprising lack of consensus on statistical approach and a concomitant lack of software tools suitable for tackling the problem. Graphical methods (Travis and Land, 1990), maximum likelihood estimation methods (Helsel, 1990), and mean and variance adjustment methods were all considered.

The overall statistical approach was taken from the U.S. EPA document "Practical Methods for Data Analysis" (http://www.epa.gov/quality/qa_docs.html). In general, each parameter from each station was examined to determine whether or not it fit a normal or lognormal distribution using the Shapiro-Wilk method (an Excel spreadsheet with macros for calculating the Shapiro-Wilk W-statistic is available from the Oregon Department of Environmental Quality at http://www.deq.state.or.us/wmc/tank/ucls.htm). Generally, all parameters except for pH were lognormally distributed, but there were exceptions. In a number of cases, the population of results did not follow either a normal or lognormal distribution. These exceptions are noted where they were encountered.

For parameters where there were 'non-detects' (measurements below the limit of detection of the analytical procedure), Cohen's adjustment was used to prepare an estimate of the mean. Cohen's adjustment is one of several techniques that can be used to make estimates of summary statistics for populations of data where significant numbers of observations are below the limit of detection for an analytical method. In many cases, however, non-detectable values represented more than 50% of the reported results, and meaningful statistical estimates of means or variances were not possible, since it is not advisable to apply this technique to populations with more than 50% 'non-detects'.

Cohen's adjustment to estimates of means and variances is outlined in detail in the U.S. EPA document 'Assigning Values to Non-detected/Non-quantified Pesticide Residues in Human Health Food Exposure Assessments' (March, 2000) (http://www.epa.gov/pesticides/trac/science/trac3b012.pdf). The appropriate statistics for calculating Cohen's adjustment were also calculated in Excel.

Briefly, Cohen's technique for lognormally distributed censored data (data that have been truncated at a detection limit) involves the following steps:

1. Determine N = total sample size
2. Determine n = number of quantitated measurements

3. Calculate $h = (N-n)/N$
4. Determine $X_0 = \ln(LOD)$ [where LOD = "Limit of Detection"]
1. Determine $\gamma = \underline{S}_L^2/(\underline{X}_L - X_0)^2$ where $\underline{X}_L$ and $\underline{S}_L^2$ are the mean and population variance of the log-transformed detectable data, respectively.
6. Use Cohen's look-up tables for h and γ to determine λ
7. Calculate adjusted mean $M_L = \underline{X}_L - \lambda \underline{X}_L - X_0)$
8. Calculate adjusted variance $s_L^2 = \underline{S}_L^2 + \lambda \underline{X}_L - X_0)^2$

Untransformed estimates of means and variances from lognormal distributions were calculated as follows:

9. $M_a = \exp(M_L + 0.5\, s_L^2)$
10. $s_a^2 = M_a^2[\exp(s_L^2)-1]$

where M_L is the Cohen's adjusted mean of the log-transformed population of results and s_L is the variance of the log-transformed results, also adjusted according to Cohen's method. In the cases of parameters where there were no results less than detection limit, these statistics were calculated on unadjusted means and variances of the log-transformed results.

3. Data Exclusions

He intent of the Prairie Creek data set is to document any responses of water quality to discharges from the mine site. The data set must allow valid comparisons of water quality between sites on a given sampling date and across all dates sampled. Integrity of the environmental data set can only be assured where details of sampling location and analysis can be verified, and where results reflect responses of the receiving waters to the water quality parameters of interest.

The vast majority of the samples were analyzed at the Taiga Environmental Laboratory of the Department of Indian Affairs and Northern Development in Yellowknife, NT. There were also samples taken by Beak Consultants (1980), Hardy and Associates (1984), and Chemex (1984). In order to eliminate differences in data due to dissimilarities in sampling, preservation or analytical methods, the latter sets of samples were excluded from further analysis.

In addition to the results excluded because of analysis at different laboratories, the following results were also excluded:

Table 1. Exclusion of Samples

Date	Sample Site	Reason for Exclusion
20-May-81	932-3 Camp sewage effluent	Too few samples taken at site
2-Feb-82	932-3 Camp sewage effluent	Too few samples taken at site

Table 1. Exclusion of Samples

Date	Sample Site	Reason for Exclusion
7-Apr-82	932-3 Camp sewage effluent	Too few samples taken at site
20-May-81	932-2 Industrial waste treatment system effluent	Only sample taken at site
27-Aug-82	Minewater in mine*RIGHT AT PORTAL	Only sample taken at site
31-Mar-81	Minewater in mine	Not being discharged
30-Apr-81	Minewater in mine	Not being discharged
7-Apr-82	Minewater in mine	Not being discharged
23-Aug-83	Minewater in mine	Not being discharged
28-Sep-83	Minewater in mine	Not being discharged
24-May-84	Minewater in mine	Not being discharged
6-Jul-84	Minewater in mine	Not being discharged
9-Jan-85	Minewater in mine	Not being discharged
26-Jul-85	Minewater in mine	Not being discharged
24-Sep-85	Minewater in mine	Not being discharged
30-Apr-81	site drainage	Only sample taken at site

These exclusions left four sampling sites to be considered (Table 2).

Table 2. Sampling Sites Considered for Statistical Analysis

Site	Description
932-4	Final discharge point from settling pond
932-6	Prairie Creek at the confluence of Galena Creek
932-7	Prairie Creek upstream of the airstrip
932-9	2850 portal

To further reduce the complexity of the analysis, parameters not directly related to mining impacts, or parameters sampled infrequently, were excluded. The list of parameters considered was: Alkalinity, Ammonia-N, pH, Cadmium, Chromium, Cobalt, Copper, Dissolved Solids, Iron, Lead, Manganese, Mercury, Nickel, Suspended-Solids, Zinc, Arsenic, Sulphate and Phosphorus. This filtering of the data set provided results that could be substantiated for analytical technique, which represented reproducible locations in the receiving environment and which represented parameters of direct relevance to the mining operation and the responses of the Prairie Creek.

4. Results

A detailed description of the data set is provided by Beavers (2002). Even after excluding samples analyzed by different laboratories and eliminating sample sites that were rarely visited as described in Section 3, there were three major deficiencies in the data set:

1. **Low Number of Samples:**
   Many of the parameters had been sampled at a specific site on less than 20 occasions. This limits the range of statistical approaches that can be applied to the data sets.

2. **Large Number of Non-Detected Values:**
   In a number of cases, 50% or greater of the analyses for a parameter at a site were less than the detection limit. Estimates of population means are not possible for these situations.

3. **Variable Detection Limits** Further Complicate Statistical Analysis:
   The samples were analyzed over a 20-year period, during which time methods of analysis changed. Strictly, Cohen's method of adjustment of means and variances should not be applied to variable detection limits, but alternative statistical approaches were not found.

Two criteria were applied to the remaining data to determine whether or not to proceed with further statistical analyses:

Criterion 1: 50% or more of the analyses had to be above the detection limit, and

Criterion 2: there had to be at least 10 detectable values.

The criterion that 50% of the values had to be above the detection limit was based on advice by the U.S. EPA. Methods such as Cohen's method, Winsorized means or Atchison's method for dealing with values below the detection limit are appropriately applied only for cases where 50% or less of the values are 'non-detects'. The limit of ten detectable results was assigned as a lower limit of the number of samples required to assess whether or not a population was appropriately treated as normally or lognormally distributed. Table 3 shows the parameters and sites considered. Those combinations of sites and parameters that did not meet criterion 1 are indicated in **bold** type, while those that did not meet criterion 2 are indicated in ***bold italic***.

Table 3. Parameters Meeting Criteria for Further Assessment

Parameter	2850 Portal			Upstream of Airport			Downstream at Galena			Final Discharge		
	Analyses	*Number <DL*	*% undetected*	*Analyses*	*Number <DL*	*% undetected*	*Analyses*	*Number <DL*	*% undetected*	*Analyses*	*Number <DL*	*% undetected*
Alkalinity	25	0	0.0	32	0	0.0	29	0	0.0	22	0	0.0
Ammonia-N	12	1	8.3	**18**	**14**	**77.8**	**18**	**14**	**77.8**	13	1	7.7
NO3-N+NO2-N	12	0	0.0	21	3	14.3	19	2	10.5	13	1	7.7
pH	24	0	0.0	34	0	0.0	31		0.0	25	0	0.0
Tot-Cadmium(ICP-MS)	26	7	26.9	**35**	**29**	**82.9**	**32**	**26**	**81.3**	26	6	23.1
Tot-Chromium(ICP-MS)	**17**	**9**	**52.9**	**29**	**16**	**55.2**	**27**	**16**	**59.3**	20	8	40.0
Tot-Cobalt(ICP-MS)	**10**	**5**	**50.0**	**12**	**6**	**50.0**	***11***	***5***	***45.5***	***10***	***2***	***20.0***

Table 3. Parameters Meeting Criteria for Further Assessment

Parameter	2850 Portal			Upstream of Airport			Downstream at Galena			Final Discharge		
	Analyses	*Number <DL*	*% undetected*	*Analyses*	*Number <DL*	*% undetected*	*Analyses*	*Number <DL*	*% undetected*	*Analyses*	*Number <DL*	*% undetected*
Tot-Copper(ICP/MS)	26	1	3.8	**35**	**24**	**68.6**	**32**	**19**	**59.4**	26	3	11.5
Tot-Diss-Solids	***7***	***0***	***0.0***	11	0	0.0	***8***	***0***	***0.0***	***6***	***0***	***0.0***
Tot-Iron(AA)	25	3	12.0	34	10	29.4	31	7	22.6	24	4	16.7
Tot-Lead(ICP-MS)	26	3	11.5	**35**	**23**	**65.7**	**32**	**20**	**62.5**	27	3	11.1
Tot-Manganese(ICP-MS)	***7***	***0***	***0.0***	***7***	***3***	***42.9***	***6***	***1***	***16.7***	***5***	***0***	***0.0***
Tot-Mercury(water)	***9***	***1***	***11.1***	14	3	21.4	***14***	***4***	***28.6***	***6***	***1***	***16.7***
Tot-Nickel(ICP-MS)	26	0	0.0	35	16	45.7	**32**	**17**	**53.1**	27	9	33.3
Tot-Suspended-Solids	22	8	36.4	**30**	**17**	**56.7**	**27**	**16**	**59.3**	**22**	**16**	**72.7**
Tot-Zinc(ICP-MS)	26	0	0.0	35	7	20.0	32	6	18.8	27	0	0.0
Tot-Arsenic	24	8	33.3	**33**	**30**	**90.9**	**29**	**21**	**72.4**	24	10	41.7
Sulphate	11	0	0.0	18	0	0.0	17	0	0.0	***9***	***0***	***0.0***
T-Phosphorus	***3***	***0***	***0.0***	***7***	***0***	***0.0***	***6***	***0***	***0.0***	***4***	***0***	***0.0***

Notes: **Bold:** >= 50% of results less than detection
Bold italic: Sample size of detectable results < 10

Some parameters (Phosphorus, Cobalt, Manganese) had either too many 'non-detects' or insufficient sample size to warrant further analysis. Of the remaining parameters, only Alkalinity, Nitrate + nitrite, iron, zinc and pH had populations of results from all sites that met the criteria.

Table 4. Cohen's Adjusted Means and Variances for Parameters in the Prairie Creek Data Set[1]

Parameter	2850 Portal		Upstream of Airport		Downstream at Galena		Final Discharge	
	Mean	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*
Alkalinity	**245.78**	**11.76**	**174.12**	**10.44**	***165.17***	***1622.09***	**202.71**	**11.31**
Ammonia-N	2.15	25.32					0.50	7.52E+05
NO3-N+NO2-N	1.51	0.08	0.12	0.01	0.15	2.06	1.31	1.59
PH	***7.85***	***0.06***	***8.15***	***0.07***	***8.15***	***0.02***	***8.04***	***0.09***
Tot-Cadmium(ICP-MS)	43.76	5.50E+05					**0.52**	**38.44**
Tot-Chromium(ICP-MS)							1.00	2.90
Tot-Cobalt(ICP-MS)								
Tot-Copper(ICP/MS)	91.40	5.99E+04					**1.84**	**3503.85**
Tot-Diss-Solids			**247.06**	**19.11**				
Tot-Iron(AA)	6.60	4.75E+12	0.11	11.71	**0.06**	**0.18**	**0.71**	**1.67E+06**
Tot-Lead(ICP-MS)	119.48	4.65E+05					**57.60**	**2.81E+11**
Tot-Manganese(ICP-MS)								
Tot-Mercury(water)			0.02	0.004	0.03	0.003		
Tot-Nickel(ICP-MS)	36.29	1146.50	2.52	3.93			**1.79**	**18.72**
Tot-Suspended-Solids	64.57	2.69E+06						
Tot-Zinc(ICP-MS)	**15963.63**	**423.78**	**14.53**	**2842.17**	**7.76**	**2290.34**	587.83	63.41
Tot-Arsenic	42.62	66126.03					**2.73**	**774.13**
Sulphate	417.13	26.94	61.93	8.02	54.74	6.86		
T-Phosphorus								

Notes: 1. All concentrations are given in mg/L.
Bold: population does not conform to lognormal or normal distribution
Bold italic: statistics calculated on untransformed data

Table 4 contains the results of Cohen's adjustment to a range of parameters from the most-frequently sampled sites. It should be noted that the application of Cohen's method is not entirely appropriate for these data due to variable detection limits. Where multiple detection limits were encountered, the most frequently reported detection limit was used for Cohen's adjustment.

It should also be noted that a number of the sites had populations of results that did not conform to normal or lognormal distributions, further complicating the assessment of the data. It is also clear that, for the metal samples, the variance is several orders of magnitude greater than the mean, such that hypothesis testing would not produce conclusions of statistical significance.

5. Discussion

The data available from the Prairie Creek monitoring are, in general, not suitable for formulating and testing formal statistical hypotheses. As noted above, the data suffer from a number of deficiencies, most notably low numbers of results, large numbers of 'non-detectable' data, variable detection limits and high between-sample variance. These factors combine to make rigorous statistical evaluation difficult.

Attempts were made to calculate means and variances adjusted by Cohen's method for selected parameters and sites. However, variable detection limits and the frequent occurrence of populations that did not follow either normal or lognormal distributions made the application of Cohen's methodology questionable. Even those populations where lognormal distributions were followed frequently had extremely large estimates of variance that precluded the application of hypotheses testing to determine the significance of differences in means.

Despite the lack of success in applying formal statistical procedures to evaluating the impact of the Prairie Creek mine site on water quality, there is a key conclusion made in the original report (Beavers, 2002) that warrants repeating:

> *"At the final discharge point from the settling pond into Harrison Creek there have been violations of the limits established under the old water licence, and in some cases the MMLERs. One sample each of copper, lead, and mercury exceeded the relevant water licence limit, 14% of samples collected exceeded the TSS limit, and 15% of samples collected exceeded the limit for zinc. The MMLERs were exceeded once by lead, TSS, and zinc. It should be emphasized that over 20 years there were in total only 49 sampling visits to the Prairie Creek site and not all stations were sampled on every visit. Accordingly, these numbers are only an indicator of possible long term poor quality drainage at this site."*

The lack of success in determining statistically significant differences between the sampling sites due to reasons elaborated earlier in this report does not detract from the fact that various water licence limits and MMLER's (Metal Mining Liquid Effluent Regulations) have been exceeded. The existing data set, however, appears to be inadequate for statistically substantiating the magnitude and significance of the impact to receiving waters.

The initial peer review of the report made several recommendations for further evaluation of the site:

a) consistency in the water quality parameters measured;

b) consistency in analytical procedures, laboratories used and reporting limits;

c) more frequent and consistent sampling strategy;

d) well-designed QA/QC procedures for both sampling and analysis;

e) an additional sampling station downstream of the mine site, but upstream of the confluence of major tributaries (the existing sites are not adequately located) in order to assess impacts to receiving waters; and

f) given that water quality in the creek has been impacted, any follow-up surveys should include benthic community assessments and trace metals in fish tissue to assess the significance of the water quality reported here.

This further statistical examination of the data reinforces those recommendations.

In summary, the data set does not support a statistical evaluation of the impacts of mine drainage to Prairie Creek. Individual observations of specific water quality parameters do indicate, however, that licence limits and guidelines have been exceeded in the discharge and suggest the potential for impacts to Prairie Creek. Further studies are warranted but should be guided by the recommendations made above.

This report was prepared by Bernie Neary and reviewed by Neil Hutchinson, at Gartner Lee Limited Please do not hesitate to contact either of us if you have further questions or concerns regarding our findings.

Yours very truly,
GARTNER LEE LIMITED

Bernie P. Neary, B.Sc.
Senior Scientist

Neil J. Hutchinson, Ph.D.
Senior Aquatic Scientist
Principal

BPN:mm

6. References

Beavers, R., 2002:
'Historical Water Quality of the Prairie Creek Project Area'. Water Resources Division. Department of Indian Affairs and Northern Development. 34 pp + appendices.

Helsel, D.R., 1990:
Less than obvious: Statistical treatment of data below the detection limit. Environ. Sci. Technol. 24(12): 1766-1774.

Gartner Lee, 2002:
Peer Review Comments – Prairie Creek Water Quality Report. GLL 22-594, 9pp.

Travis, C.C. and M.L. Land, 1990:
Estimating the mean of data sets with nondetectable values. Environ. Sci. Technol. 24(9): 961-962.