WEST KITIKMEOT / SLAVE STUDY SOCIETY

Re: Investigation of Aquatic Impacts of On-Ice Exploratory Diamond Drilling Final Report

STUDY DIRECTOR RELEASE FORM

The above publication is the result of a project conducted under the West Kitikmeot / Slave Study. I have reviewed the report and advise that it has fulfilled the requirements of the approved proposal and can be subjected to independent expert review and be considered for release for public.

Study Director

September 19, 2000
Date

INDEPENDENT EXPERT REVIEW FORM

I have reviewed this publication for scientific content and scientific practices and find the report is acceptable given the specific purposes of this project and subject to the field conditions encountered.

Reviewer

November 1, 2000
Date

INDEPENDENT EXPERT REVIEW FORM

I have reviewed this publication for scientific content and scientific practices and find the report is acceptable given the specific purposes of this project and subject to the field conditions encountered.

Reviewer

December 7, 2000
Date

BOARD RELEASE FORM

The Study Board is satisfied that this final report has been reviewed for scientific content and approves it for release to the public.

Chair
West Kitikmeot/Slave Study Society

December 8, 2000
Date

ANNUAL REPORT TO THE WEST KITIKMEOT/SLAVE STUDY SOCIETY
Investigation of Aquatic Impacts of On-Ice Exploratory Diamond Drilling:

May 15, 2000
Submitted by Anne Wilson

SUMMARY

A three-year study has been completed which examines the impacts of exploratory drilling from lake ice surfaces. Exploration drilling involves using diamond drills to extract rock core samples, and in the process generates return water which contains rock fines or solids, plus residues of any additives which may have been used. Disposal of this effluent is difficult at cold temperatures, so this research was done to see what effects occurred when the drilling waste was deposited on the lake bottom. Impacts of short holes involving limited discharges were measured in 1996/97 on Great Slave Lake, with @before@ and Aafter@ samples collected for analysis and evaluation. A longer hole with higher quantities of effluent released was studied at Baton Lake; baseline measurements were done in 1997, and follow up work has been done for water quality and benthic samples. In the winter of 1998, drilling in kimberlite geology was examined for two short holes at Lac de Gras, with follow up work done in March of 1999. Short holes such as those examined in this study are typical of first-stage mineral exploration drilling, and so the results of this research are relevant to much of the drilling activity in the NWT.

This report presents the final results of the 1998/99 work which were still outstanding at last annual report and summarizes all results to date. Detailed results can be found in previous reports; the 1999 data for benthic communities and sediment characterization are new to this report.

Baton Lake:

Effluent containing approximately one cubic metre of rock fines was released in Baton Lake in February of 1997. Water clarity showed short-term cloudiness after drilling, but fines settled out quickly. Benthic, sediment and water samples were collected in early 1998 at the discharge site and at reference sites for comparison to pre-drilling conditions. Benthic samples were identified taxonomically and the abundance of each group was determined. Statistical comparison showed no significant changes in numbers of individuals of the two dominant groups of organisms (cyclopoid copepods and nematode worms) but the overall diversity had dropped slightly in the other groups (from an average of four different types to 2.4 per sample). Particle size analysis was done on samples collected the summer after drilling, and one year later. The clay fraction was elevated after drilling (compared to the reference site) but by February of 1998, had returned to pre-drilling levels, due to the lake's high natural sedimentation rate. Overall sediment chemistry was not significantly changed by the addition of the drill fines, with the exception of increases in aluminum and magnesium. No resuspension of fines was seen in summer.

Great Slave Lake:

Eight short holes drilled on Great Slave Lake were studied in early 1997, with water quality, sediment chemistry, and benthic invertebrate measurements taken prior to and shortly after drilling effluent release. Effluent contained between 0.2 to 0.6 cubic metres of rock fines, which resulted in a patchy layer up to about 1 mm thick on the lake bottom. While there were significantly fewer benthic animals at the drilling discharge point after effluent release, there was no significant effect at 15 metres away, indicating that impacts were fairly localized. Overall sediment chemistry was not significantly changed by the addition of the drill fines. During effluent release suspended solids did not get above 11 mg/L (averaging close to 4 mg/L) and settled fairly quickly. Summer work confirmed that there was no difference in water clarity between release sites and reference sites.

Lac de Gras:

Release of kimberlite effluent at two short holes was studied in the winter of 1998, with follow-up sampling done in both 1998 (approximately one month after release) and 1999 (one year after release). The first hole involved the release of 1.0 cubic meter of drilling solids, and the second, 0.6 m. Because of an unexpected drilling rig move, there is only one Apre@ site, but two sets of post-drilling measurements were taken for the adjacent holes. Water clarity, measured with turbidity, averaged 7-16 NTUs during the release, dropping very shortly after drilling to 5-8 NTUs. Sediment chemistry measurements were taken before and after effluent release were within ranges seen at the reference sites, with the exception of manganese which showed increases following drilling. Benthic invertebrate data for the first hole showed significant decreases in numbers of individuals several weeks after effluent release, but not by one year later. In both cases, the numbers of taxa (groups or families of animals) present were increased by the addition of the effluent. For the second hole, numbers of individuals were significantly lower one month after drilling as compared to the first hole pre-drilling, but by one year later there was no difference. The number of taxa present significantly increased by one year later at the second hole. At the reference sites, there were no significant differences from year to year in either numbers of individuals, nor taxa present.

ACKNOWLEDGMENTS

The researcher would like to acknowledge the contribution of the West Kitikmeot/Slave Study Society for funding; Dr. Buster Welch and Kathleen Martin for scientific advice and provision of equipment; Fisheries and Oceans for providing laboratory facilities; Royal Oak Mines Inc. and Diavik Diamond Mines Inc. and their drilling contractors (Connors, Canamera, and Midwest) for site access and logistical support including accommodation, meals, and transportation; Taiga Environmental Lab for analytical work; DIAND=s Mineral Development Division for funding of benthic analyses, and Environment Canada for equipment, summer student support, and lab analyses. Ron Bujold, Frankie Nitsiza, Patrick Adzin, Thorben Bieger and Dean Halifax, Bart Blais spent long hours in equipment preparation, out on the ice sampling, and/or in the lab processing samples. Thanks to Steve Harbicht for assistance in the summer water quality work, and with the DGPS operation.

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OBJECTIVES

The objective of this study is to evaluate impacts of on-ice drilling on water and sediment quality and on benthic life, and to continue to compile data on baseline conditions. The overall study seeks to answer the following main questions: 1. does first-stage exploration drilling significantly affect water clarity and sediment quality; and 2. is the benthic community significantly impacted in the immediate area of drilling when effluent is released to the lake bottom? This information will help with management of drilling waste disposal such that the least environmental effects are caused.

DESCRIPTION

Background:

Work was initiated in early 1997 to examine the effects of first stage diamond drilling programs working from lake ice surfaces. Samples were taken to assess the changes in water quality and effects on benthic invertebrates for three sites: Baton Lake, where a fairly deep hole was drilled; Great Slave Lake, where 11 shallow holes were drilled; and Lac de Gras, where two short holes were drilled into kimberlite ore. Reference sites provided baseline data as well as points for comparison later in time. Water clarity and changes to the benthic communities are the main indicators examined to determine magnitude and duration of effects. Initial work dealt with non-kimberlite targets only because of the potential toxicity of kimberlite effluents; however, in 1998 a kimberlite target was examined using two shallow holes at the Diavik lease on Lac de Gras, with followup work done in March of 1999.

Study Area:

The lakes under study are in the Slave Geological Province (see Figure 1), and include Baton Lake (at Colomac Mine), Great Slave Lake (Yellowknife Bay) and Lac de Gras (Diavik Diamond Mines Inc.). Great Slave Lake (Figure 3) and Lac de Gras (Figure 4) are both large lakes, and can be classified as oligotrophic and ultra-oligotrophic, respectively. The substrate in the area of drilling at Great Slave Lake consisted of a fine layer of organic material over clay and/or rocks; at Lac de Gras, the sediments were iron-rich, with silty consistency, and were poorly consolidated for the top 0.5 metre sampled. Baton Lake is a long narrow lake confined within a bedrock valley (Figure 2); the sediments consist of highly unconsolidated organic materials.

Methodology:

During the first stage at each study lake, baseline data were collected for water quality, sediment chemistry and benthic community composition. Discharge of drilling fines was done at five metres above lake bottom using a diffuser pipe for all sites except the Lac de Gras ones, where a one-inch hose was used following plugging problems with the diffuser. Water quality data were collected using a Hydrolab Multiprobe with a 50 m cable and underwater stirrer, connected to a Surveyor 3 Display logger. Instrument calibrations were done prior to going out and approximately twice weekly thereafter. Water samples for Total Suspended Solids were collected with a van dorn type water sampler. A modified KB corer was used to collect sediment cores; the corer was lowered and raised by a 12 V battery-powered winch mounted on a tetrapod frame. Four inch (100 mm inside diameter) plexiglass tubes were used to bring up core samples, which were then extruded so the top oxidized layer could be retained in 500 ml plastic bottles.

Benthic samples were taken back to Yellowknife for separation in the lab. Sediments were rinsed through a 72 - 112 micron screen, then separated by flotation using sugar water at a specific gravity of 1.16. Animals were alive at the time of flotation, with samples held at 4^{o} C for a maximum of 5 days before processing. Sorted sediments to be discarded were examined under the dissecting microscope for live invertebrates which hadn't floated, and these were picked out. Animals were stained using rose bengal, fixed in 10% formalin, and stored in 70% ethanol for shipment to the lab.

Statistical analyses were done by or with the help of Llwellyn Armstrong and Jeff Babb at the University of Manitoba's Statistical Advisory Service, using the SAS JMP and SPSS statistical software. For comparisons of the Great Slave Lake benthic communities, multivariate analysis of variance (MANOVA) was done on log transformed counts (most to family level identification) to test for differences between holes and time/position effects. This procedure was also run with the data expressed as percent composition. Univariate (whole-model test) analysis of variance was done for log-transformed counts, with contrast analysis done to identify sources of significant differences. Multidimensional scaling was run to assess patterns or groups within the observations. For comparisons of turbidity and sediment chemistry data, nonparametric tests (Wilcoxon-Kruskal-Wallis) were used. For Baton Lake data, analysis of variance and t-tests were run to statistically evaluate changes in benthic numbers for the dominant taxa, and for sediment chemistry parameters. Benthic data from Lac de Gras were evaluated using the Wilcoxon Signed-Rank test.

Baton Lake

Sample stations for Baton Lake were set up in a grid pattern, with the discharge point at the centre, stations at the four compass points 15 m and 30 m away, and intermediate points 21 m away (see Figure 2). The centre hole, C, was located at the greatest lake depth of 16.5 m. Reference points (R1, R2, and R3) were located to the south, well away from the area of disturbance, at depths of about 14 m. Effluent samples were taken from the drill return water stream. Because of the short notice given, limited water quality and core samples were taken for baseline work. Measurements were next taken at one year after discharge. Effluent containing approximately one cubic metre of rock fines was released.

Great Slave Lake

Eleven short holes were drilled along a line that was about 5.5 km long (Figure 3). Of these, eight were suitable for release of effluent to the lake bed, based on depth and proximity to shoals. At each hole sampled (all but numbers 1, 8, and 11) stations were set up at 0, 15, and 50 metres. Where the bottom type permitted, four core samples were taken at the hole collar (point of discharge), and four at 15 m away in the direction of increasing depth prior to effluent discharge (on the assumption that deposition would follow the depth gradient). Approximately one week after drilling, four cores were taken from the hole collar, again at 15 m, and also at 50 m from the collar (triplicate benthic invertebrate samples plus one chemistry sample for each station). For each of these holes water quality data were also taken before and after effluent release. Using the Hydrolab meter, measurements were taken for turbidity, pH, dissolved oxygen (DO), and temperature. Sediment chemistry analyses included metals, organic content, and nutrients, and particle size. Effluent released at each hole contained between 0.2 and 0.6 cubic metres of rock fines.

Lac de Gras

Two holes were drilled at Lac de Gras, designated A5-1 and A5-2. It had been hoped the first hole would go for a longer time, but it was through the kimberlite early on and so drilling was ended and a second hole drilled about 150 metres to the south-west. The first hole went through considerable bedrock and drilled approximately 60 metres through kimberlite (the total depth was 239.5 m) while the second hole encountered kimberlite immediately and was drilled to 137 metres with interruptions due to problems with the mud-like consistency encountered in A5-2. Larger quantities of additives (viscosifiers) were required for the second hole. Volumes of fines released were 1.02 m^3 for A5-1 and 0.58 m^3 for A5-2. Sample stations were set up in a similar pattern as was used for

Baton Lake, with 8 stations 15 m from the discharge point, in the four compass directions plus NE, SE, NW and SW, and 4 stations 30 metres from discharge, at each of the compass points. Field water quality measurements were done using a Hydrolab metre to measure water quality parameters. Water samples were collected using a van dorn type water sampler, and tested by Taiga Environmental Lab for total suspended solids, turbidity, and total metals. Benthic samples were collected in triplicate from each station, and professionally identified and enumerated after sorting in Yellowknife. Samples were taken before drilling at A5-1, then follow-up sampling was done approximately one month and one year after drilling at both A5-1 and A5-2.

Lab Experiments

Drilling effluent samples from Great Slave Lake were used to do preliminary lab experiments on the effects of addition of drill wastes to the water and sediment surfaces. Chironomid larvae of two species: *Chironomus* spp. and *Derotanypus alaskensis* were collected from Kam Lake (near Yellowknife) and held in test aquaria for use in smothering experiments (Didiuk and Wright 1975). Each experiment involved controls plus 3 test aquaria in which sufficient fines were added to form a surface layer 1, 3, or 7 mm thick.

ACTIVITIES FOR THE YEAR

Results new to this report are Lac de Gras benthic data and sediment chemistry for 1999 which had been awaiting analysis. Summaries are presented of overall findings to date; actual data are presented in previous reports to the WKSS.

RESULTS

Great Slave Lake:

Release of effluent resulted in short-term loss of water clarity, with total suspended solids reaching a maximum of 11 mg/L but settling out quickly. Core samples showed minor accumulations of rock fines on the sediment surface; a thin coating (less than 1 mm) was seen in the area of the discharge, and occasional dustings only at 15 m away. Sediment chemistry was not significantly altered by the addition of the limited volumes of rock fines. At the discharge point, comparisons of benthic invertebrate numbers and diversity before and after effluent release showed statistically significant effects. At the sample station 15 m from discharge, no significant differences were detected. Changes to summer water clarity were difficult to assess, given high natural turbidity with wind and wave action, but turbidity values at release sites were all within the range of adjacent reference areas.

Baton Lake

Release of the drilling effluent resulted in a layer of fines up to 7mm thick at the discharge point, settling out fairly close to the discharge point. By the next winter, natural sedimentation had covered this up with 1-2 cm of unconsolidated organic materials, which had been re-colonized by the benthic invertebrates. Sediment chemistry changed somewhat, with overall increases in aluminum and magnesium, and decreases in total organic carbon. The benthic community did not change significantly in numbers of individuals for the two major taxa, from before to one year after drilling. Taxa (groups or types of benthic animals) decreased slightly, from an average of four at each hole to 2.4. Water clarity during effluent release had total suspended solids reaching 11 mg/L for one result; most were in the range of 4 mg/L. No resuspension of fines was observed in summer.

Lac de Gras

Water clarity observations noted peaks in turbidity readings of up to 39.4 NTU at two sites, although average water column profile turbidities ranged from 6.1 to 16.2 NTU during discharge and dropped to 5-8 NTU very shortly after drilling. Previous work done on behalf of Diavik to correlate TSS and turbidity in kimberlites would suggest that the turbidity averages measured would correlate to a TSS range of 11.8 to 36.3 mg/L (Bryant 1996). Measurements of nutrients and metals in sediments after drilling fell within pre-drilling and reference values for all parameters except manganese, which showed an order of magnitude increase. Statistical analysis of numbers of benthic invertebrate individuals detected significant decreases at both sites one month after drilling in comparison to the A5-1 site before drilling. By one year later, there were no significant differences for either site; the reference sites showed no year-to-year differences either. Surprisingly, the numbers of taxa present increased significantly for both sites in the long term, and for the A5-1 site in the short term (one month) measurement.

Table 2. Statistical Summary	Timing	# of Individuals	# of Taxa
A5-1 pre to A5-1	One month after	Significant decrease	Significant increase
A5-1 pre to A5-1	One year after	Not significant	Significant increase

A5-1 pre to A5-2	One month after	Significant decrease	Not significant
A5-1 pre to A5-2	One year after	Not significant	Significant increase
Reference pre to Reference	One year after	Not significant	Not significant

Lab Experiments

Drilling effluent samples from Great Slave Lake were used to do preliminary lab experiments on the effects of addition of drill wastes to the water and sediment surfaces. Each experiment involved controls plus 3 test aquaria in which sufficient fines were added to form a surface layer 1, 3, or 7 mm thick. For the *Chironomus* spp. the control aquarium had 4% mortality (1 larvae), while the 1, 3, and 7 mm aquaria had respectively, 8, 4, and 8% mortality. This species is a burrower, and was able to construct new burrows in the 1 and 3 mm of fines, but not in the 7 mm. *D. alaskensis* showed similar tolerance, with no mortality in the control, 1, 3 or 7 mm tanks. In the 3 and 7 mm tanks, most larvae remained in the food layer under the fines, but surfaced while the tank was being disturbed; in the 1 mm tank the majority were already at surface.

DISCUSSION / CONCLUSIONS

Great Slave Lake

Effects of the release of the drilling effluent were short term and very localized. Amounts of rock fines associated with short drill holes results in a thin layer of fines which may affect benthic invertebrates in the short term, but which should quickly be mixed and recolonized by benthic animals. Water quality effects were of limited duration, and remained, on average, within the limit of a 10% increase in TSS recommended by the CCME Guidelines for the protection of freshwater aquatic life (CCREM 1987).

Baton Lake

Benthic results showed no significant differences in numbers of invertebrates present before and one year after release. Unfortunately, only limited baseline data were collected for benthic community samples (5 sites) so the test only utilized data for stations C, E1, N1, S1 and W1. For those sites, there were sufficient numbers of individuals in two taxa (cyclopoid copepods and nematode worms) so these were used to perform the analysis. Because of the extremely small number of taxa inhabiting the sediments of Baton Lake, interpretation of a significant drop in numbers of taxa should be done with caution. Reference sites showed no observable difference in individuals or taxa from 1997 to 1998. Statistically significant increases in sediment aluminum and magnesium were seen, as well as a drop in total organic carbon, which is to be expected with the addition of the rock fines in the area of discharge. Effects on water quality were limited in extent and duration, and as with Great Slave Lake, generally remained within guidelines for the protection of freshwater aquatic life.

Lac de Gras

Effluent chemistry was done for a sample from A5-2, and showed moderately high levels of total aluminum and magnesium. Toxicity testing of the effluent revealed problems with toxicity as it failed the rainbow trout bioassay. 1999 chemistry data (Table 1) for extractable metals indicate that post-drilling concentrations of these are consistent with pre-drilling and reference site measurements for all parameters except manganese. Benthic data are plotted on Figures 5 and 6 for comparisons of numbers of individuals, and of taxa, respectively. As shown on Table 2, the differences in individuals seen one year following release are not significant. There is no clear indication as to factors which would account for the enhanced numbers of taxa observed after effluent release. Speculation would have to include substrate alteration to favour more species, or an initial boost in some nutrients or micronutrients which are normally limited. The reference sites verged on being significantly higher with respect to numbers of taxa, so for the one year results it may be also associated with natural variability. In any event, the significant decreases in individuals in the short term only indicates that the physical effects are transient. Lac de Gras has an extremely low sedimentation rate, so the longer-term change in taxa composition would be expected to persist until the substrate returned over time to more organic sediments. It must be noted that although the aquatic effects may be of low significance, because of potential effluent toxicity, release of kimberlite-associated drilling effluent cannot be done without prior testing to establish non-toxicity.

LINKS WITH PARALLEL STUDIES

There are no links with other studies on the effects of drilling waste release to lake beds; this is believed to be the only such work in progress. Related information and research materials are being provided by industry, such as effluent samples for toxicity testing, results of effluent treatment technology advances, and any field measurements that companies may take.

TRAINING ACTIVITIES AND RESULTS

Local technicians were hired to assist with the field work, and received training on the sampling equipment, sample handling, use of the Hydrolab Multiprobe, recording and entering data, and preparing data for statistical analysis.

EXPENDITURES AND SOURCE OF FUNDS

WKSS Funding:	$5633.55
Analytical Costs	$5633.55
Total:	**$5633.55**

Other resources included: from Environment Canada (EC), provision of staff time; shipping of samples (about $200); and sediment analytical work done in-house ($2,000) .

REFERENCES

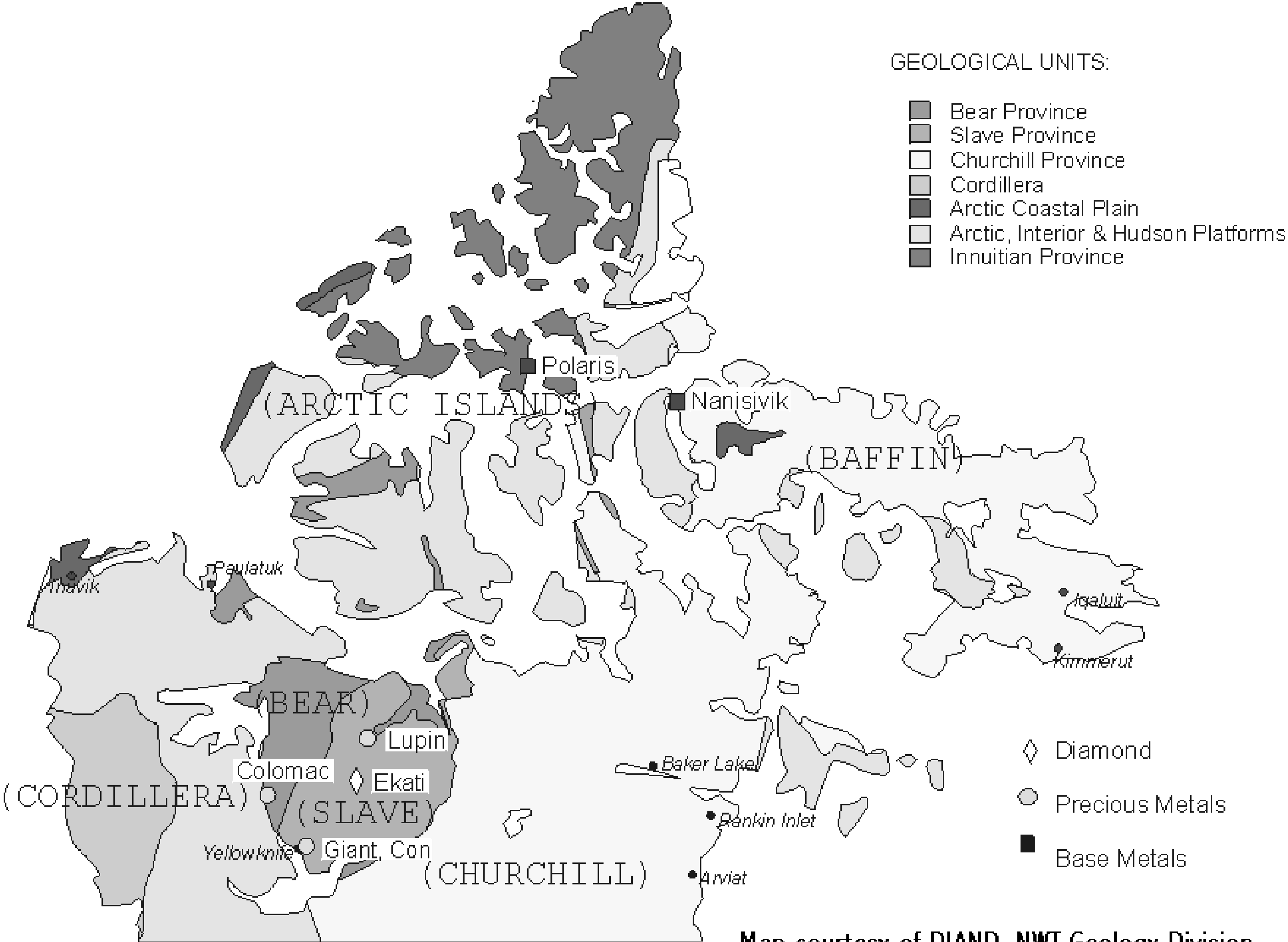
Beak Consultants Ltd. 1987. Baseline environmental monitoring at the Colomac Project site, 1987. Report prepared for Neptune Resources Corporation.

Bryant Environmental Consultants Ltd. 1996 Correlation Table Determination of Total Suspended Solids (TSS) from Field Turbidity Measurements. Unpublished data.

CCREM (Canadian Council of Resource and Environment Ministers). 1987. Canadian water quality guidelines for total suspended solids. Prepared by the Task Force on Water Quality Guidelines. Ottawa, Canada.

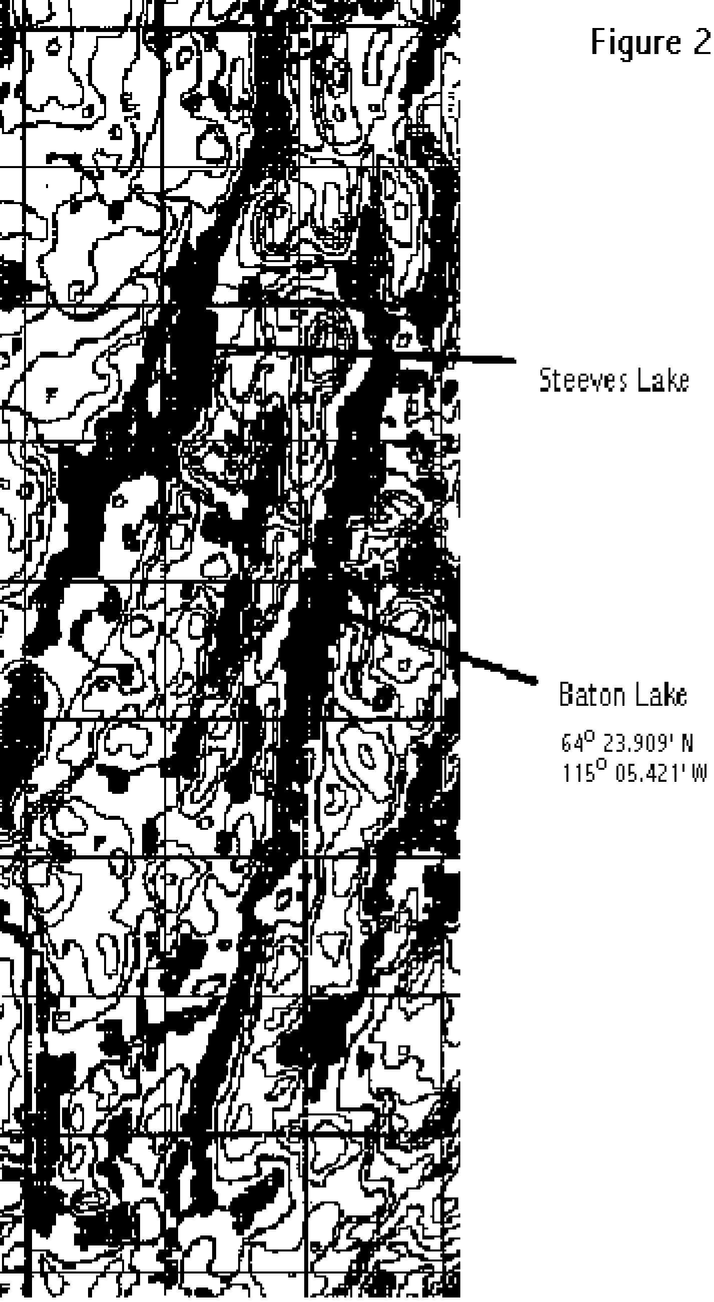
Didiuk, A., and Wright, D. 1975. The effect of a drilling waste on the survival and emergence of the chironomid *Chironomus tentans* (fabricius). Fish. Mar. Serv. Res. Dev. Tech. Rep. 586. 18 pp.

Geological Map of the Northwest Territories and Nunavut

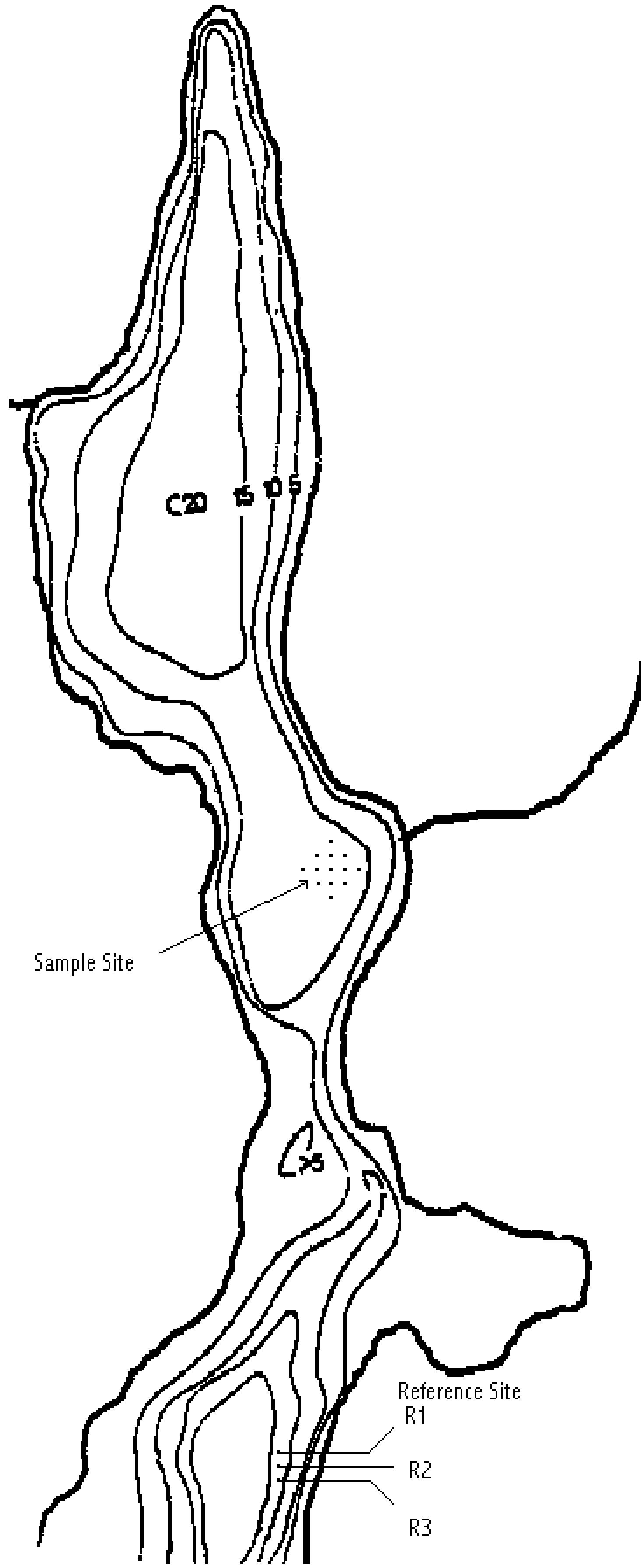


Map courtesy of DIAND, NWT Geology Division

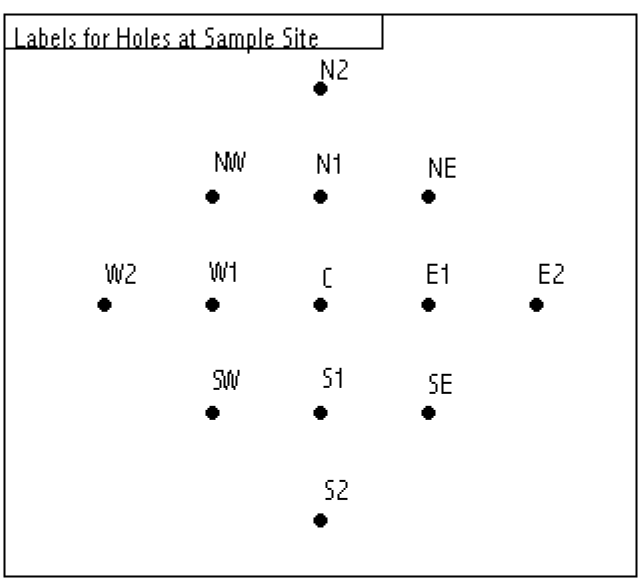
Figure 2. Baton Lake Sample Sites



(NTS map # 86B/6)



(After Beak, 1987)



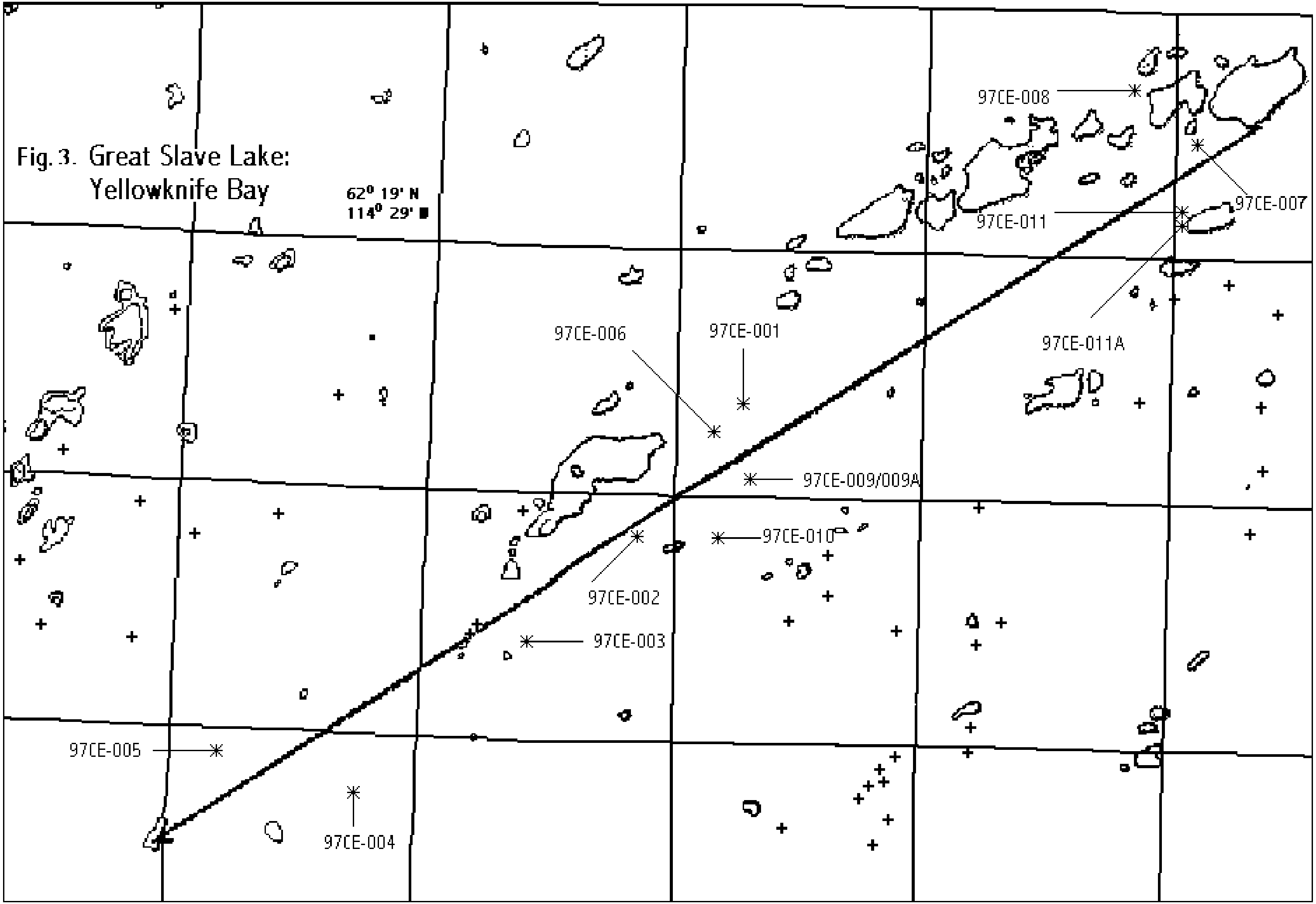


Fig. 3. Great Slave Lake: Yellowknife Bay

(NTS maps 85I/7 and 85I/8)

Figure 4. Lac de Gras - East Island
Diavik Diamond Mines Inc.

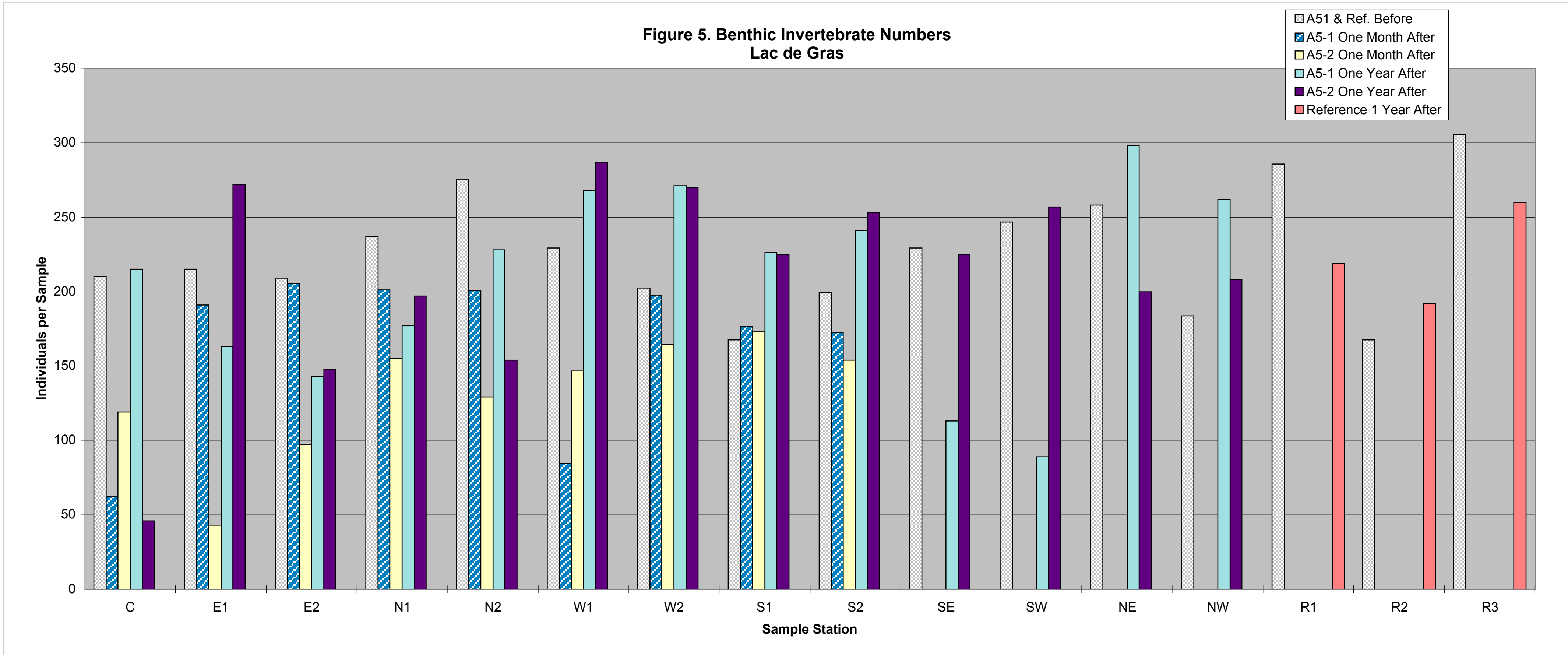


Figure 5. Benthic Invertebrate Numbers
Lac de Gras
A51 & Ref. Before
A5-1 One Month After
A5-2 One Month After
A5-1 One Year After
A5-2 One Year After
Reference 1 Year After
Individuals per Sample
0
50
100
150
200
250
300
350
C
E1
E2
N1
N2
W1
W2
S1
S2
SE
SW
NE
NW
R1
R2
R3
Sample Station

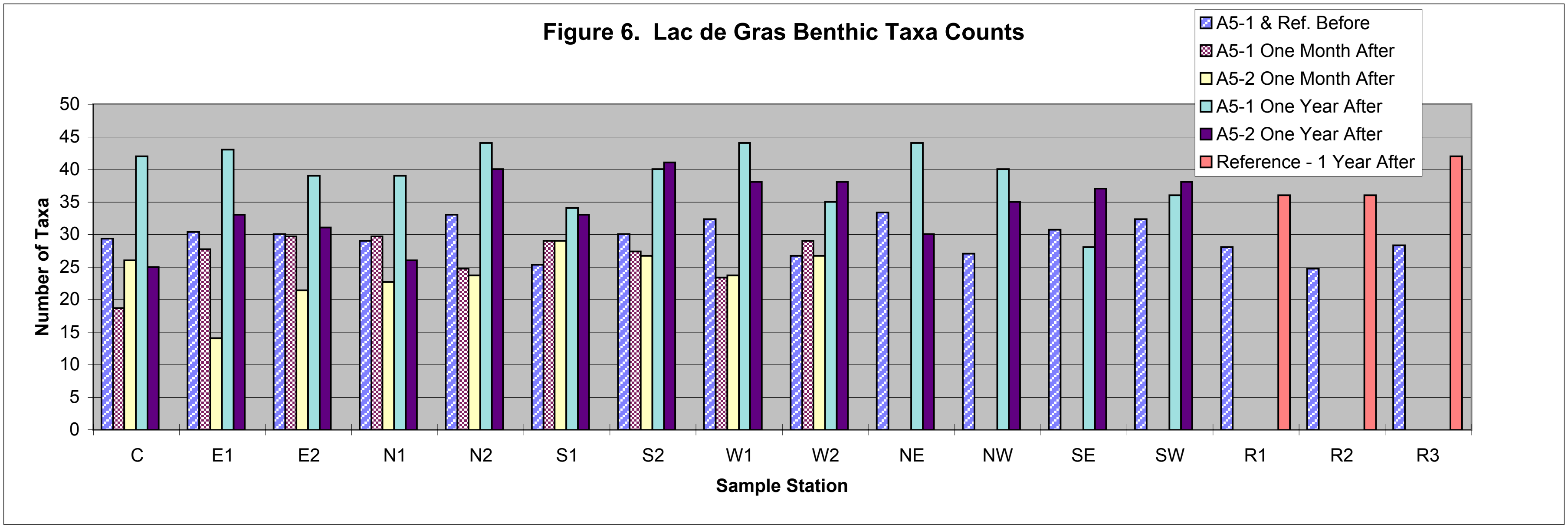


Figure 6. Lac de Gras Benthic Taxa Counts
A5-1 & Ref. Before
A5-1 One Month After
A5-2 One Month After
A5-1 One Year After
A5-2 One Year After
Reference - 1 Year After
Number of Taxa
0
5
10
15
20
25
30
35
40
45
50
C
E1
E2
N1
N2
S1
S2
W1
W2
NE
NW
SE
SW
R1
R2
R3
Sample Station

Table 1. Lac de Gras Sediment Chemistry

		A5-1 "Before"				A5-1 One Month After				A5-2 One Month After 1998				A5-1 One Year After				A5-2 One Year After				Reference Site 1998				Reference Site 1999			
		Min	Max	Mean	St.Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Organic Carbon%	Total	1.17	2.09	1.73	0.28	0.95	2.41	1.97	0.43	0.56	2.20	1.81	0.48									1.05	1.67	1.36	0.44				
Carbon%	Total	1.62	2.73	2.16	0.29	1.47	3.02	2.44	0.44	0.75	2.76	2.30	0.61									1.34	2.09	1.72	0.53				
TKN	Total	1080	2550	1746	364	777	2440	1863	474	539	2120	1624	479	1640	2840	2291	376	2020	3890	2803	431	1165	1580	1373	293	695	2270	1362	815
Ammonia - Nitrogen,	Extractable	2.9	5.5	4.0	1.0	2.5	12.5	7.1	3.1	1.9	10.0	5.0	2.3	3.5	9.5	6.2	1.8	4.0	11.5	6.3	2.3	0.9	2.0	1.4	0.8	1.5	4.0	2.5	1.3
Nitrate - Nitrogen,	Extractable	0.3	5.1	1.0	1.4	0.1	1.6	0.7	0.5	0.2	12.4	2.7	4.8	0.9	3.4	2.0	0.9	0.3	3.0	1.2	1.0	0.3	0.8	0.5	0.3	0.7	1.4	1.0	0.4
Aluminum	Extractable	10000	11500	10714	570	11500	12700	12189	382	9710	15100	12679	1568	9240	12400	9969	866	9530	12000	10410	749	14200	14300	14250	71	11800	17700	15200	3051
Aluminum	Total	55400	62400	59423	1935	55500	64100	59000	2803	44700	66200	59500	6640									64950	65500	65225	389				
Arsenic	Extractable													14	168	39	43	8	28	18	6					24	121	60	53
Barium	Extractable	66	132	95	25	76	415	155	102	64	843	176	251	67	349	139	78	68	210	102	43	80	85	83	4	94	115	102	12
Barium	Total	353	478	444	36	421	677	478	77	393	1070	515	210									459	498	479	28				
Beryllium	Extractable	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0
Beryllium	Total	0	1	1	0	1	1	1	0	1	1	1	0									1	1	1	0				
Cadmium	Extractable	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	4	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	3	B.D.	B.D.
Cadmium	Total	B.D.	B.D.	B.D.	B.D.	1	2	1	1	B.D.	B.D.	B.D.	B.D.									B.D.	B.D.	B.D.	B.D.				
Calcium	Extractable	849	1210	1045	99	969	29400	4463	9362	918	23900	4354	7359	926	5640	1540	1297	1160	2090	1434	246	1155	1325	1240	120	976	1530	1232	279
Calcium	Total	8710	10000	9307	478	8440	30400	11518	7090	8400	25400	11583	5250									9140	9395	9267	180				
Chromium	Extractable	32.4	36.0	34.3	1.4	32.6	63.0	37.1	9.7	27.6	98.1	42.4	21.3	32.0	52.0	35.5	5.5	33.0	46.0	37.1	4.1	41.1	42.4	41.7	0.9	39.0	51.0	46.0	6.2
Chromium	Total	40.2	49.6	46.0	3.0	44.8	152.0	59.4	34.8	35.7	306.7	78.8	85.8									52.9	59.6	56.2	4.8				
Cobalt	Extractable	18	66	40	16	21	82	51	22	12	62	30	15	24	109	58	28	22	68	33	14	28	29	28	0	34	59	44	13
Cobalt	Total	20	70	43	17	24	91	55	24	14	65	34	15									28	31	30	2				
Copper	Extractable	24.6	32.7	28.3	2.7	27.4	184.0	46.4	51.6	21.2	54.9	31.0	9.5	25.0	61.0	31.9	9.5	28.0	37.0	30.4	2.3	32.4	39.2	35.8	4.8	34.0	41.0	37.3	3.5
Copper	Total	26.6	32.4	29.5	2.1	26.2	164.0	43.9	45.1	22.5	69.2	33.0	13.9									32.0	38.3	35.2	4.5				
Iron	Extractable	15900	44600	28586	9032	21200	44300	29733	6987	13600	35700	23756	7329	18700	59700	29675	11886	16900	27900	20658	3117	22850	29050	25950	4384	27300	52400	36033	14185
Iron	Total	20050	49900	33295	9372	25500	51900	33900	8290	16600	40400	27911	7099									26600	32150	29375	3924				
Lead	Extractable	B.D.	B.D.	B.D.	B.D.	5	169	24	54	B.D.	B.D.	B.D.	B.D.	B.D.	55	B.D.	B.D.	B.D.	10	B.D.	B.D.	12	13	12	1	B.D.	11	B.D.	B.D.
Lead	Total	6	32	19	9	8	254	44	79	13	74	22	20									31	33	32	1				
Magnesium	Extractable	4580	5110	4839	199	4620	23600	7127	6181	4420	65200	12059	19955	4080	16400	5474	3457	4520	10100	5716	1813	6045	6220	6133	124	5230	7500	6387	1136
Magnesium	Total	6200	7060	6590	218	6140	23600	8501	5666	5830	68100	13963	20331									7735	7750	7743	11				
Manganese	Extractable	785	19100	7560	5380	1780	21600	13159	6995	1390	27300	11166	9755	2480	33000	16242	10660	1600	48900	12805	14895	1190	2960	2075	1252	2170	11600	5410	5363
Manganese	Total	908	19200	7863	5469	1800	20500	13669	7291	1530	27700	11276	9729									1170	3075	2123	1347				
Molybdenum	Extractable	B.D.	B.D.	B.D.	B.D.	5	8	6	2	2	6	4	2	B.D.	6	B.D.	B.D.	B.D.	5	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.	4	6	5	1
Molybdenum	Total	B.D.	B.D.	B.D.	B.D.	3	7	4	1	1	9	4	2									3	3	3	0				
Nickel	Extractable	27	115	61	32	34	131	89	35	25	438	91	132	29	167	89	46	31	123	58	29	44	55	50	8	43	67	53	13
Nickel	Total	32	119	62	29	36	137	92	36	27	462	97	138									46	58	52	9				
Potassium	Extractable	2600	2900	2741	97	2800	5400	3156	844	2700	4200	3067	487	2280	4820	2661	689	2370	3140	2629	234	3250	3300	3275	35	2820	3750	3250	469
Potassium	Total	18800	20900	20027	605	18500	22900	19844	1302	16300	22200	20144	1793									22100	23000	22550	636				
Selenium	Extractable													B.D.	12	B.D.	B.D.	B.D.	B.D.	B.D.	B.D.					9	13	11	3
Sodium	Extractable	100	150	126	17	130	290	194	56	120	280	184	53	135	437	185	86	155	249	182	27	145	160	153	11	147	189	171	22
Sodium	Total	18300	20800	19500	847	17300	22500	19011	1523	10600	22100	18589	3310									20200	20300	20250	71				
Titanium	Extractable	587	683	629	32	601	845	650	75	408	737	614	95	515	866	586	92	503	637	571	50	772	776	774	3	641	964	807	162
Titanium	Total	1660	2100	1985	124	1880	2200	2016	99	1720	2430	2152	226									2235	2365	2300	92				
Vanadium	Extractable	24	28	27	1	24	33	26	3	22	47	29	7	23	35	26	3	26	30	28	1	33	34	34	1	31	45	40	8
Vanadium	Total	38	49	45	3	42	49	45	2	38	93	53	16									52	57	55	4				
Zinc	Extractable	42	69	52	10	44	130	67	25	34	90	53	16	43	83	64	14	44	79	54	11	60	61	60	1	57	75	66	9
Zinc	Total	48	73	59	9	51	153	78	30	42	106	62	18									66	67	66	1				

Results are in micrograms per gram dry weight, except where reported as % weight/weight.

TKN - Total Kjeldhal Nitrogen