Attachment 6

March 4, 2011

LABORATORY REPORT ON

TAILINGS TESTING THOR LAKE PROJECT NORTHWEST TERRITORIES

Submitted to:
Mr. David Swisher
Avalon Rare Metals Inc.
130 Adelaide Street West
Suite 901
Toronto, ON M5H 3P5

REPORT

Report Number: 10-9002-0059

Distribution:

1 Copy: Avalon Rare Metals Inc., Toronto, ON

1 Copy: Golder Paste Technology Ltd., Sudbury, ON

Golder PasteTec

Study Limitations

This report was prepared for the exclusive use of Avalon Rare Metals Inc. (Avalon) on the Thor Lake Project. The report, which specifically includes all tables, figures and appendices, is based on measurements and observations made and data and information collected during the laboratory studies conducted by Golder Paste Technology Ltd. (Golder PasteTec) for Avalon. The test results are based solely on the ambient conditions of the laboratory at the time the measurements and tests were conducted.

The services performed, as described in this report, were conducted in a manner consistent with that level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

The sample(s) provided for the tests are assumed to be representative of material found at the site. The test data given herein pertains to the sample(s) provided, and may not be applicable to material from other production periods or zones. Assessment of the sample environmental conditions and possible hazards associated with the material composition is based on the results of chemical analysis of samples which are possibly from a limited number of locations. However, it is never possible, even with exhaustive sampling and testing, to dismiss the possibility that part of a site or a production line may remain undetected. The results found from the tests may not be reproducible under the field conditions.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder PasteTec by Avalon, communications between Golder PasteTec and Avalon, and to any other reports prepared by Golder PasteTec for Avalon relative to the specific site described in the report, tables, drawings, figures and appendices. ***In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder PasteTec cannot be responsible for use of portions of the report without reference to the entire report.***

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The findings and conclusions of this report are valid only as of the date of this report. If new information is discovered in future work, Golder PasteTec should be requested to re-evaluate the conclusions of this report, and to provide amendments as required.

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1.0 INTRODUCTION

Avalon Rare Metals Inc. (Avalon) has retained Golder Paste Technology Ltd. (Golder PasteTec) to carry out laboratory testing on Thor Lake tailings to assess material characteristics, rheological, dewatering and strength properties. The purpose of the work was to assess the suitability of the tailings to produce cemented backfill material in support of the underground mining operations.

2.0 SAMPLE RECEIPT AND PREPARATION

2.1 Sample Receipt

Samples received by PasteTec's Sudbury laboratory are summarized in Table 1. All samples were received in good condition; however, the lids from the first shipment did not form a tight seal which resulted in some of the sample spilling during transport. The total weight of all the shipments was 730 kg. The samples were shipped via Manitoulin Transport and Purolator.

Table 1: Sample Receipt Summary

Date	Amount / Container	Label as Received	Golder Paste Tec Sample ID
November 08, 2010	13 – 10L pails	Avalon Combined Tails Batch #1	10-9002-0059 Combined Tails
November 08, 2010	13 – 10L pails	Avalon Combined Tails Batch #2	10-9002-0059 Combined Tails
November 11, 2010	1 – 200L drum	Avalon RO Tails OCT 4 03:00	10-9002-0059 RO tails / 10-9002-0059 Final Tails decant
December 15, 2010	2 – 15L pails	Combined Tailings Slurry	10-9002-0059 Combined Tails S2
December 15, 2010	2 – 15L pails	Final Tails Decant Water	10-9002-0059 Final Tails Decant

All samples received by Golder PasteTec are subjected to material property characterization tests to establish properties and allow for comparison should future testing be required.

2.2 Hazard Assessment

Prior to handling the samples, each pail was assessed separately for hazardous gases. The gas analysis results are presented in Table 2.

Table 2: Sample Hazard Assessment

Date	Label as Received	Golder PasteTec Sample ID	VOC (ppm)	HCN (ppm)	H_2S (ppm)
November 10, 2010	Avalon Combined Tails Batch #1	10-9002-0059 Combined Tails	0	0	0
November 10, 2010	Avalon Combined Tails Batch #2	10-9002-0059 Combined Tails	0	0	0
January 04, 2011	Combined Tailings Slurry	10-9002-0059 Combined Tails S2	0	0	0
January 04, 2011	Final Tails Decant Water	10-9002-0059 Final Tails Decant	0	0	0

Date	Label as Received	Golder PasteTec Sample ID	VOC (ppm)	HCN (ppm)	H_2S (ppm)
January 05, 2011	Avalon RO Tails OCT 4 03:00	10-9002-0059 RO Tails / 10-9002-0059 Final Tails Decant	0	0	0

Metals analysis using Inductively Coupled Plasma with a Mass Spectrometer detector (ICP-MS) was performed on a composite sample obtained via individual pipe samples from each pail. This testing helps to identify health and safety hazards such as heavy metals which may be present. Additionally, the decant samples were also analyzed and compared. The samples were sent to an external laboratory for ICP-MS analysis, Figure 1, Figure 2 and Appendix A present the results.

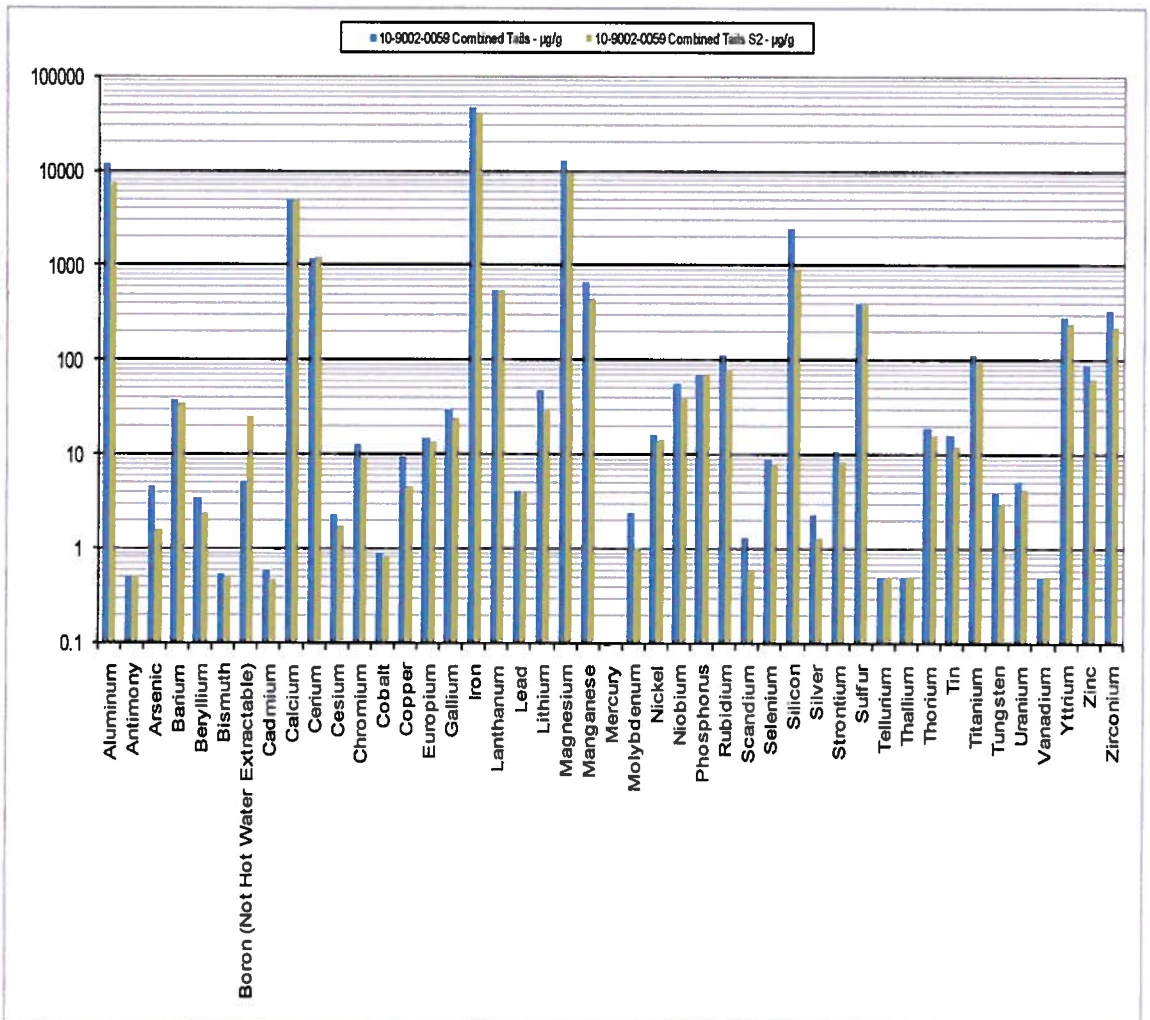


Figure 1: ICP-MS Results - Solids

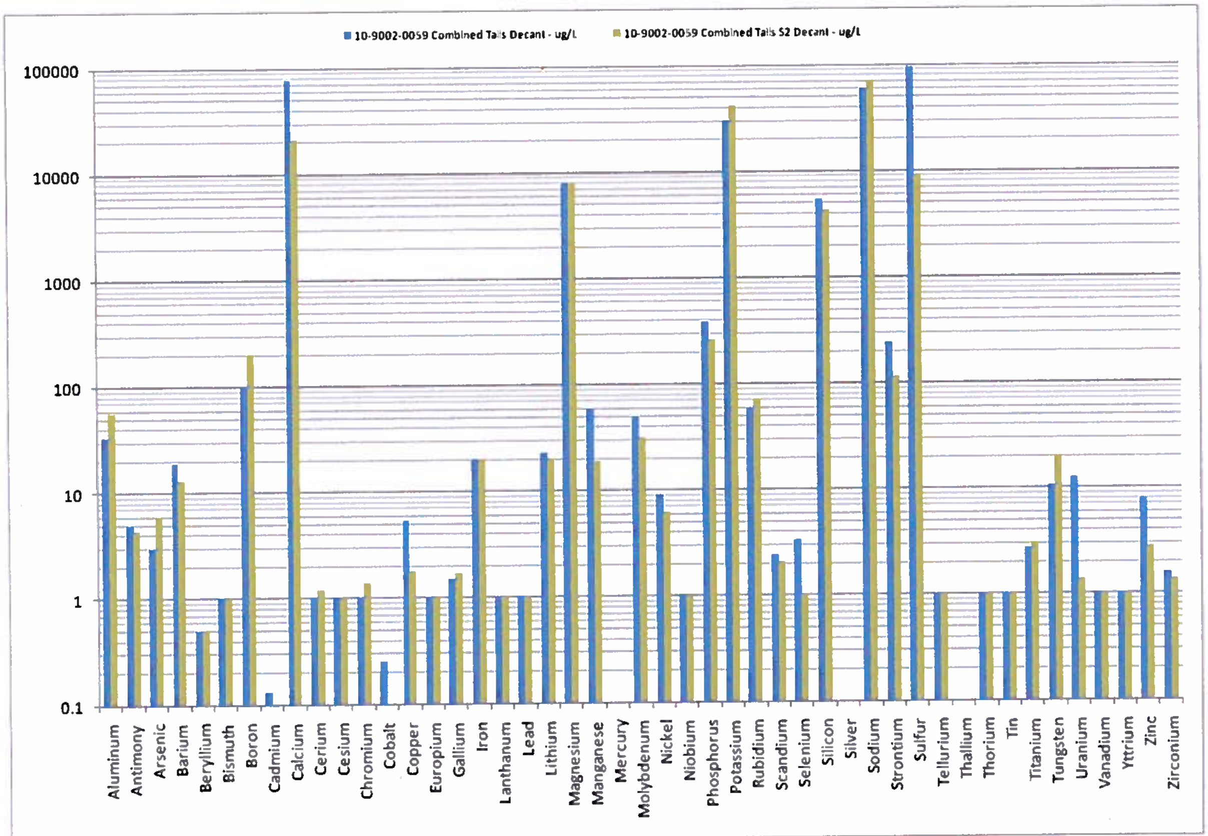


Figure 2: ICP MS Results - Water

No hazardous gases were detected in any of the samples. Also, the concentrations of heavy metals were considered to be acceptable to handle according to Golder PasteTec's established protocols.

2.3 Sample Preparation

Proper sample preparation technique is a critical first step to ensure proper homogenization of solids, representative sub-sampling and reproducibility of results.

The clear supernatant from the various pails of 10-9002-0059 Combined Tails (first sample received) was separated and combined and used during testing. The dewatered solids were then combined, homogenized and treated as one sample for the remainder of the test program.

The drum labelled Avalon RO Tails OCT 4 03:00, process water, was combined with the pails of Final decant accompanying the second sample, labelled "10-9002-0059 RO Tails / 10-9002-0059 Final Tails Decant" and was shipped to Outotec at the request of Avalon.

The second sample was received in order to confirm material characteristics and perform comparison testing for settling and rheology. The supernatant water was decanted from the 10-9002-0059 Combined Tails S2 samples and the remaining solids were combined and treated as one sample. The decant water was used during testing.

3.0 MATERIAL CHARACTERIZATION

3.1 pH Analysis

Table 3 presents the pH of each sample and the temperature at which it was measured.

Table 3: pH Analysis

Sample	pH	Temperature (°Celsius)
10-9002-0059 Combined Tails	9.2	20
10-9002-0059 Combined Tails Decant	8.0	20
10-9002-0059 Combined Tails S2	9.1	16
10-9002-0059 Combined Tails S2 Decant	8.3	16

3.2 Particle Size Distribution

Particle size distribution (PSD) was determined using mechanical sieving and a Fritsch laser particle size analyzer according to ASTM D4464.

Specific values are presented in Table 4. The gradation parameter DXX, tabulated in microns refers to the average particle diameter that XX% by weight of material is smaller than.

Table 4: Particle Size Distribution

Sample	D10 (µm)	D30 (µm)	D50 (µm)	D60 (µm)	D80 (µm)
10-9002-0059 Combined Tails	2	7	19	26	46
10-9002-0059 Combined Tails S2	2	6	19	27	47

Figure 3 presents the results.

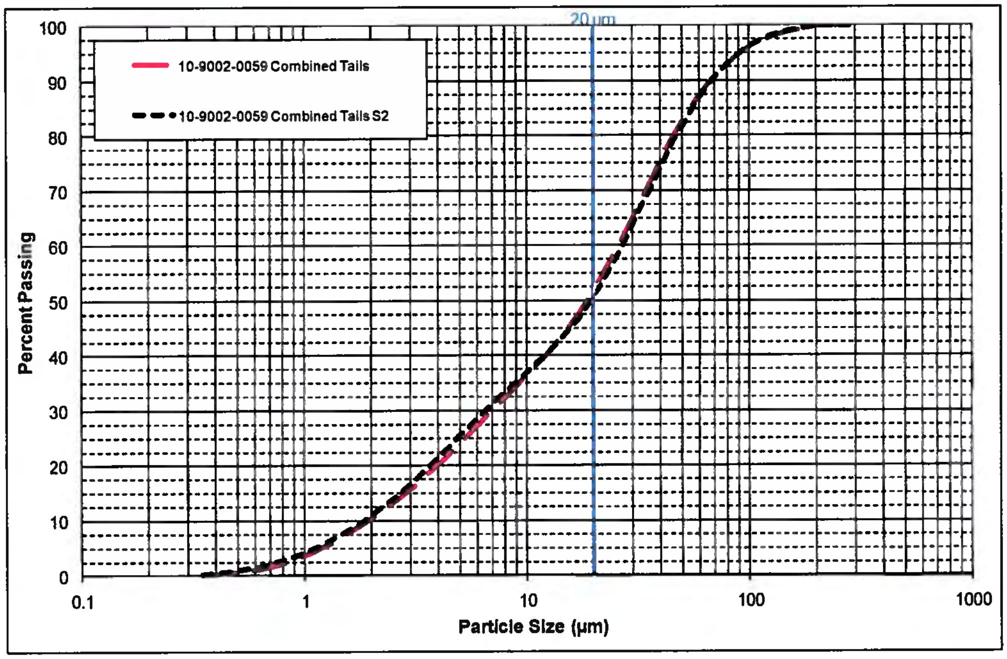


Figure 3: PSD Results

3.3 Specific Gravity

The specific gravity (SG) of the sample was determined using vacuum de-aired water. Each slurry sample was also vacuum de-aired prior to SG measurement. The results are presented in Table 5.

Table 5: Specific Gravity Results

Sample	Trial 1	Trial 2	Average
10-9002-0059 Combined Tails	2.8	2.8	2.8
10-9002-0059 Combined Tails S2	2.7	2.7	2.7

3.4 Chemistry and Mineralogy

Chemical and mineralogical analyses are performed using whole rock analysis (WRA) by inductively coupled plasma (ICP) and X-ray diffraction (XRD) via semi-quantitative analysis by Rietveld Method, respectively. The results are presented in Tables 6 and 7 as well as on Figures 4 and 5.

Table 6: Chemical Composition (wt%)

Sample	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	LOI	MgO	MnO	Na_2O	P_2O_5	S	SiO_2	SrO	TiO_2	Total
10-9002-0059 Combined Tails	12.70	0.01	0.65	<0.01	10.95	5.44	1.30	2.23	0.09	3.08	0.05	0.01	58.50	<0.01	0.03	95.00

Table 7: Semi Quantitative Mineralogical Composition - 10-9002-0059 Combined Tails

Mineral SQ-XRD	Chemical Formula	Wt%
Albite	NaAlSi3O8	34.87
Quartz	SiO2	19.69
Annite/Phlogopite	KFe2(Si,Al)4O10(OH)2	17.64
Diopside	CaMgSi2O6	11.78
Orthoclase	KAlSi3O8	8.92
Dolomite\Ankerite	Ca(Mg0.67Fe0.33)(CO3)2	3.23
Hematite	Fe2O3	2.15
Chlorite	(Mg,Fe)6(Si,Al)4O10	1.72
	Total	**100.00**

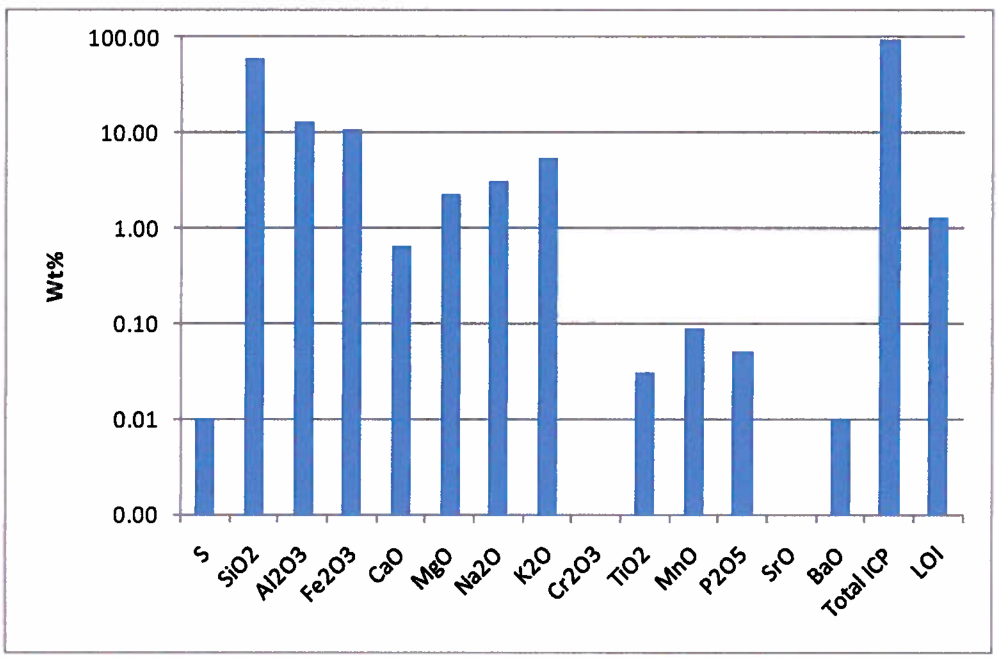


Figure 4: WRA Results

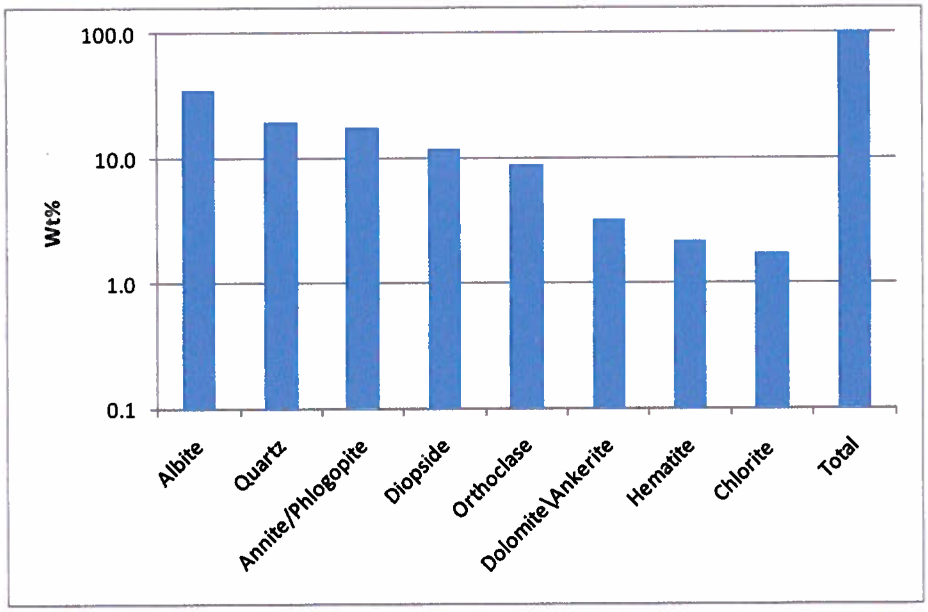


Figure 5: XRD Results

4.0 RHEOLOGICAL CHARACTERIZATION

Rheological testing is carried out to evaluate flow and handling properties. These tests provide an indication regarding the material's behaviour in the course of mixing, slump adjustment, pumping, flowing and also while sitting idle. Rheological characterization provides data for the selection of process equipment such as mixers, pumps and pipelines.

4.1 Slump vs. Solids Content

To gauge sensitivity to water additions, small increments of water were added to the bulk sample. After each addition, slump and solids content was determined. This generates a relationship between slump and solids content which is typically used to determine the degree of process control required to maintain slump control of the final product. The results are presented on Figure 6.

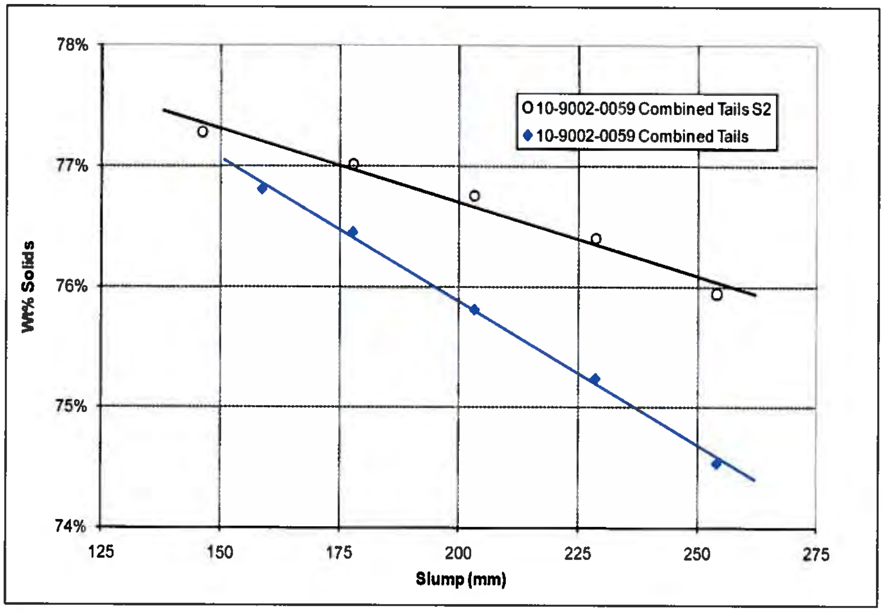


Figure 6: Solids Content vs. Slump

4.2 Static Yield Stress Testing

Yield stress is defined as the minimum force required to initiate flow. Static yield stress is determined by using a very slow moving (0.2 RPM) vane spindle attached to a torque spring. The spindle is immersed in the sample and measurements are taken at various solids contents. There are different test methods to determine yield stress, one termed 'static' and the other 'dynamic'. Figure 7 presents the static yield stress testing results.

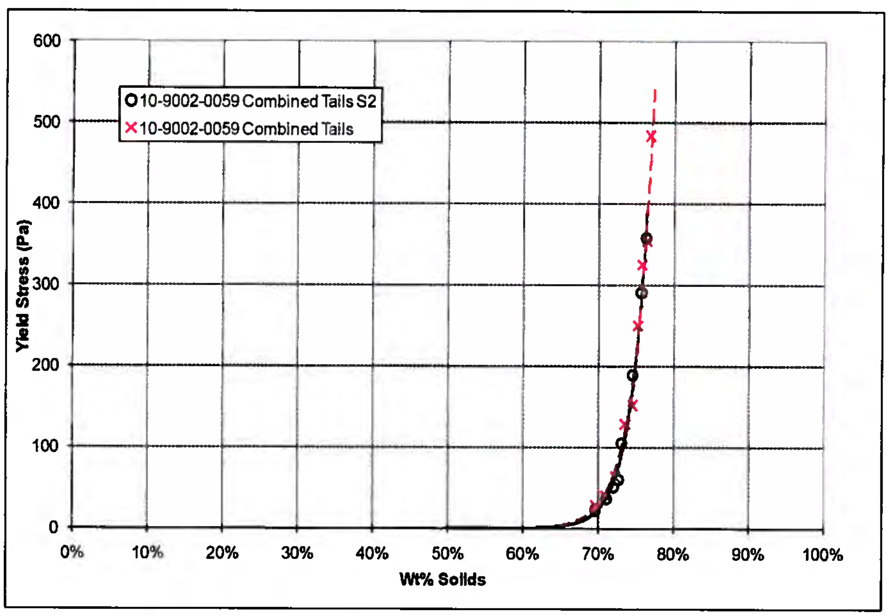


Figure 7: Static Yield Stress vs. Wt% Solids

4.3 Water Bleed and Yield Stress vs. Time

Moisture retention testing was carried out to assess the water bleed properties of the paste while sitting idle in test beakers. Two slump consistencies are tested at four time intervals. At each time interval the water bleed and yield stress were measured. Figure 8 presents the results.

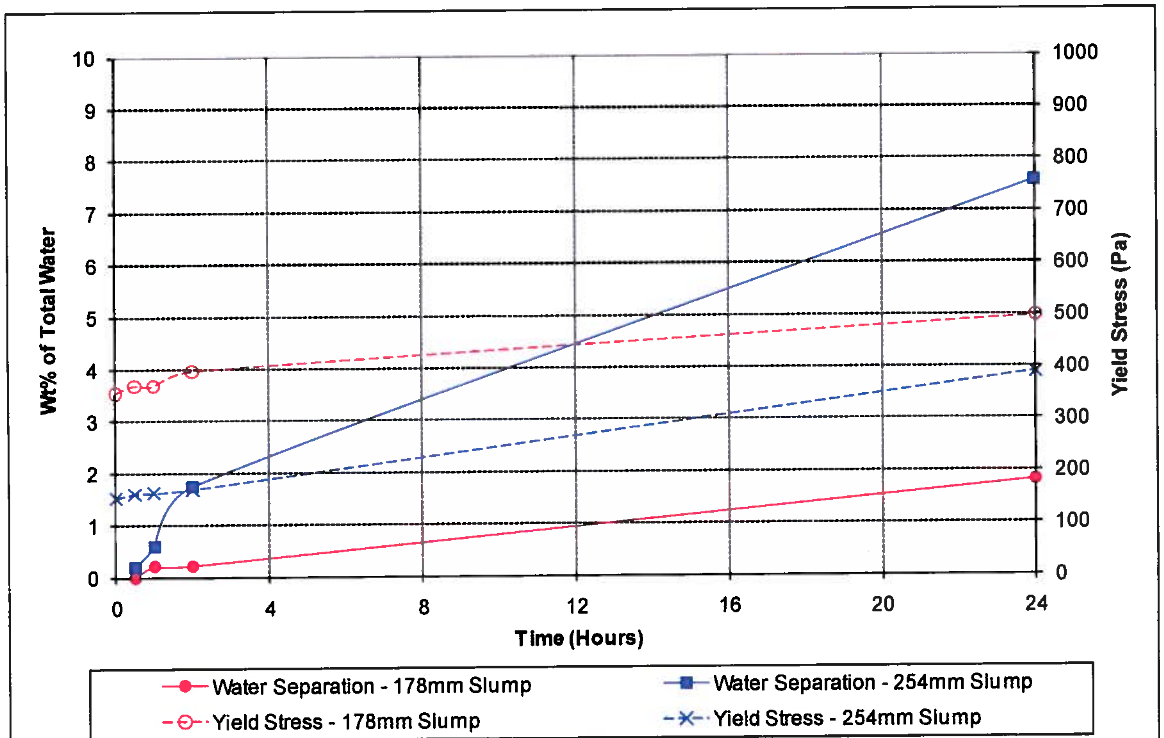


Figure 8: Water Bleed and Yield Stress vs. Time – 10-9002-0059 Combined Tails

4.4 Plug Yield Stress

Plug yield stress analysis is performed to determine if segregation has occurred throughout a cross-section of idle paste material, as may be present in a pipeline's cross-section. Two slump consistencies of material are allowed to sit idle for two hours, and a specially designed vane spindle is immersed at three depths to measure yield stress. Figure 9 presents the results.

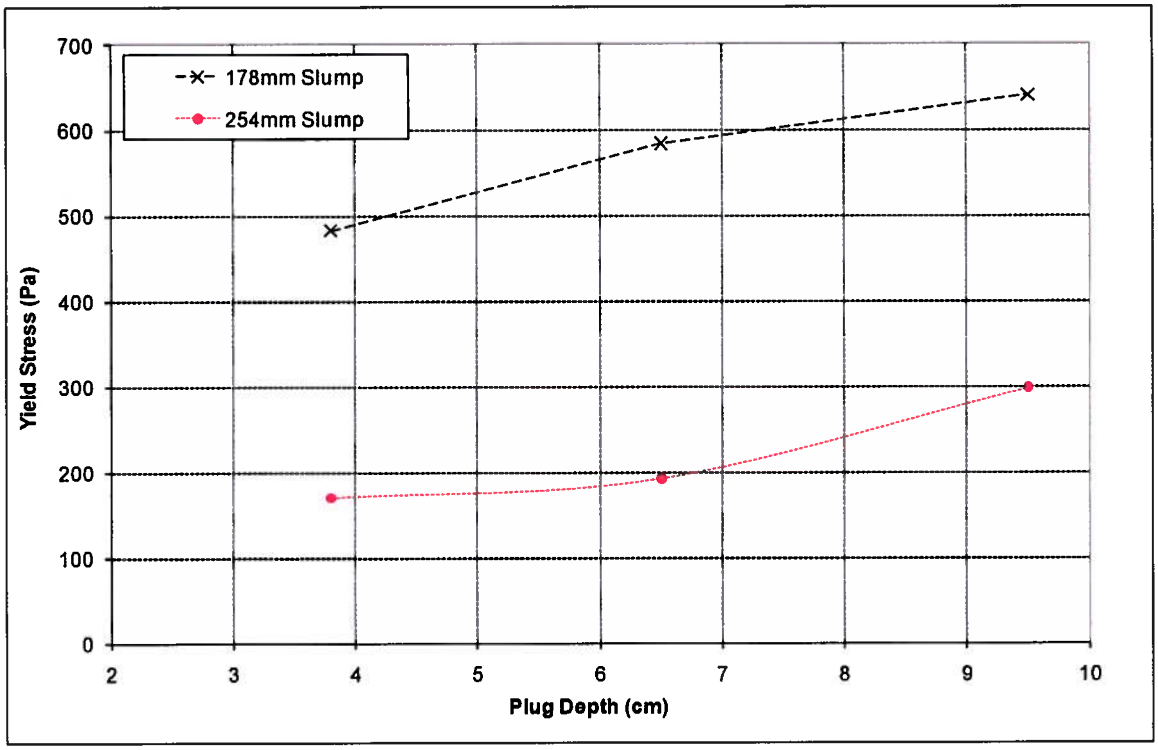


Figure 9: Plug Yield Stress Results – 10-9002-0059 Combined Tails

4.5 Viscosity and Dynamic Yield Stress Determination

Viscosity testing provides bench scale flow properties and fluid characterization. Dynamic viscosity and yield stress data is essential for mixer, pump and pipeline design. In order to compare or duplicate viscosity results of non-Newtonian fluids, it is important to test according to the same conditions. Test conditions and parameters such as cycle time and instrument sensor configuration are critical to producing usable data from bench scale viscometers.

The yield stress determined through this testing is referred to as dynamic yield stress since it is extrapolated from dynamic shear stress data, extrapolated to zero shear. The instrument sensor or bob rotates inside the cup which contains the sample and torque measurements are recorded at several incremental speeds or shear rates.

The rheograms are presented in Appendix B and summarized test results are presented on Figures 10 and 11.

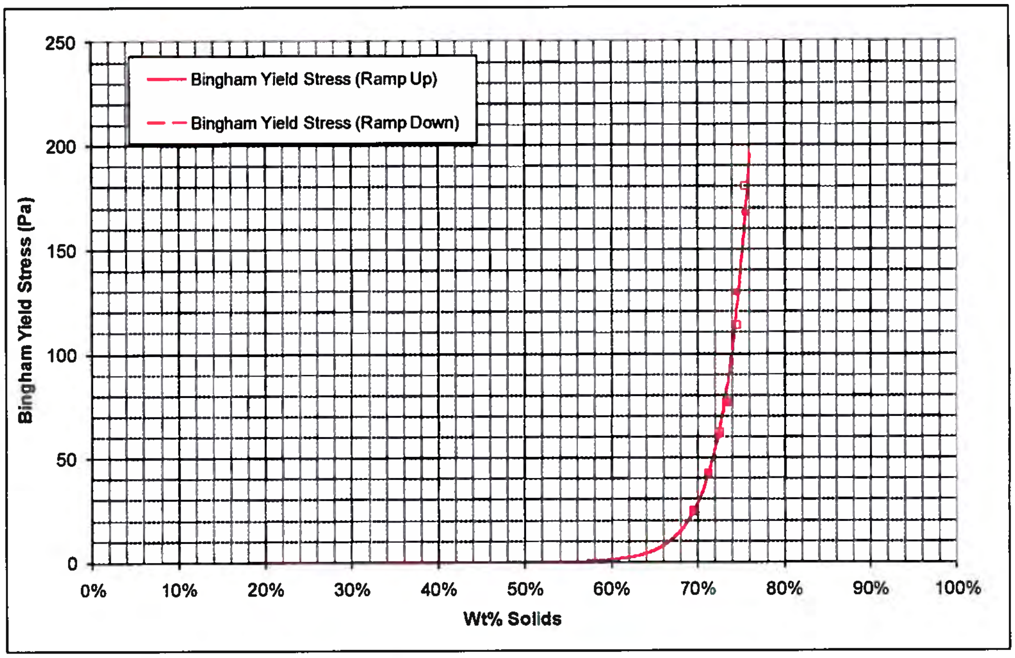


Figure 10: Bingham Yield Stress Results – 10-9002-0059 Combined Tails

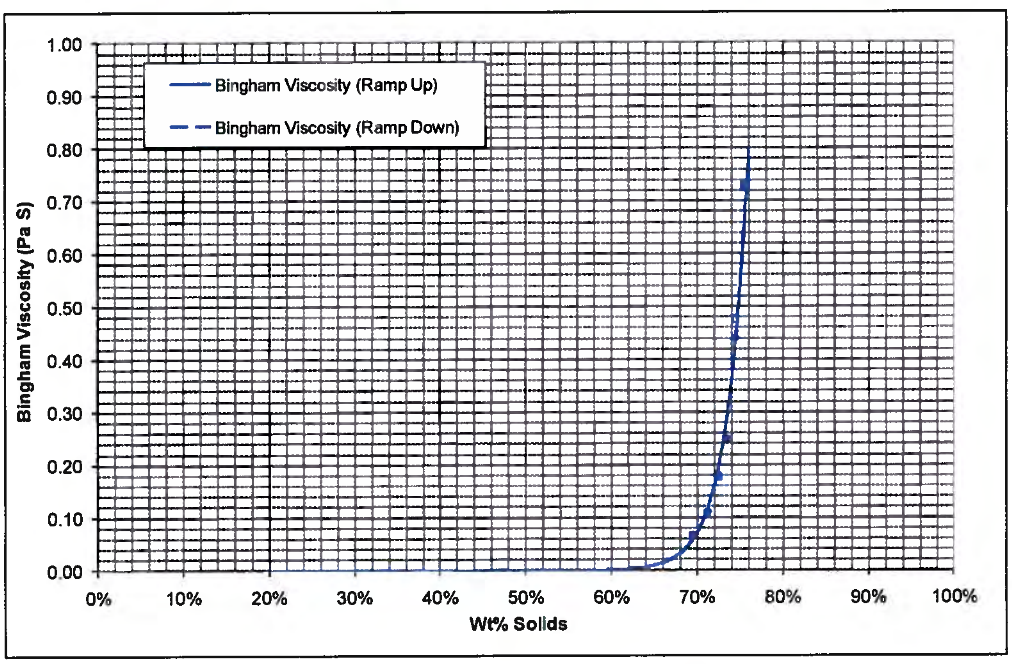


Figure 11: Bingham Viscosity Results – 10-9002-0059 Combined Tails

5.0 DEWATERING TESTING

5.1 Dewatering Summary

Dewatering tests were performed using settling, centrifuge and vacuum filtration techniques. A summary of all tests illustrating the resulting underflow densities in weight percent solids (wt% solids) is presented on Figure 12.

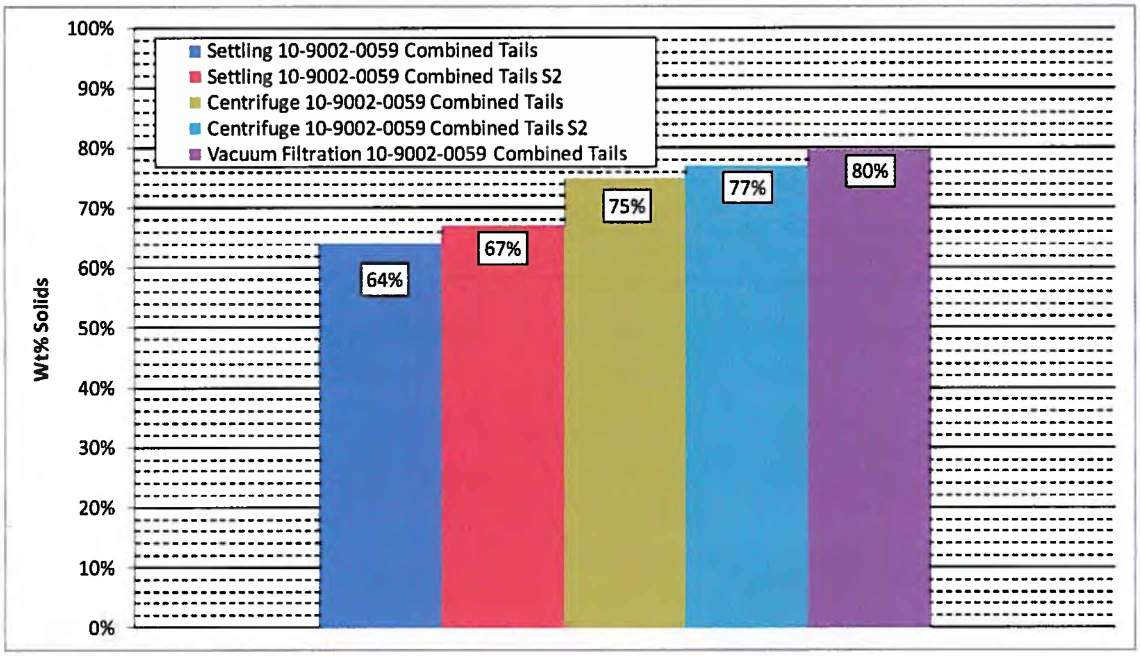


Figure 12: Dewatering Summary

5.2 Settling Tests

The first stage of settling tests usually consists of an assessment of the potential for thickening through use of synthetic polymers. Several types of flocculants are screened in order to test a range of parameters such as charge density and molecular weight. The typical types of flocculants considered are the anionic and non ionic polymers. Table 8 shows the flocculants which were examined and their properties.

Table 8: Flocculant properties

Flocculant	Manufacturer	Type	Ionicity (mole %)	Molecular Weight
AN 920 VHM	SNF	Non - ionic	0	Very High
AN 905 VHM	SNF	Anionic	5	Very High
AN 926 VHM	SNF	Anionic	25	Very High
AN 945 SH	SNF	Anionic	40	High
AN 977 SH	SNF	Anionic	70	High
MF 919	BASF	Anionic	46	Very High

To select the most effective flocculant, several factors are examined such as initial settling velocity, overflow clarity, floc size and structure as well as underflow density. The overflow clarity is measured in NTU (Nephelometric Turbidity Unit) where lower numbers indicate clearer water. The screening results are presented in Table 9, Figure 13 and Figure 14. All screening tests were performed in 500 mL cylinders.

Table 9: Flocculant Screening Results

Flocculant	Dosage (g/tonne)	Feed Solids (Wt% Solids)	Overflow Clarity after 45 minutes (NTU)	Initial Settling Rate (m/hour)	Calculated Underflow Density (Wt% Solids)	Floc Size	Floc Structure
AN 920 VHM	22	10	982	13	54	Small	Normal
AN 905 VHM	22	10	530	63	53	Small	Normal
AN 926 VHM	22	10	790	72	51	Medium	Normal
AN 945 SH	22	10	676	50	51	Medium	Normal
AN 977 SH	22	10	630	7	51	Small	Normal
MF 919	22	10	764	42	51	Medium	Normal

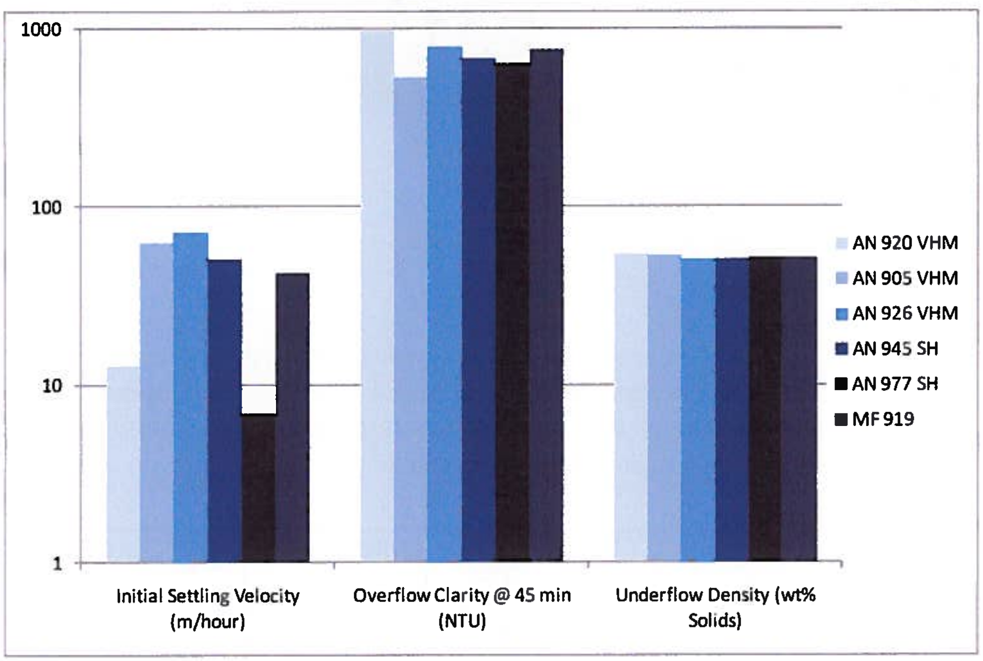


Figure 13: Flocculant Screening Results – 10-9002-0059 Combined Tails

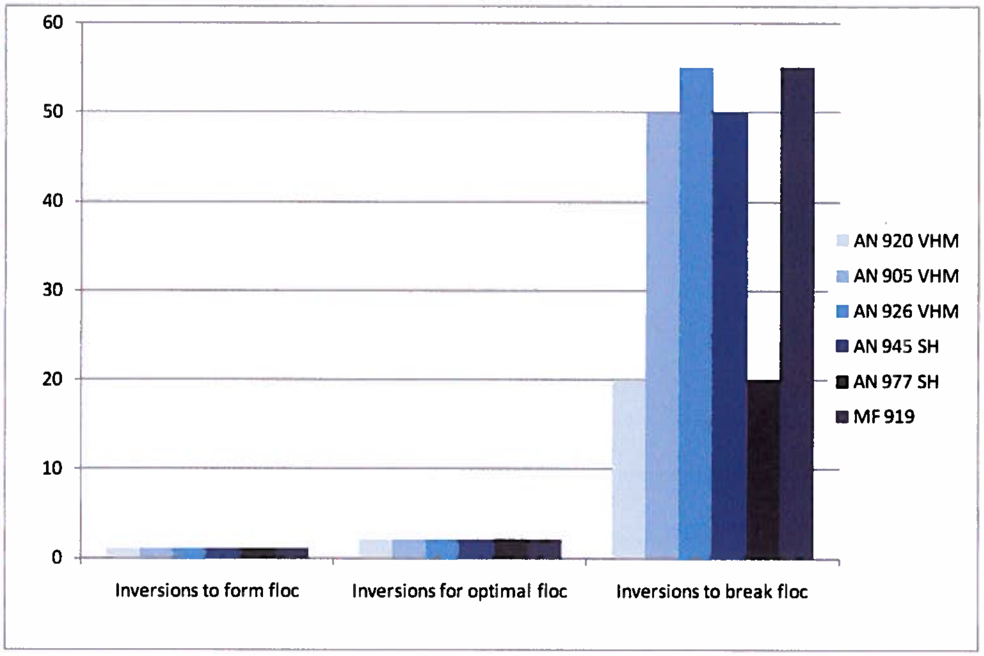


Figure 14: Flocculant Strength Results – 10-9002-0059 Combined Tails

Based on the screening results, AN 905 VHM was chosen as the best flocculant for dewatering the 10-9002-0059 Combined Tails sample. The next step in the settling tests was to optimize flocculant dosage and feed solids. The dosage represents the amount of flocculant (polymer) in grams for each tonne of material. These tests were carried out in 1L cylinders and underflow solids were raked and measured after settling for 45 minutes. Overflow clarity measurement were also taken at the 45 minute interval. Additionally, a correlation between NTU and total suspended solids (TSS) measured in parts per million (ppm) from the overflow was established. This was performed since a 500 ppm limit was communicated from the client. The results are summarized in Table 10 and Figure 15 to Figure 17.

Table 10: NTU to TSS Correlation

NTU	TSS (ppm)
163	36
384	280
696	466

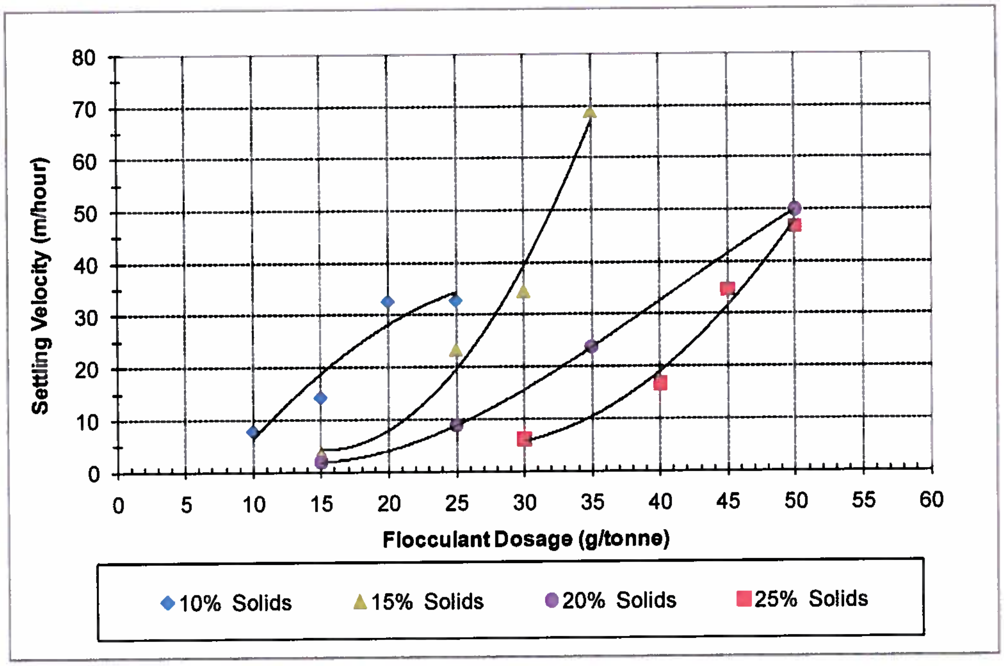


Figure 15: Settling Velocity vs. Flocculant Dosage at Varying Feed Solids – 10-9002-0059 Combined Tails

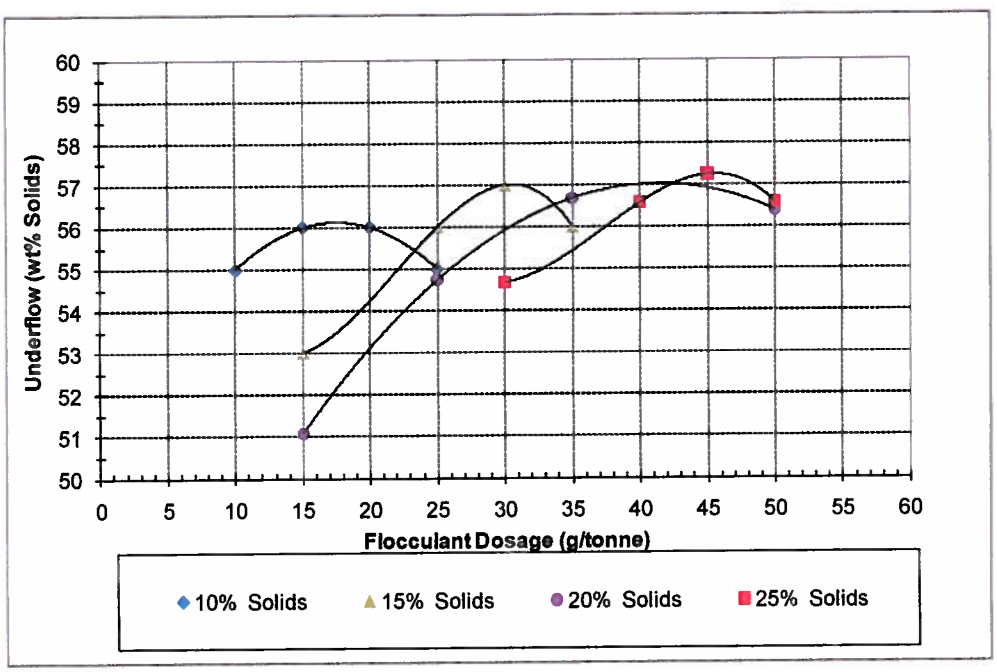


Figure 16: Underflow Wt% Solids vs. Flocculant Dosage at Varying Feed Solids – 10-9002-0059 Combined Tails

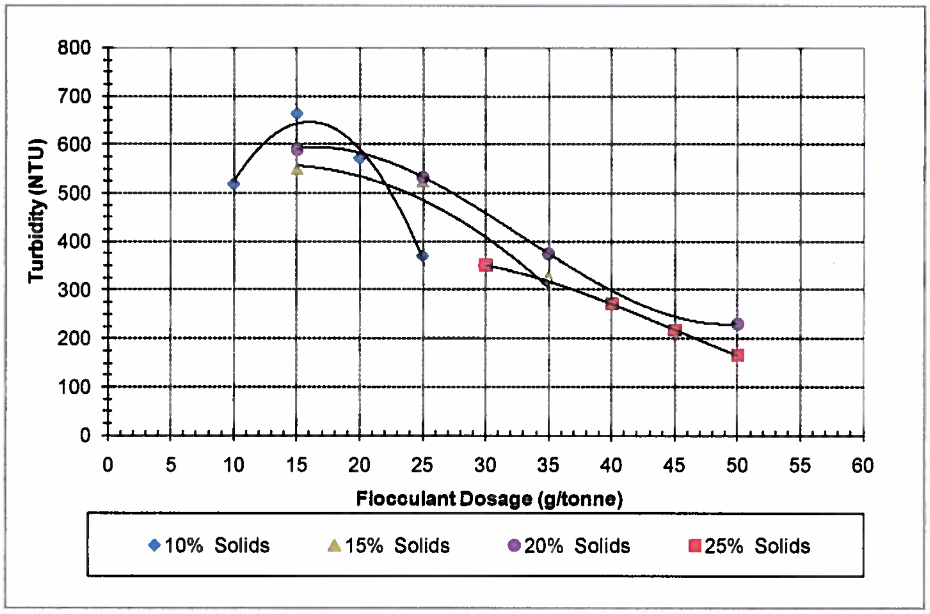


Figure 17: Turbidity vs. Flocculant Dosage at Varying Feed Solids – 10-9002-0059 Combined Tails

Subsequently, 2 stage flocculation was examined in order to investigate if overflow clarity could be improved where 25% of the flocculant dose was used as the initial amount followed by the remainder of the polymer after a 30 second interval. Figure 18 presents a summary and also compares the results of the 2 stage flocculation with the single stage flocculation.

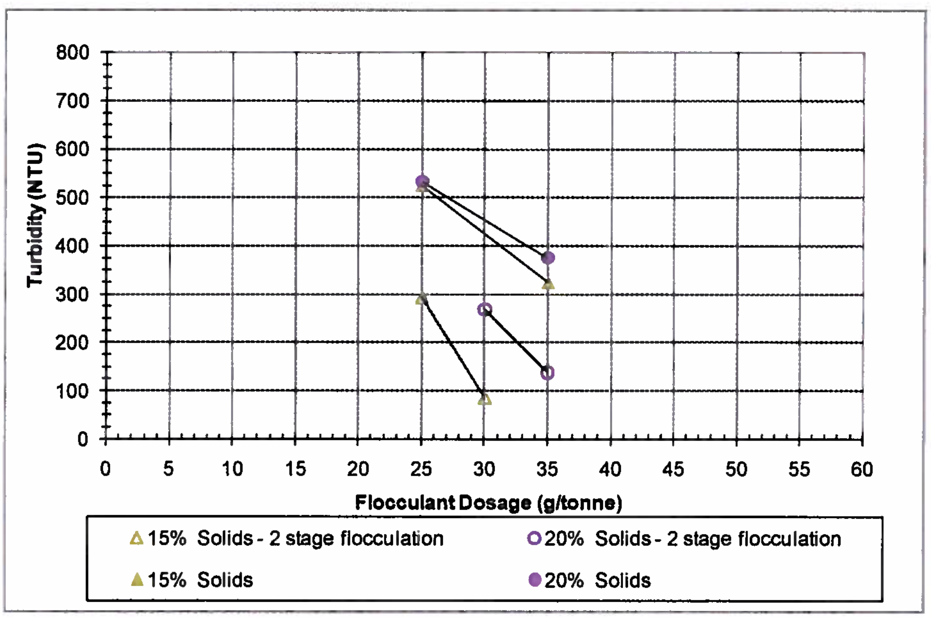


Figure 18: Turbidity vs. Flocculant Dosage at Varying Feed Solids - Single and Double Stage Flocculation – 10-9002-0059 Combined Tails

The optimal conditions from the screening results were carried forward to larger scale 4L tests to more accurately determine the underflow density. These tests are considered static, bench scale and actual underflow solids depending on thickener technology may differ.

Based on the results obtained during the screening process, it was determined that a feed density of 15 wt% solids and a flocculant dosage of 25 g/tonne would provide good settling characteristics for the 10-9002-0059 Combined Tails sample. Figures 19 and 20 present the settling curves and the summary is presented in Table 11.

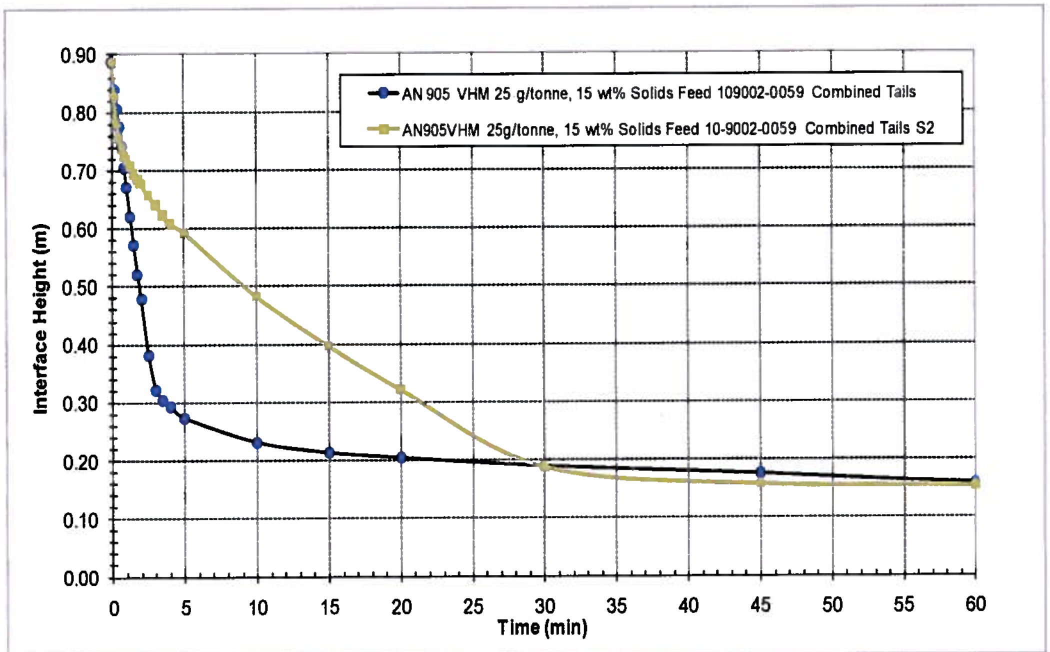


Figure 19: Settling Curve, 15% Solids Feed, 25 g/tonne

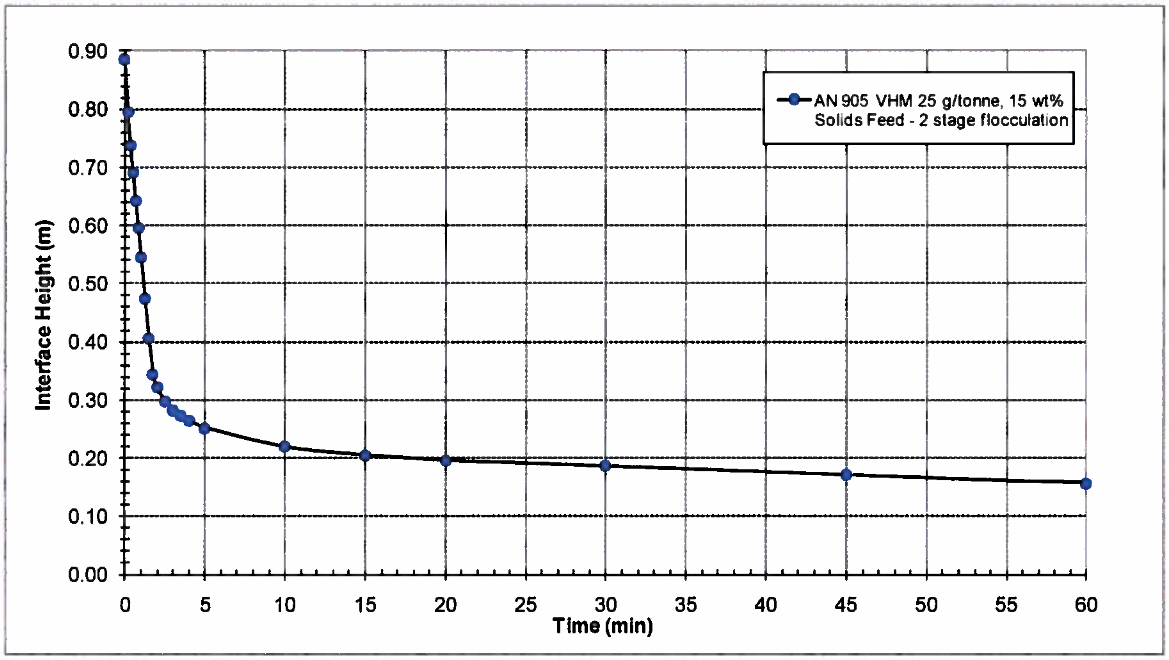


Figure 20: Settling Curve, 15% Solids Feed, 25 g/tonne – 2 Stage Flocculation– 10-9002-0059 Combined Tails

Table 11: 4L Settling Summary

Sample	Flocculation	Overflow Clarity after 45 minutes (NTU)	Calculated Underflow Density after 1 hour (wt%)	Calculated Underflow Density after 2 hours (wt%)	Calculated Underflow Density after 24 hours (wt%)	Measured Underflow Density after 24 hours (wt%)
10-9002-0059 Combined Tails	Single stage	196	57	62	64	64
10-9002-0059 Combined Tails S2	Single stage	719	58	60	68	67
10-9002-0059 Combined Tails	2 stage	170	58	62	64	64

5.3 Centrifuge Testing

Samples of the underflow solids from the 4L settling tests were centrifuged until no further change in density was observed. This testing provides the 'phi max' value, which relates to the maximum density achievable by use of high compression gravimetric settling methods. Table 12 presents the results.

Table 12: Centrifuge Results

Sample	Flocculation	Flocculant Dosage (g/tonne)	Feed Solids (Wt% Solids)	Measured Underflow Density from 4L Settling (Wt% Solids)	Calculated Underflow Density from Centrifuge (Wt% Solids)
10-9002-0059 Combined Tails	Single stage	25	15	64	75
10-9002-0059 Combined Tails S2	Single stage	25	15	67	77
10-9002-0059 Combined Tails	2 stage	25	15	64	75

5.4 Filtration Testing

Tests were conducted to evaluate vacuum filtration as a possible dewatering treatment option for paste production. A range of sample consistencies were tested using the underflow density results from the 4L settling tests as the intermediate wt% solids to examine. Additional consistencies of sample at 5 wt% greater and 5 wt% lower were also tested.

The filter leaf is equipped with a small section of industrial grade polypropylene felt filter cloth. The leaf is immersed into the slurry and simulates production scale vacuum filters where the sectors dip into the slurry in an agitated filter tank as the disc rotates. Proper technique and cycle times simulating continuous filters provide an estimate of cake loading, moisture and discharge characteristics.

Since the test is performed in the laboratory, under ideal conditions, actual loading is multiplied by 0.7 to reflect variable or upset conditions which may occur in plant operations.

The following parameters were used for testing:

Vacuum Level: 635 mm (25") and 711 mm (28") Hg
Temperature: 18°C (64°F)
Filter Cloth: Industrial grade polypropylene felt 133-03 (25-40 cfm rating)
Apparatus: 100 mm (4 inch) diameter, dip style filter head

The results are presented in Tables 13 through 15 and on Figures 21 and 22.

Table 13: Filtration Results - 69 wt% Solids – 10-9002-0059 Combined Tails

Vacuum Level (mm Hg)	Cycle Time (sec)	Cake Thickness (mm)	Cake Loading (kg/m^2/hr)	Cake Moisture (wt%)	Final Density (wt% Solids)
635	30	8	923	20	80
635	45	9	730	20	80
635	90	11	460	20	80
635	153	14	379	20	80

Vacuum Level (mm Hg)	Cycle Time (sec)	Cake Thickness (mm)	Cake Loading ($kg/m^2/hr$)	Cake Moisture (wt%)	Final Density (wt% Solids)
635	180	14.4	309	20	80
711	90	11	486	20	80

Table 14: Filtration Results - 64 wt% Solids – 10-9002-0059 Combined Tails

Vacuum Level (mm Hg)	Cycle Time (sec)	Cake Thickness (mm)	Cake Loading ($kg/m^2/hr$)	Cake Moisture (wt%)	Final Density (wt% Solids)
635	30	6	148	21	79
635	45	7	117	21	79
635	90	8	73	2	80
635	153	10.5	58	20	80
635	180	11.5	50	19	81
711	90	9	76	20	80

Table 15: Filtration Results - 59 wt% Solids – 10-9002-0059 Combined Tails

Vacuum Level (mm Hg)	Cycle Time (sec)	Cake Thickness (mm)	Cake Loading ($kg/m^2/hr$)	Cake Moisture (wt%)	Final Density (wt% Solids)
635	30	4	107	21	79
635	45	5	83	21	79
635	90	7	55	20	80
635	153	7.5	42	21	79
635	180	8	34	21	79
711	90	6	54	20	80

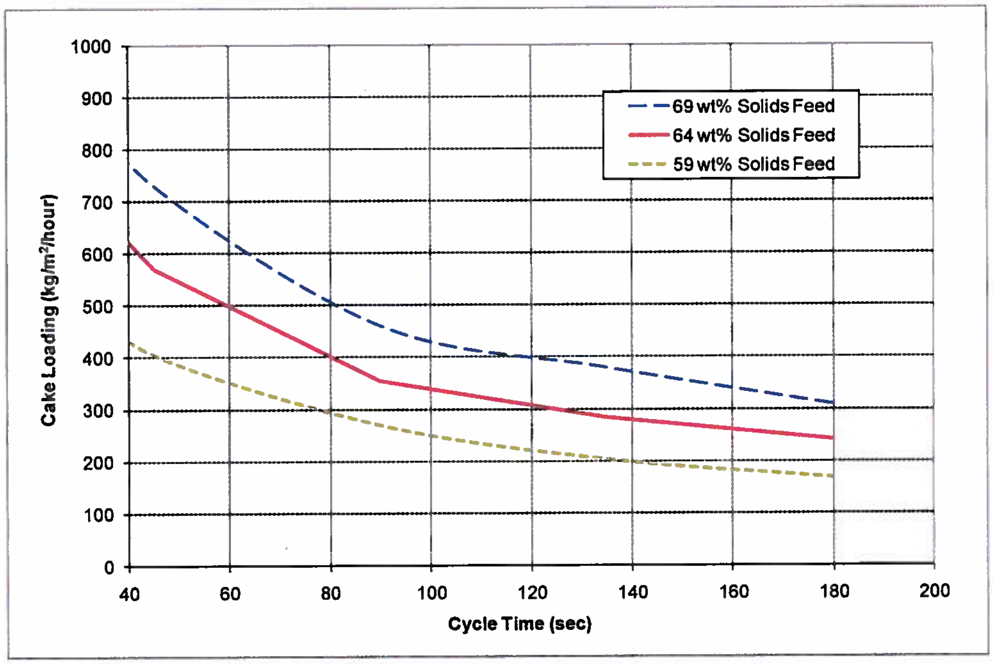


Figure 21: Cake Loading vs. Cycle Time at various feed solids – 10-9002-0059 Combined Tails

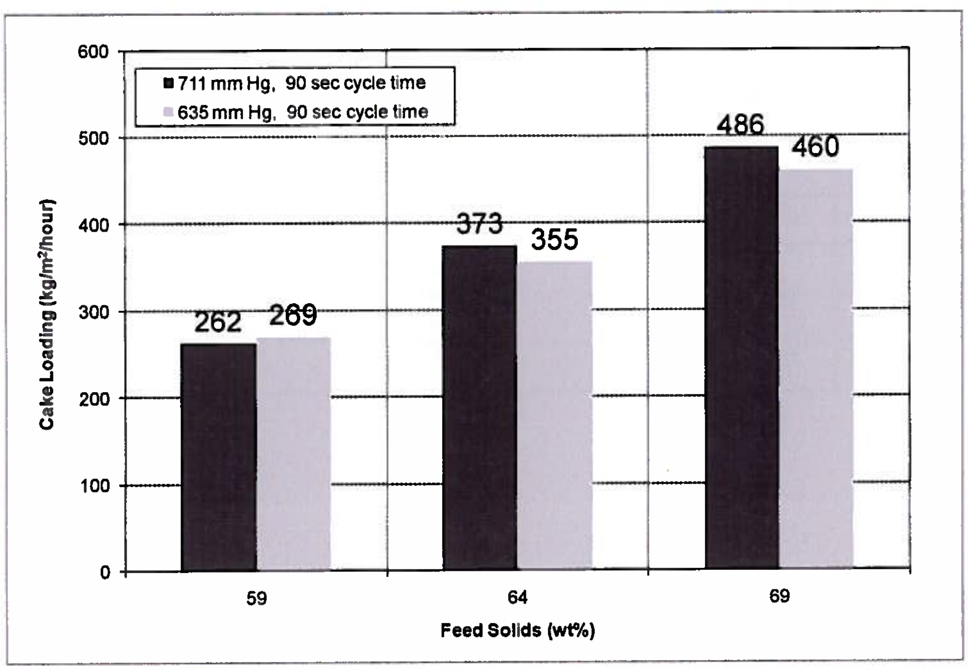


Figure 22: Cake Loading vs. Feed Solids at various vacuum levels – 10-9002-0059 Combined Tails

6.0 UNCONFINED COMPRESSIVE STRENGTH TESTING

Unconfined compressive strength (UCS) testing was carried out using a Humboldt HM3000 digital load frame. The load was measured using s-type load cells. Depending on strength either a 10 kN or 45 kN (2,000 lb or 10,000 lb) load cell was utilized.

The cured cylinder was placed between two platens and during testing the bottom platen advances at a rate of 2 mm (0.08 inches) per minute. The load was continuously monitored and the peak load was automatically recorded by the instrument.

6.1 UCS Program and Results

The UCS program was carried out to assess the backfill strength using 76 x 152 mm (3" x 6") cylinders. The cylinders were cured in a high humidity environment maintained at 20 to 25°C (68 to 77°F). Three cylinders per curing period were cast and the results were averaged. The test program is presented in Table 16 and the results are presented on Figure 23.

Table 16: UCS Testing Program

Mix	Wt% Binder	Binder	Material	Slump (mm)	Curing 7 days	Curing 28 days	Curing 56 days	Total
1	3	NPC	10-9002-0059 Combined Tails	178	3	3	3	9
2	5	NPC	10-9002-0059 Combined Tails	178	3	3	3	9
3	7	NPC	10-9002-0059 Combined Tails	178	3	3	3	9
4	3	NPC	10-9002-0059 Combined Tails	254	3	3	3	9
5	5	NPC	10-9002-0059 Combined Tails	254	3	3	3	9
6	7	NPC	10-9002-0059 Combined Tails	254	3	3	3	9
7	5	90:10 BFS:NPC	10-9002-0059 Combined Tails	178	3	3	0	6
8	5	79:30 NPC:FA	10-9002-0059 Combined Tails	178	3	3	0	6

NPC: Normal Portland Cement
BFS: Blast Furnace Slag
FA: Flyash

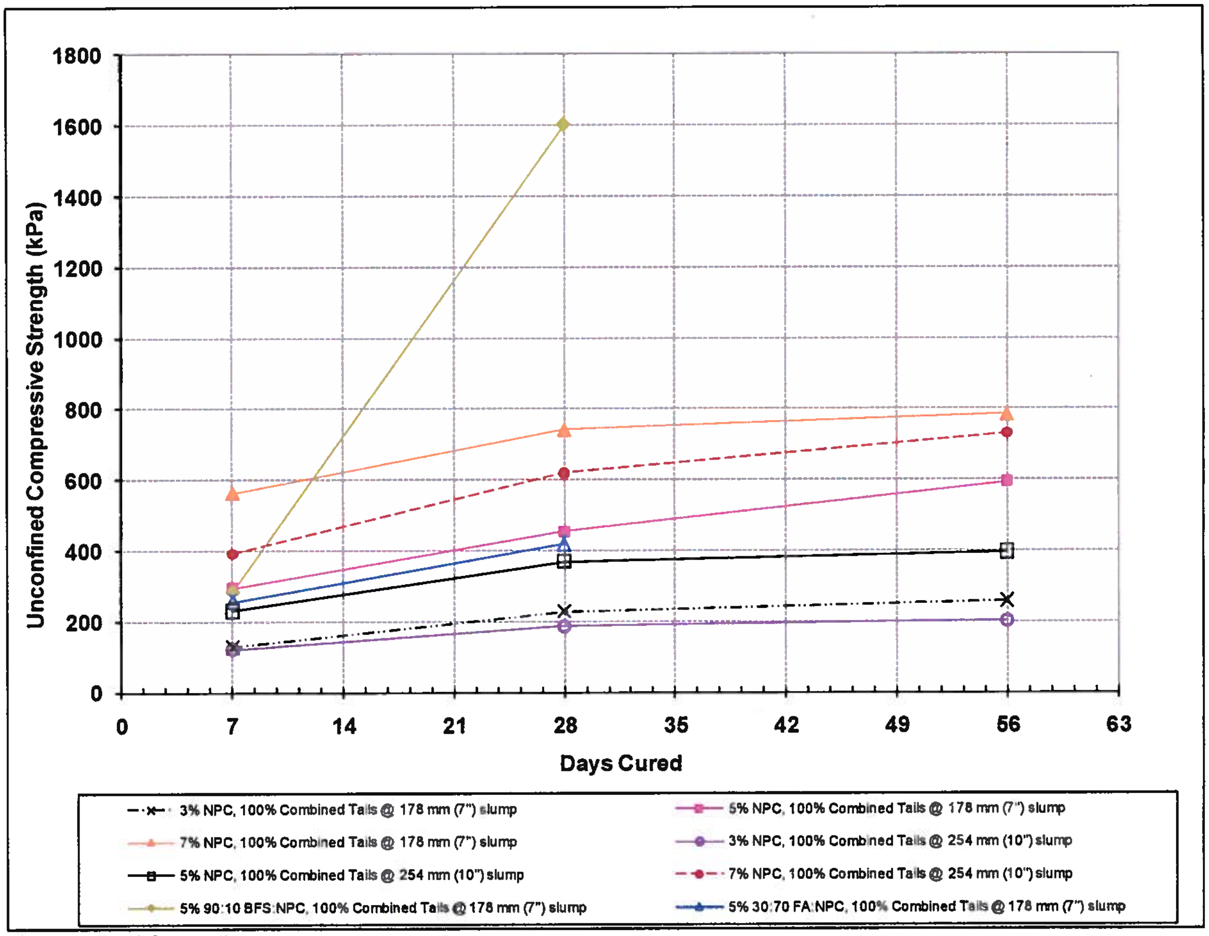


Figure 23: UCS Results

7.0 DISCUSSION AND RECOMMENDATIONS

The objective of the test program was to evaluate the Thor Lake tailings with regard to their paste (backfill) making properties. The first "Combined Tails" sample received was comprised of 13 wt% slimes, 6 wt% magnetic concentrate, 44 wt% rougher tails and 37 wt% cleaner scavenger tails. Based on the laboratory test results the tailings sample tested demonstrated the required properties for producing a suitable paste backfill material.

To formulate a stable paste, tailings typically need to contain a minimum of 15 wt% passing 20 microns material in order for the material to retain sufficient water and have reasonable flow characteristics. In the case of the Thor Lake tailings, the percent passing 20 microns is around 50 wt%, similar to many gold tailings. Even with the higher fines content, the sample demonstrated good settling and dewatering properties. It is worth nothing that two, as opposed to single stage, flocculation provided better overflow quality.

The second sample tested for comparison had a very similar particle size distribution, specific gravity and chemical composition to that of the first sample tested. The decant water also had similar water quality and pH.

However, the optimum settling parameters identified for the first sample did not provide the expected results with this second sample. For this reason additional testing would be required to determine the optimum conditions for this second sample. Avalon may wish to investigate the differences between the samples from the perspective of variation in the ore grade, process history or age of the two samples provided. Nonetheless, the underflow densities achieved were similar.

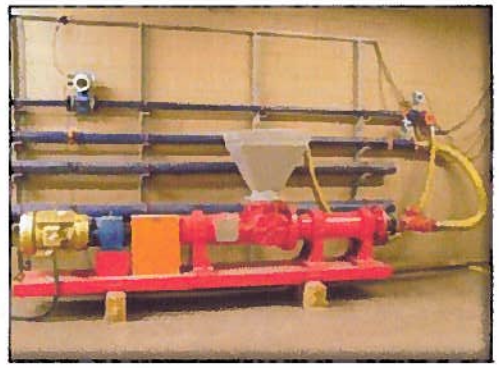
Larger scale, dynamic dewatering testing using Golder PasteTec's mini plant or compression settling tubes would be beneficial in providing increased confidence in thickener underflow density predictions considering the differences observed in the two samples tested. Compression thickening is considered a semi-continuous test where the effect of bed depth is investigated. The test entails the addition of flocculated material to multiple large tubes equipped with rakes. The underflow bed depth in each tube is maintained at a separate static height ranging from 0.5 to 2 metres.

Mini plant dewatering would offer an even better prediction of full scale thickener operation since this test is continuous and several parameters can be varied.

Additionally, in both the compression thickening and mini plant testing, underflow samples are collected in order to measure the sheared and unsheared yield stress and wt% solids of the material at specified time intervals.

The rheological characteristics of the two samples varied slightly, another indication that there are small differences between the two Thor Lake samples tested. There is a difference in the slump value at the same wt % solids. In addition, for slumps between 175 mm to 250 mm, the range typically used for underground backfill operations, the slope of the line is different. The slope of this line is an indication of the material's sensitivity to water addition. With a difference of 1 wt% solids between the two slump values above, it indicates that the second sample tested is representative of final tailings that would be very sensitive to water addition and that a more stringent control strategy would be required for consistent quality paste. Once the metallurgical process has been further developed it may worthwhile for additional testing to be performed on a few different tailings samples.

Lab or pilot scale flow loop testing is also recommended for design of the pump and pipeline systems. The lab scale flow loop includes 50 mm (2 inches) and 75 mm (3 inches) diameter schedule 40 steel piping, pressure transmitters and a flow meter where the material is pumped by a progressive cavity or centrifugal pump at various consistencies. The instruments are linked to a computer equipped with a data acquisition system where pipeline pressure loss can be calculated at several flow rates.



As expected, based on the result of the UCS testing program, increasing the wt% solids (lower slump) and/or increasing the wt% binder yields better strength results. However, the overall strength and the increase/change observed is not as significant as typically observed with tailings having a similar particle size distribution. Interesting, however, is the high strength values obtained using a blend of iron blast furnace slag and normal Portland cement. Blast furnace slag typically reacts in the presence of sulphide mineralizations. The solids do not appear to contain significant sulphur species. What set off the reaction is not evident.

Advanced UCS testing should be carried out where moisture content, bulk density and the stress strain curves would be. Additionally, UCS testing using the specific binder which will be available at the mine site should be investigated since, as observed with the blast furnace slag result, the chemical composition variances between binders may yield different results.

8.0 CLOSURE

If there are any questions regarding this report, please do not hesitate to contact the undersigned.

GOLDER PASTE TECHNOLOGY LTD.

Pierre Primeau, P.Eng.
Senior Process Engineer

Bruno Mandl, P.Eng.
Senior Mining Engineer

PP/BM/ns

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APPENDIX A

ICP-MS Results

TESTMARK Laboratories Ltd.

Committed to Quality and Service

Analytical Report

Client:	Michelle Levesque	**Work Order Number:**	**116212**
Company:	Golder Paste Technology	**Date Order Received:**	11/11/10
Address:	1010 Lorne St.	**Regulation:**	Information not provided
	Sudbury, ON, P3A 4S4	**PO #:**	
Phone:	(705) 524-5533	**Project #:**	
Fax:	(705) 524-9636		
Email:	mlevesque@golder.com		

Analyses were performed on the following samples submitted with your order.

The results relate only to the items tested.

Sample Name	Lab #	Matrix	Type	Comments	Date Collected	Time Collected
10-9002-0059 Avilon Comb. Tails	317532	Soil	None		11/10/10	15:00

The following instrumentation and reference methods were used for your sample(s)

Method Name	Description	Reference
ICPMS Soil	Determination of Metals in Soil by ICP/MS by Strong Acid Leachable Metals **Instrument group:** Perkin Elmer ICPMS	Based on SW846-6020

This report has been approved by:

Brad Halvorson, B. Sc.
Inorganic Section Head

TESTMARK Laboratories Ltd.

Committed to Quality and Service

Golder Paste Technology　　　　Work Order: 116212

Sample Data:

Sample Name: 10-9002-0059 Avilon Comb. Tail　Date: 11/10/10　　Matrix: Soil　　Lab #: 317532

ICPMS Soil				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Aluminum	5	11600	µg/g	20101115.R13na
Antimony	0.5	<0.5	µg/g	20101115.R13na
Arsenic	0.5	4.5	µg/g	20101115.R13na
Barium	0.5	38.1	µg/g	20101115.R13na
Beryllium	0.5	3.5	µg/g	20101115.R13na
Bismuth	0.5	0.54	µg/g	20101115.R13na
Boron (Not Hot Water Extractable)	1	5.2	µg/g	20101115.R13na
Cadmium	0.05	0.573	µg/g	20101115.R13na
Calcium	25	4920	µg/g	20101115.R13na
Cerium	5	1160	µg/g	20101115.R13na
Cesium	0.5	2.3	µg/g	20101115.R13na
Chromium	0.5	12.4	µg/g	20101115.R13na
Cobalt	0.05	0.858	µg/g	20101115.R13na
Copper	0.5	9.28	µg/g	20101115.R13na
Europium	0.5	14.5	µg/g	20101115.R13na
Gallium	0.5	29.9	µg/g	20101115.R13na
Iron	1000	47600	µg/g	20101115.R13na
Lanthanum	5	551	µg/g	20101115.R13na
Lead	0.5	4	µg/g	20101115.R13na
Lithium	2.5	48	µg/g	20101115.R13na
Magnesium	20	12600	µg/g	20101115.R13na
Manganese	5	669	µg/g	20101115.R13na
Mercury	0.05	<0.05	µg/g	20101115.R13na
Molybdenum	0.5	2.4	µg/g	20101115.R13na
Nickel	0.5	15.7	µg/g	20101115.R13na
Niobium	0.5	56	µg/g	20101115.R13na
Phosphorus	25	68	µg/g	20101115.R13na
Rubidium	0.5	111	µg/g	20101115.R13na
Scandium	0.5	1.3	µg/g	20101115.R13na
Selenium	0.5	8.77	µg/g	20101115.R13na
Silicon	0.5	2430	µg/g	20101115.R13na
Silver	0.05	2.32	µg/g	20101115.R13na
Strontium	0.5	10.7	µg/g	20101115.R13na
Sulfur	400	<400	µg/g	20101115.R13na
Tellurium	0.5	<0.5	µg/g	20101115.R13na
Thallium	0.5	<0.5	µg/g	20101115.R13na
Thorium	0.5	19.1	µg/g	20101115.R13na
Tin	0.5	15.7	µg/g	20101115.R13na
Titanium	0.5	112	µg/g	20101115.R13na
Tungsten	0.5	3.9	µg/g	20101115.R13na
Uranium	0.5	5.2	µg/g	20101115.R13na
Vanadium	0.5	<0.5	µg/g	20101115.R13na
Yttrium	0.5	289	µg/g	20101115.R13na
Zinc	0.5	86.1	µg/g	20101115.R13na

TESTMARK Laboratories Ltd.

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Golder Paste Technology | Work Order: 116212

Sample Name: 10-9002-0059 Avilon Comb. Tail Date: 11/10/10 Matrix: Soil Lab #: 317532

ICPMS Soil				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Zirconium	0.5	328	µg/g	20101115.R13na

MDL Method detection limit or minimum reporting limit.
% Rec Surrogate compounds are added to the sample in some cases and the recovery is reported as a percent recovered.
QAQCID This is a unique reference to the quality control data set used to generate the reported value.
Data reported for organic analysis in soil samples are corrected for moisture content
Matrix If the matrix is a leachate, the sample was extracted according to regulation 558.
INT Interferences
TNTC Too numerous to count
ND Not detected

TESTMARK Laboratories Ltd.

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Golder Paste Technology — Work Order: 116212

Quality Control Data:

ICPMS Soil

5 ppm Cal. Check						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	0.05	µg/g	30	26.3	20	20101115.R13na
Arsenic	0.05	µg/g	6	5.51	4	20101115.R13na
Barium	0.05	µg/g	6	5.14	4	20101115.R13na
Beryllium	0.05	µg/g	6.25	5.37	3.75	20101115.R13na
Cadmium	0.05	µg/g	6	5.77	4	20101115.R13na
Calcium	2.5	µg/g	60	53.6	40	20101115.R13na
Chromium	0.05	µg/g	6	5.4	4	20101115.R13na
Cobalt	0.05	µg/g	6	5.6	4	20101115.R13na
Copper	0.05	µg/g	6	5.58	4	20101115.R13na
Iron	1	µg/g	30	27.7	20	20101115.R13na
Lead	0.05	µg/g	6	4.91	4	20101115.R13na
Magnesium	0.2	µg/g	60	49.9	40	20101115.R13na
Manganese	0.05	µg/g	6	5.35	4	20101115.R13na
Molybdenum	0.05	µg/g	6	5.17	4	20101115.R13na
Nickel	0.05	µg/g	6	5.63	4	20101115.R13na
Selenium	0.05	µg/g	6	4.97	4	20101115.R13na
Thallium	0.05	µg/g	6	5.05	4	20101115.R13na
Vanadium	0.05	µg/g	6	4.96	4	20101115.R13na
Zinc	0.05	µg/g	6	6	4	20101115.R13na

Blank						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	2	µg/g	<2	<2	<2	20101115.R13na
Antimony	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Arsenic	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Barium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Beryllium	2.5	µg/g	<2.5	<2.5	<2.5	20101115.R13na
Bismuth	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Cadmium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Calcium	2.5	µg/g	<2.5	<2.5	<2.5	20101115.R13na
Cerium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Cesium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Chromium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Cobalt	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Copper	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Europium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Gallium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Iron	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Lanthanum	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Lead	0.05	µg/g	0.1	<0.05	<0.05	20101115.R13na
Magnesium	1	µg/g	<1	<1	<1	20101115.R13na
Manganese	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Mercury	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Molybdenum	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Nickel	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na

ICPMS Soil

Blank						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Niobium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Phosphorus	25	µg/g	<25	<25	<25	20101115.R13na
Rubidium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Scandium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Selenium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Silver	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Strontium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Thallium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Thorium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Tin	2.5	µg/g	<2.5	<2.5	<2.5	20101115.R13na
Titanium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Tungsten	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Uranium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Vanadium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Yttrium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Zinc	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na
Zirconium	0.5	µg/g	<0.5	<0.5	<0.5	20101115.R13na

SS2 CRM						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	5	µg/g	19787	12600	6743	20101115.R13na
Arsenic	0.5	µg/g	125	89.3	25	20101115.R13na
Barium	0.5	µg/g	281	223	149	20101115.R13na
Calcium	25	µg/g	138279	109000	87443	20101115.R13na
Chromium	0.5	µg/g	54	32.1	14	20101115.R13na
Cobalt	0.05	µg/g	15	12.4	9	20101115.R13na
Copper	5	µg/g	243	200	139	20101115.R13na
Iron	100	µg/g	29261	20600	12831	20101115.R13na
Lead	0.5	µg/g	184	122	68	20101115.R13na
Lithium	2.5	µg/g	23	15	5	20101115.R13na
Magnesium	20	µg/g	14502	10300	7628	20101115.R13na
Manganese	5	µg/g	590	476	324	20101115.R13na
Nickel	0.5	µg/g	75	56.4	33	20101115.R13na
Strontium	0.5	µg/g	272	254	156	20101115.R13na
Titanium	5	µg/g	1402	958	298	20101115.R13na
Vanadium	0.5	µg/g	51	36.1	17	20101115.R13na
Zinc	5	µg/g	597	514	337	20101115.R13na

UCL Upper Control Limit
LCL Lower Control Limit

TESTMARK Laboratories Ltd.

Committed to Quality and Service

(Revised) Analytical Report

Client:	Mark Labelle	**Work Order Number:**	**120338**
Company:	Golder Paste Technology	**Date Order Received:**	01/25/11
Address:	1010 Lorne St.	**Regulation:**	None
	Sudbury, ON, P3A 4S4	**PO #:**	
Phone:	(705) 524-6861	**Project #:**	10-9002-0059
Fax:	(705) 524-9636		
Email:	mlabelle@golder.com		
Notes:	Revised to include P in ICPMS scan. 02/02/11 am		
	Supercedes report printed :01/31/11		

Analyses were performed on the following samples submitted with your order.
The results relate only to the items tested.

Sample Name	Lab #	Matrix	Type	Comments	Date Collected	Time Collected
10-9002-0059 Combined Tails Decant	328130	Water	Grab		01/25/11	9:30
10-9002-0059 Combined Tails S2 Decant	328131	Water	Grab		01/25/11	9:30
10-9002-0059 Combined Tails S2	328132	Soil	Grab		01/25/11	9:30

The following instrumentation and reference methods were used for your sample(s)

Method Name	Description	Reference
Anions Water	Determination of Anions by Ion Chromatography **Instrument group:** Dionex IC	Based on SW846-9056
CONDWATER	Determination of Conductivity in Water **Instrument group:** Metrohm Analyzer	Based on APHA-2510
ICPMS Soil	Determination of Metals in Soil by ICP/MS by Strong Acid Leachable Metals **Instrument group:** Perkin Elmer ICPMS	Based on SW846-6020
ICPMS Water	Determination of Metals in Water by ICP/MS **Instrument group:** Perkin Elmer ICPMS	Based on SW846-6020

This report has been approved by:

Brad Halvorson, B. Sc.
Inorganic Section Head

TESTMARK Laboratories Ltd.

Committed to Quality and Service

Golder Paste Technology — Work Order: 120338

Sample Data:

Sample Name: 10-9002-0059 Combined Tails D Date: 01/25/11 Matrix: Water Lab #: 328130

Anions Water				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Bromide	0.1	<0.1	mg/L	20110126.R5D
Chloride	0.2	30.6	mg/L	20110126.R5D
Fluoride	0.1	3.71	mg/L	20110126.R5D
Nitrate (as N)	0.1	<0.1	mg/L	20110126.R5D
Nitrite (as N)	0.03	<0.03	mg/L	20110126.R5D
Phosphate	1	<1	mg/L	20110126.R5D
Sulfate	1	249	mg/L	20110126.R5D

CONDWATER				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Conductivity	1	852	µS/cm	20110126.R12B

ICPMS Water				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Aluminum	1	33.4	ug/L	20110128.R13na8
Antimony	0.5	4.9	ug/L	20110128.R13na8
Arsenic	1	3	ug/L	20110128.R13na8
Barium	1	19	ug/L	20110128.R13na8
Beryllium	0.5	<0.5	ug/L	20110128.R13na8
Bismuth	1	<1	ug/L	20110128.R13na8
Boron	2	99.5	ug/L	20110128.R13na8
Cadmium	0.1	0.13	ug/L	20110128.R13na8
Calcium	50	78000	ug/L	20110128.R13na8
Cerium	1	<1	ug/L	20110128.R13na8
Cesium	1	<1	ug/L	20110128.R13na8
Chromium	1	1	ug/L	20110128.R13na8
Cobalt	0.1	0.25	ug/L	20110128.R13na8
Copper	1	5.3	ug/L	20110128.R13na8
Europium	1	<1	ug/L	20110128.R13na8
Gallium	1	1.5	ug/L	20110128.R13na8
Iron	20	<20	ug/L	20110128.R13na8
Lanthanum	1	<1	ug/L	20110128.R13na8
Lead	1	<1	ug/L	20110128.R13na8
Lithium	5	23	ug/L	20110128.R13na8
Magnesium	4	7940	ug/L	20110128.R13na8
Manganese	1	57.8	ug/L	20110128.R13na8
Mercury	0.1	<0.1	ug/L	20110128.R13na8
Molybdenum	1	49	ug/L	20110128.R13na8
Nickel	1	9.2	ug/L	20110128.R13na8
Niobium	1	<1	ug/L	20110128.R13na8
Phosphorus	50	380	ug/L	20110128.R13na8
Potassium	100	30400	ug/L	20110128.R13na8
Rubidium	1	58	ug/L	20110128.R13na8
Scandium	1	2.4	ug/L	20110128.R13na8
Selenium	1	3.3	ug/L	20110128.R13na8

Sample Name: 10-9002-0059 Combined Tails D Date: 01/25/11 Matrix: Water Lab #: 328130

ICPMS Water				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Silicon	600	5500	ug/L	20110128.R13na8
Silver	0.1	<0.1	ug/L	20110128.R13na8
Sodium	100	60000	ug/L	20110128.R13na8
Strontium	1	241	ug/L	20110128.R13na8
Sulfur	800	94000	ug/L	20110128.R13na8
Tellurium	1	<1	ug/L	20110128.R13na8
Thallium	0.1	<0.1	ug/L	20110128.R13na8
Thorium	1	<1	ug/L	20110128.R13na8
Tin	1	<1	ug/L	20110128.R13na8
Titanium	1	2.7	ug/L	20110128.R13na8
Tungsten	1	10.4	ug/L	20110128.R13na8
Uranium	1	12.6	ug/L	20110128.R13na8
Vanadium	1	<1	ug/L	20110128.R13na8
Yttrium	1	<1	ug/L	20110128.R13na8
Zinc	1	7.9	ug/L	20110128.R13na8
Zirconium	1	1.6	ug/L	20110128.R13na8

Sample Name: 10-9002-0059 Combined Tails S Date: 01/25/11 Matrix: Water Lab #: 328131

Anions Water				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Bromide	0.1	<0.1	mg/L	20110126.R5D
Chloride	0.2	53.7	mg/L	20110126.R5D
Fluoride	0.1	11.8	mg/L	20110126.R5D
Nitrate (as N)	0.1	<0.1	mg/L	20110126.R5D
Nitrite (as N)	0.03	<0.03	mg/L	20110126.R5D
Phosphate	1	<1	mg/L	20110126.R5D
Sulfate	1	14.7	mg/L	20110126.R5D

CONDWATER				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Conductivity	1	649	µS/cm	20110126.R12B

ICPMS Water				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Aluminum	1	56.3	ug/L	20110128.R13na8
Antimony	0.5	4.4	ug/L	20110128.R13na8
Arsenic	1	5.8	ug/L	20110128.R13na8
Barium	1	13.1	ug/L	20110128.R13na8
Beryllium	0.5	<0.5	ug/L	20110128.R13na8
Bismuth	1	<1	ug/L	20110128.R13na8
Boron	2	198	ug/L	20110128.R13na8
Cadmium	0.1	<0.1	ug/L	20110128.R13na8
Calcium	50	21400	ug/L	20110128.R13na8
Cerium	1	1.2	ug/L	20110128.R13na8
Cesium	1	<1	ug/L	20110128.R13na8
Chromium	1	1.4	ug/L	20110128.R13na8

Sample Name: 10-9002-0059 Combined Tails S Date: 01/25/11 Matrix: Water Lab #: 328131

ICPMS Water				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Cobalt	0.1	<0.1	ug/L	20110128.R13na8
Copper	1	1.8	ug/L	20110128.R13na8
Europium	1	<1	ug/L	20110128.R13na8
Gallium	1	1.7	ug/L	20110128.R13na8
Iron	20	<20	ug/L	20110128.R13na8
Lanthanum	1	<1	ug/L	20110128.R13na8
Lead	1	<1	ug/L	20110128.R13na8
Lithium	5	20	ug/L	20110128.R13na8
Magnesium	4	7910	ug/L	20110128.R13na8
Manganese	1	19.1	ug/L	20110128.R13na8
Mercury	0.1	<0.1	ug/L	20110128.R13na8
Molybdenum	1	31.8	ug/L	20110128.R13na8
Nickel	1	6.2	ug/L	20110128.R13na8
Niobium	1	<1	ug/L	20110128.R13na8
Phosphorus	50	260	ug/L	20110128.R13na8
Potassium	100	42100	ug/L	20110128.R13na8
Rubidium	1	70.1	ug/L	20110128.R13na8
Scandium	1	2.1	ug/L	20110128.R13na8
Selenium	1	<1	ug/L	20110128.R13na8
Silicon	600	4300	ug/L	20110128.R13na8
Silver	0.1	<0.1	ug/L	20110128.R13na8
Sodium	100	70100	ug/L	20110128.R13na8
Strontium	1	115	ug/L	20110128.R13na8
Sulfur	800	9020	ug/L	20110128.R13na8
Tellurium	1	<1	ug/L	20110128.R13na8
Thallium	0.1	<0.1	ug/L	20110128.R13na8
Thorium	1	<1	ug/L	20110128.R13na8
Tin	1	<1	ug/L	20110128.R13na8
Titanium	1	3.1	ug/L	20110128.R13na8
Tungsten	1	19.5	ug/L	20110128.R13na8
Uranium	1	1.4	ug/L	20110128.R13na8
Vanadium	1	<1	ug/L	20110128.R13na8
Yttrium	1	<1	ug/L	20110128.R13na8
Zinc	1	2.8	ug/L	20110128.R13na8
Zirconium	1	1.4	ug/L	20110128.R13na8

Sample Name: 10-9002-0059 Combined Tails S Date: 01/25/11 Matrix: Soil Lab #: 328132

ICPMS Soil				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Aluminum	5	7660	µg/g	20110128.R13na3
Antimony	0.5	<0.5	µg/g	20110128.R13na3
Arsenic	0.5	1.6	µg/g	20110128.R13na3
Barium	0.5	35.2	µg/g	20110128.R13na3
Beryllium	0.5	2.4	µg/g	20110128.R13na3
Bismuth	0.5	<0.5	µg/g	20110128.R13na3

TESTMARK Laboratories Ltd.

Committed to Quality and Service

Golder Paste Technology — Work Order: 120338

Sample Name: 10-9002-0059 Combined Tails S Date: 01/25/11 Matrix: Soil Lab #: 328132

ICPMS Soil				
Parameter	**MDL**	**Result**	**Units**	**QAQCID**
Boron (Not Hot Water Extractable)	1	24.8	µg/g	20110128.R13na3
Cadmium	0.05	0.48	µg/g	20110128.R13na3
Calcium	25	4750	µg/g	20110128.R13na3
Cerium	5	1210	µg/g	20110128.R13na3
Cesium	0.5	1.7	µg/g	20110128.R13na3
Chromium	0.5	9.56	µg/g	20110128.R13na3
Cobalt	0.05	0.835	µg/g	20110128.R13na3
Copper	0.5	4.6	µg/g	20110128.R13na3
Europium	0.5	13.8	µg/g	20110128.R13na3
Gallium	0.5	23.6	µg/g	20110128.R13na3
Iron	1000	41100	µg/g	20110128.R13na3
Lanthanum	5	551	µg/g	20110128.R13na3
Lead	0.5	3.8	µg/g	20110128.R13na3
Lithium	2.5	29.3	µg/g	20110128.R13na3
Magnesium	20	9630	µg/g	20110128.R13na3
Manganese	5	435	µg/g	20110128.R13na3
Mercury	0.05	<0.05	µg/g	20110128.R13na3
Molybdenum	0.5	1	µg/g	20110128.R13na3
Nickel	0.5	13.9	µg/g	20110128.R13na3
Niobium	0.5	39.2	µg/g	20110128.R13na3
Phosphorus	25	69	µg/g	20110128.R13na3
Rubidium	0.5	76.4	µg/g	20110128.R13na3
Scandium	0.5	0.61	µg/g	20110128.R13na3
Selenium	0.5	7.57	µg/g	20110128.R13na3
Silicon	300	920	µg/g	20110128.R13na3
Silver	0.05	1.3	µg/g	20110128.R13na3
Strontium	0.5	8.41	µg/g	20110128.R13na3
Sulfur	400	<400	µg/g	20110128.R13na3
Tellurium	0.5	<0.5	µg/g	20110128.R13na3
Thallium	0.5	<0.5	µg/g	20110128.R13na3
Thorium	0.5	16.1	µg/g	20110128.R13na3
Tin	0.5	12.2	µg/g	20110128.R13na3
Titanium	0.5	95.9	µg/g	20110128.R13na3
Tungsten	0.5	3	µg/g	20110128.R13na3
Uranium	0.5	4.2	µg/g	20110128.R13na3
Vanadium	0.5	<0.5	µg/g	20110128.R13na3
Yttrium	0.5	242	µg/g	20110128.R13na3
Zinc	0.5	64.6	µg/g	20110128.R13na3
Zirconium	0.5	224	µg/g	20110128.R13na3

MDL	*Method detection limit or minimum reporting limit.*
% Rec	*Surrogate compounds are added to the sample in some cases and the recovery is reported as a percent recovered.*
QAQCID	*This is a unique reference to the quality control data set used to generate the reported value.*

Data reported for organic analysis in soil samples are corrected for moisture content

Matrix	*If the matrix is a leachate, the sample was extracted according to regulation 558.*
INT	*Interferences*
TNTC	*Too numerous to count*
ND	*Not detected*

Quality Control Data:

Anions Water

Blank (IC-1)						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Bromide	0.1	mg/L	<0.1	<0.1	<0.1	20110126.R5D
Chloride	0.2	mg/L	<0.2	<0.2	<0.2	20110126.R5D
Fluoride	0.01	mg/L	<0.01	<0.01	<0.01	20110126.R5D
Nitrate (as N)	0.1	mg/L	<0.1	<0.1	<0.1	20110126.R5D
Nitrite (as N)	0.05	mg/L	<0.05	<0.05	<0.05	20110126.R5D
Phosphate	0.3	mg/L	<0.3	<0.3	<0.3	20110126.R5D
Sulfate	0.2	mg/L	<0.2	<0.2	<0.2	20110126.R5D

High Control (IC-1)						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Bromide	0.1	mg/L	115	97	85	20110126.R5D
Chloride	0.2	mg/L	115	92	85	20110126.R5D
Fluoride	0.01	mg/L	57.5	48	42.5	20110126.R5D
Nitrate (as N)	0.1	mg/L	57.5	45.6	40	20110126.R5D
Nitrite (as N)	0.05	mg/L	57.5	52.4	42.5	20110126.R5D
Phosphate	0.3	mg/L	130	95.4	70	20110126.R5D
Sulfate	0.2	mg/L	115	87.9	78	20110126.R5D

Low Control						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Bromide	0.1	mg/L	24	17.7	16	20110126.R5D
Chloride	0.2	mg/L	24	17	16	20110126.R5D
Fluoride	0.1	mg/L	12	9.43	8	20110126.R5D
Nitrate (as N)	0.1	mg/L	12	7.96	7.5	20110126.R5D
Nitrite (as N)	0.03	mg/L	12	10.4	8	20110126.R5D
Phosphate	1	mg/L	24	18.6	16	20110126.R5D
Sulfate	1	mg/L	24	17.2	16	20110126.R5D

CONDWATER

500 µS Control						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Conductivity	1	µS/cm	552	497	438	20110126.R12B

ICPMS Soil

5 ppm Cal. Check						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	0.05	µg/g	30	24.2	20	20110128.R13na3
Arsenic	0.05	µg/g	6	4.86	4	20110128.R13na3
Barium	0.05	µg/g	6	4.97	4	20110128.R13na3
Beryllium	0.05	µg/g	6.25	5.16	3.75	20110128.R13na3
Boron	0.1	µg/g	6.25	4.91	3.75	20110128.R13na3
Cadmium	0.05	µg/g	6	5.07	4	20110128.R13na3
Calcium	2.5	µg/g	60	50.1	40	20110128.R13na3
Chromium	0.05	µg/g	6	4.58	4	20110128.R13na3

ICPMS Soil

5 ppm Cal. Check						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Cobalt	0.05	µg/g	6	4.89	4	20110128.R13na3
Copper	0.05	µg/g	6	4.86	4	20110128.R13na3
Iron	1	µg/g	30	22.7	20	20110128.R13na3
Lead	0.05	µg/g	6	4.96	4	20110128.R13na3
Magnesium	0.2	µg/g	60	49.5	40	20110128.R13na3
Manganese	0.05	µg/g	6	4.69	4	20110128.R13na3
Molybdenum	0.05	µg/g	6	5.24	4	20110128.R13na3
Nickel	0.05	µg/g	6	4.83	4	20110128.R13na3
Selenium	0.05	µg/g	6	4.64	4	20110128.R13na3
Thallium	0.05	µg/g	6	5	4	20110128.R13na3
Vanadium	0.05	µg/g	6	4.8	4	20110128.R13na3
Zinc	0.05	µg/g	6	4.92	4	20110128.R13na3

Blank						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	2	µg/g	<2	<2	<2	20110128.R13na3
Antimony	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Arsenic	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Barium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Beryllium	2.5	µg/g	<2.5	<2.5	<2.5	20110128.R13na3
Bismuth	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Boron	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Cadmium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Calcium	2.5	µg/g	<2.5	<2.5	<2.5	20110128.R13na3
Cerium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Cesium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Chromium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Cobalt	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Copper	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Europium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Gallium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Iron	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Lanthanum	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Lead	0.05	µg/g	0.1	<0.05	<0.05	20110128.R13na3
Magnesium	1	µg/g	<1	<1	<1	20110128.R13na3
Manganese	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Mercury	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Molybdenum	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Nickel	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Niobium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Phosphorus	25	µg/g	<25	<25	<25	20110128.R13na3
Rubidium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Scandium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Selenium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Silver	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Strontium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3

ICPMS Soil

Blank						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Thallium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Thorium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Tin	2.5	µg/g	<2.5	<2.5	<2.5	20110128.R13na3
Titanium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Tungsten	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Uranium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Vanadium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Yttrium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Zinc	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3
Zirconium	0.5	µg/g	<0.5	<0.5	<0.5	20110128.R13na3

SS2 CRM						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	5	µg/g	19787	11800	6743	20110128.R13na3
Arsenic	0.5	µg/g	125	73.5	25	20110128.R13na3
Barium	0.5	µg/g	281	233	149	20110128.R13na3
Calcium	25	µg/g	138279	91800	87443	20110128.R13na3
Chromium	0.5	µg/g	54	29.2	14	20110128.R13na3
Cobalt	0.05	µg/g	15	11.7	9	20110128.R13na3
Copper	5	µg/g	243	196	139	20110128.R13na3
Iron	100	µg/g	29261	19700	12831	20110128.R13na3
Lead	0.5	µg/g	184	121	68	20110128.R13na3
Lithium	2.5	µg/g	23	13	5	20110128.R13na3
Magnesium	20	µg/g	14502	10400	7628	20110128.R13na3
Manganese	5	µg/g	590	470	324	20110128.R13na3
Nickel	0.5	µg/g	75	58.3	33	20110128.R13na3
Strontium	0.5	µg/g	272	206	156	20110128.R13na3
Titanium	5	µg/g	1402	937	298	20110128.R13na3
Vanadium	0.5	µg/g	51	31.7	17	20110128.R13na3
Zinc	5	µg/g	597	491	337	20110128.R13na3

ICPMS Water

Blank						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	1	ug/L	1	<1	<1	20110128.R13na8
Antimony	0.5	ug/L	0.5	<0.5	<0.5	20110128.R13na8
Arsenic	1	ug/L	1	<1	<1	20110128.R13na8
Barium	0.5	ug/L	0.5	<0.5	<0.5	20110128.R13na8
Beryllium	1	ug/L	1	<1	<1	20110128.R13na8
Bismuth	1	ug/L	3	<1	<1	20110128.R13na8
Boron	1	ug/L	1	<1	<1	20110128.R13na8
Cadmium	1	ug/L	1	<1	<1	20110128.R13na8
Calcium	50	ug/L	150	<50	<50	20110128.R13na8
Cerium	0.1	ug/L	0.1	<0.1	<0.1	20110128.R13na8
Cesium	1	ug/L	1	<1	<1	20110128.R13na8
Chromium	1	ug/L	1	<1	<1	20110128.R13na8

ICPMS Water

Blank						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Cobalt	1	ug/L	1	<1	<1	20110128.R13na8
Europium	1	ug/L	1	<1	<1	20110128.R13na8
Gallium	1	ug/L	1	<1	<1	20110128.R13na8
Iron	20	ug/L	20	<20	<20	20110128.R13na8
Lanthanum	1	ug/L	1	<1	<1	20110128.R13na8
Lead	1	ug/L	1	<1	<1	20110128.R13na8
Lithium	5	ug/L	5	<5	<5	20110128.R13na8
Magnesium	4	ug/L	4	<4	<4	20110128.R13na8
Manganese	1	ug/L	1	<1	<1	20110128.R13na8
Mercury	0.1	ug/L	0.1	<0.1	<0.1	20110128.R13na8
Molybdenum	1	ug/L	1	<1	<1	20110128.R13na8
Nickel	1	ug/L	1	<1	<1	20110128.R13na8
Niobium	1	ug/L	1	<1	<1	20110128.R13na8
Phosphorus	50	ug/L	50	<50	<50	20110128.R13na8
Rubidium	1	ug/L	1	<1	<1	20110128.R13na8
Scandium	1	ug/L	1	<1	<1	20110128.R13na8
Selenium	1	ug/L	1	<1	<1	20110128.R13na8
Silver	0.1	ug/L	0.1	<0.1	<0.1	20110128.R13na8
Strontium	1	ug/L	1	<1	<1	20110128.R13na8
Tellurium	1	ug/L	1	<1	<1	20110128.R13na8
Thallium	1	ug/L	1	<1	<1	20110128.R13na8
Thorium	1	ug/L	1	<1	<1	20110128.R13na8
Tin	1	ug/L	1	<1	<1	20110128.R13na8
Titanium	0.1	ug/L	0.1	<0.1	<0.1	20110128.R13na8
Tungsten	1	ug/L	1	<1	<1	20110128.R13na8
Uranium	1	ug/L	1	<1	<1	20110128.R13na8
Vanadium	1	ug/L	1	<1	<1	20110128.R13na8
Yttrium	1	ug/L	1	<1	<1	20110128.R13na8
Zinc	1	ug/L	1	<1	<1	20110128.R13na8
Zirconium	1	ug/L	1	<1	<1	20110128.R13na8

Positive Control (1011)						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Aluminum	1	ug/L	600	501	400	20110128.R13na8
Arsenic	1	ug/L	120	99	80	20110128.R13na8
Barium	1	ug/L	120	109	80	20110128.R13na8
Beryllium	1	ug/L	125	102	75	20110128.R13na8
Boron	2	ug/L	110	108	90	20110128.R13na8
Cadmium	1	ug/L	120	96.9	80	20110128.R13na8
Calcium	50	ug/L	1200	1010	800	20110128.R13na8
Chromium	1	ug/L	110	106	90	20110128.R13na8
Cobalt	1	ug/L	120	99.8	80	20110128.R13na8
Copper	1	ug/L	120	102	80	20110128.R13na8
Iron	20	ug/L	600	504	400	20110128.R13na8
Lead	1	ug/L	120	105	80	20110128.R13na8
Magnesium	4	ug/L	1200	980	800	20110128.R13na8

ICPMS Water

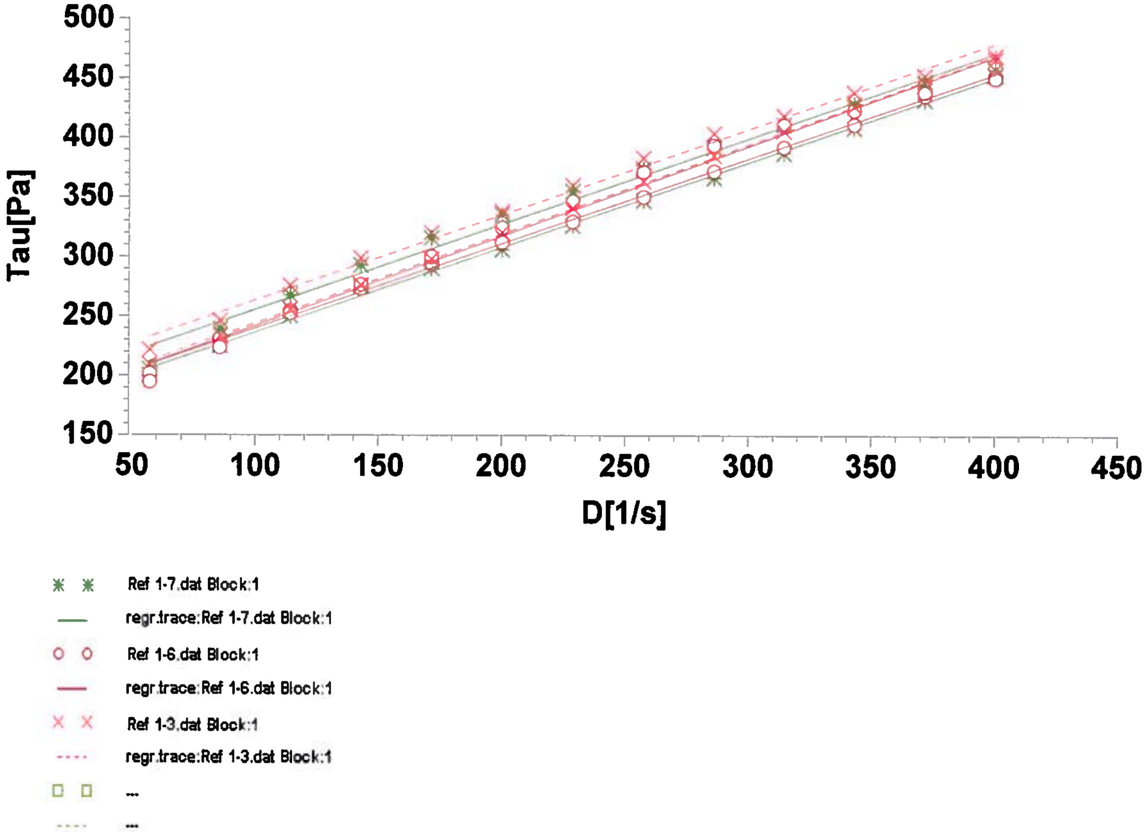
Positive Control (1011)						
Parameter	**MDL**	**Units**	**UCL**	**Result**	**LCL**	**QAQCID**
Manganese	1	ug/L	120	98.5	80	20110128.R13na8
Molybdenum	1	ug/L	120	95.9	80	20110128.R13na8
Nickel	1	ug/L	120	98.3	80	20110128.R13na8
Selenium	1	ug/L	120	99	80	20110128.R13na8
Sodium	100	ug/L	22000	20700	18000	20110128.R13na8
Thallium	1	ug/L	120	106	80	20110128.R13na8
Vanadium	1	ug/L	120	95.8	80	20110128.R13na8
Zinc	1	ug/L	120	93.5	80	20110128.R13na8

UCL Upper Control Limit
LCL Lower Control Limit

APPENDIX B

RHEOGRAMS

14:02 29/11/10
Manual Report Analysis/Regression



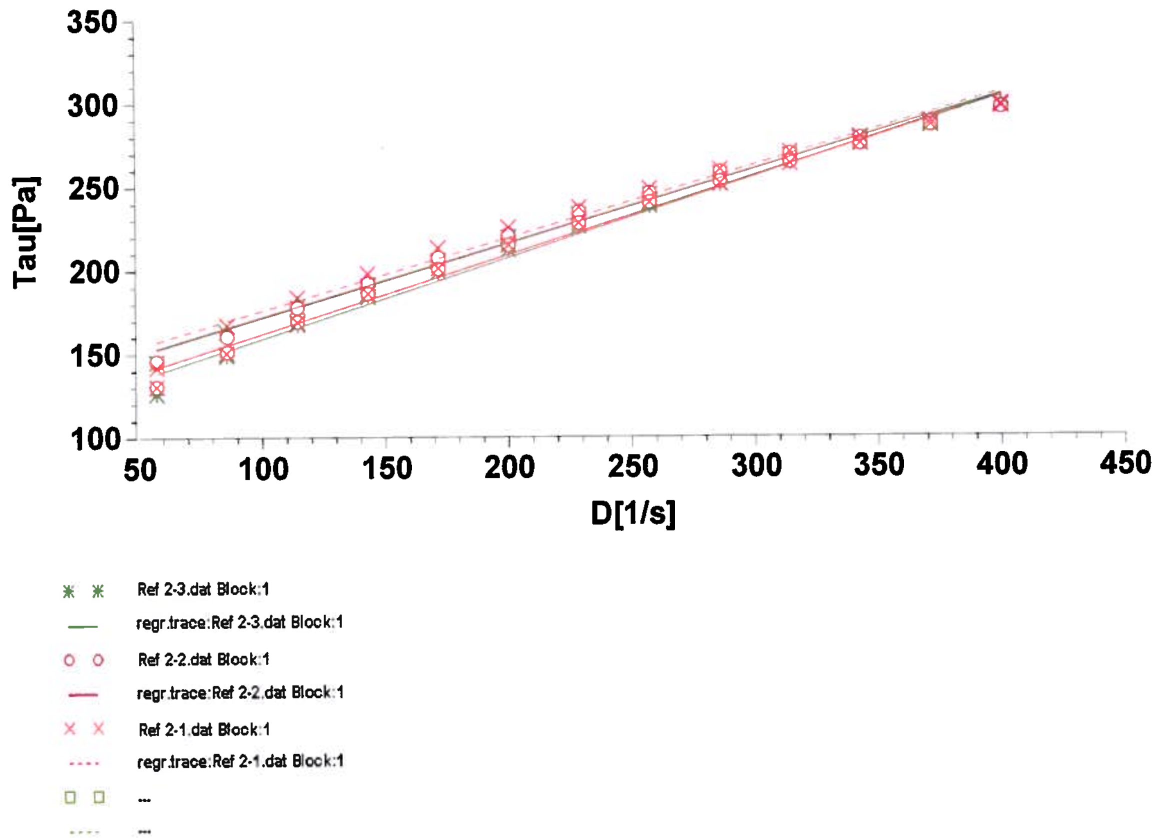
Analysis-results
Analysis data source: Ref 1-7.dat Block:1
filter activated: D[1/s]>40
step1: Bingham: Y=164.96+0.71342*X ;B=0.99807; S=3.64
step1: Bingham yieldstress[Pa]=164.9635
step1: Bingham viscosity[Pas]=0.7134
step2: Bingham: Y=183.26+0.71884*X ;B=0.98837; S=9.06
step2: Bingham yieldstress[Pa]=183.2608
step2: Bingham viscosity[Pas]=0.7188

filter activated: D[1/s]>40
step1: Bingham: Y=168.51+0.71223*X ;B=0.99837; S=3.34
step1: Bingham yieldstress[Pa]=168.5079
step1: Bingham viscosity[Pas]=0.7122
step2: Bingham: Y=166.53+0.75346*X ;B=0.98668; S=10.2
step2: Bingham yieldstress[Pa]=166.5314
step2: Bingham viscosity[Pas]=0.7535

filter activated: D[1/s]>40
step1: Bingham: Y=169.01+0.75013*X ;B=0.99972; S=1.46
step1: Bingham yieldstress[Pa]=169.0068
step1: Bingham viscosity[Pas]=0.7501
step2: Bingham: Y=191.1+0.71918*X ;B=0.9939; S=6.55
step2: Bingham yieldstress[Pa]=191.096
step2: Bingham viscosity[Pas]=0.7192
End of report

multiple data sources

14:26 29/11/10
Manual Report Analysis/Regression

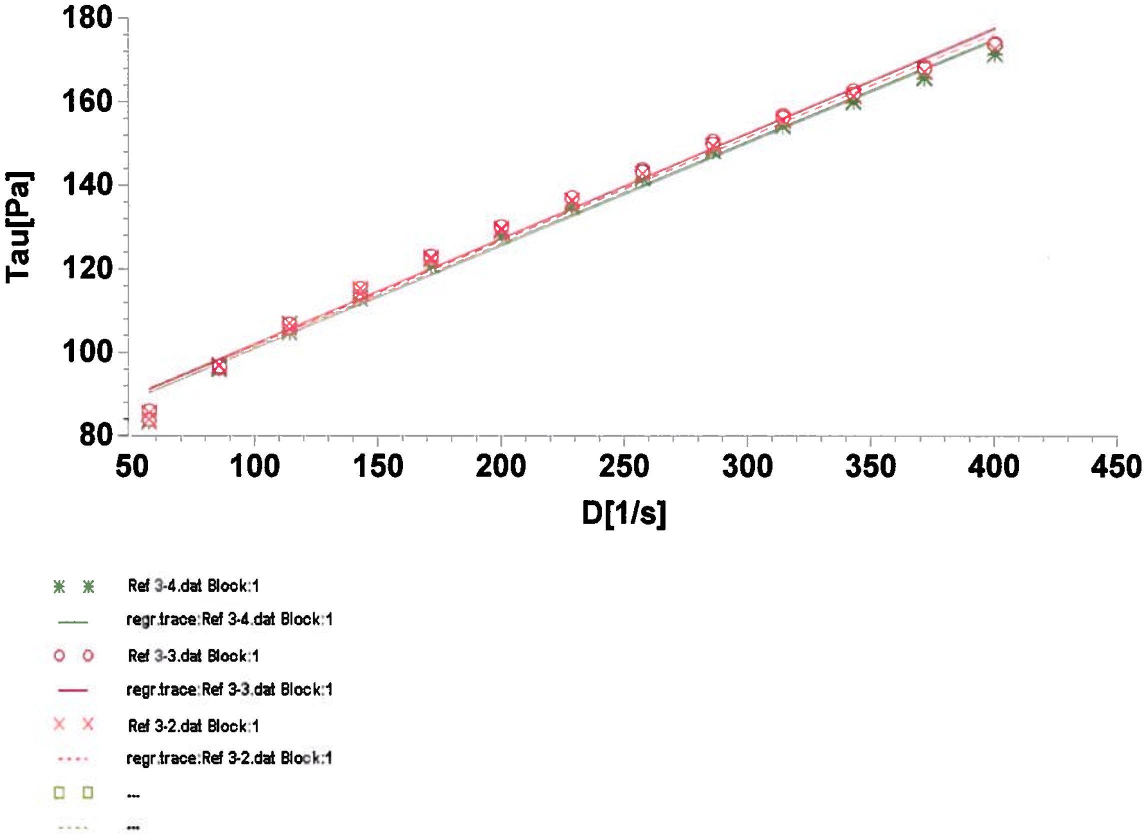


Analysis-results
Analysis data source: Ref 2-3.dat Block:1
filter activated: D[1/s]>40
step1: Bingham: Y=127.42+0.44293*X ;B=0.99434; S=3.89
step1: Bingham yieldstress[Pa]=127.4232
step1: Bingham viscosity[Pas]=0.4429
step2: Bingham: Y=110.77+0.48434*X ;B=0.99108; S=5.34
step2: Bingham yieldstress[Pa]=110.7655
step2: Bingham viscosity[Pas]=0.4843

filter activated: D[1/s]>40
step1: Bingham: Y=127.96+0.44206*X ;B=0.99079; S=4.95
step1: Bingham yieldstress[Pa]=127.9589
step1: Bingham viscosity[Pas]=0.4421
step2: Bingham: Y=114.85+0.47237*X ;B=0.99015; S=5.48
step2: Bingham yieldstress[Pa]=114.8503
step2: Bingham viscosity[Pas]=0.4724

filter activated: D[1/s]>40
step1: Bingham: Y=132.61+0.43396*X ;B=0.98268; S=6.7
step1: Bingham yieldstress[Pa]=132.6058
step1: Bingham viscosity[Pas]=0.434
step2: Bingham: Y=114.73+0.4721*X ;B=0.98998; S=5.52
step2: Bingham yieldstress[Pa]=114.7276
step2: Bingham viscosity[Pas]=0.4721
End of report

14:50 29/11/10
Manual Report Analysis/Regression

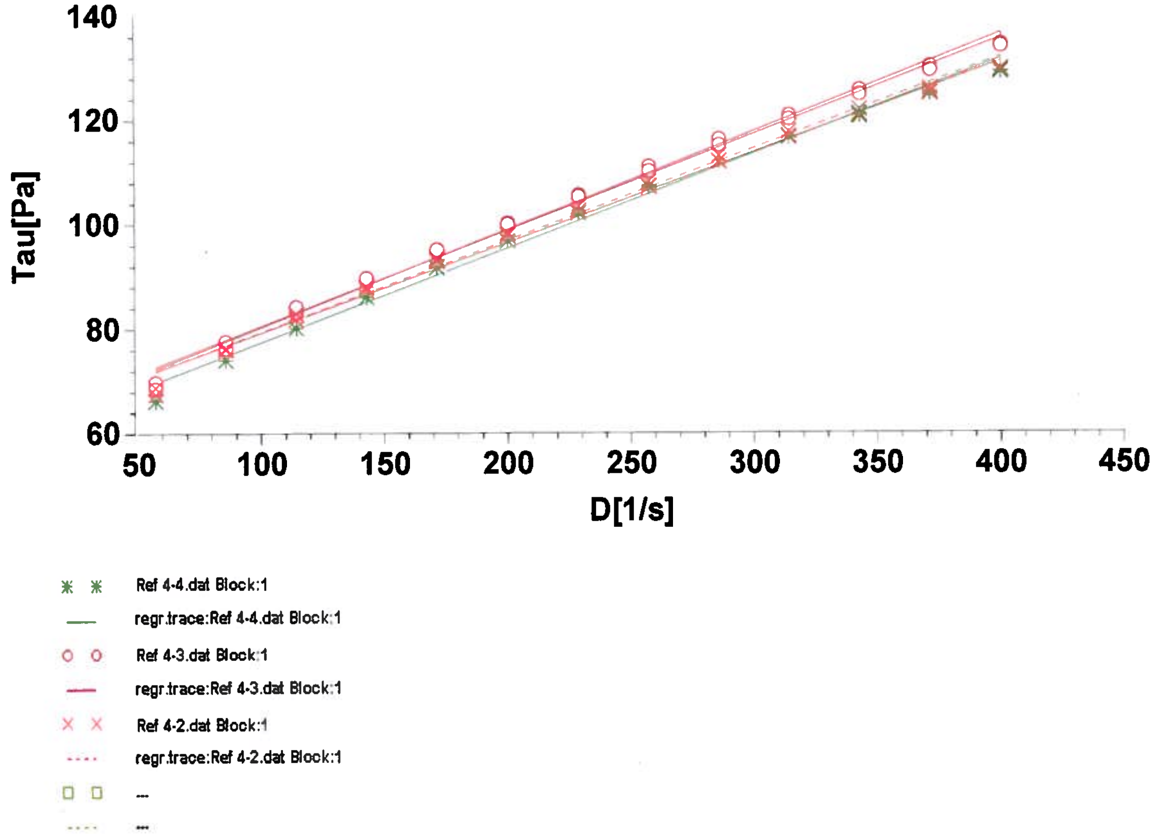


Analysis-results
Analysis data source: Ref 3-4.dat Block:1
filter activated: D[1/s]>40
step1: Bingham: Y=76.216+0.24628*X ;B=0.99245; S=2.5
step1: Bingham yieldstress[Pa]=76.216
step1: Bingham viscosity[Pas]=0.2463
step2: Bingham: Y=76.886+0.24559*X ;B=0.98716; S=3.26
step2: Bingham yieldstress[Pa]=76.8855
step2: Bingham viscosity[Pas]=0.2456

filter activated: D[1/s]>40
step1: Bingham: Y=76.712+0.25275*X ;B=0.99166; S=2.69
step1: Bingham yieldstress[Pa]=76.7118
step1: Bingham viscosity[Pas]=0.2527
step2: Bingham: Y=76.866+0.25125*X ;B=0.98793; S=3.23
step2: Bingham yieldstress[Pa]=76.8663
step2: Bingham viscosity[Pas]=0.2513

filter activated: D[1/s]>40
step1: Bingham: Y=76.879+0.24863*X ;B=0.9915; S=2.68
step1: Bingham yieldstress[Pa]=76.8791
step1: Bingham viscosity[Pas]=0.2486
step2: Bingham: Y=77.184+0.24791*X ;B=0.98767; S=3.22
step2: Bingham yieldstress[Pa]=77.1844
step2: Bingham viscosity[Pas]=0.2479
End of report

15:15 29/11/10
Manual Report Analysis/Regression

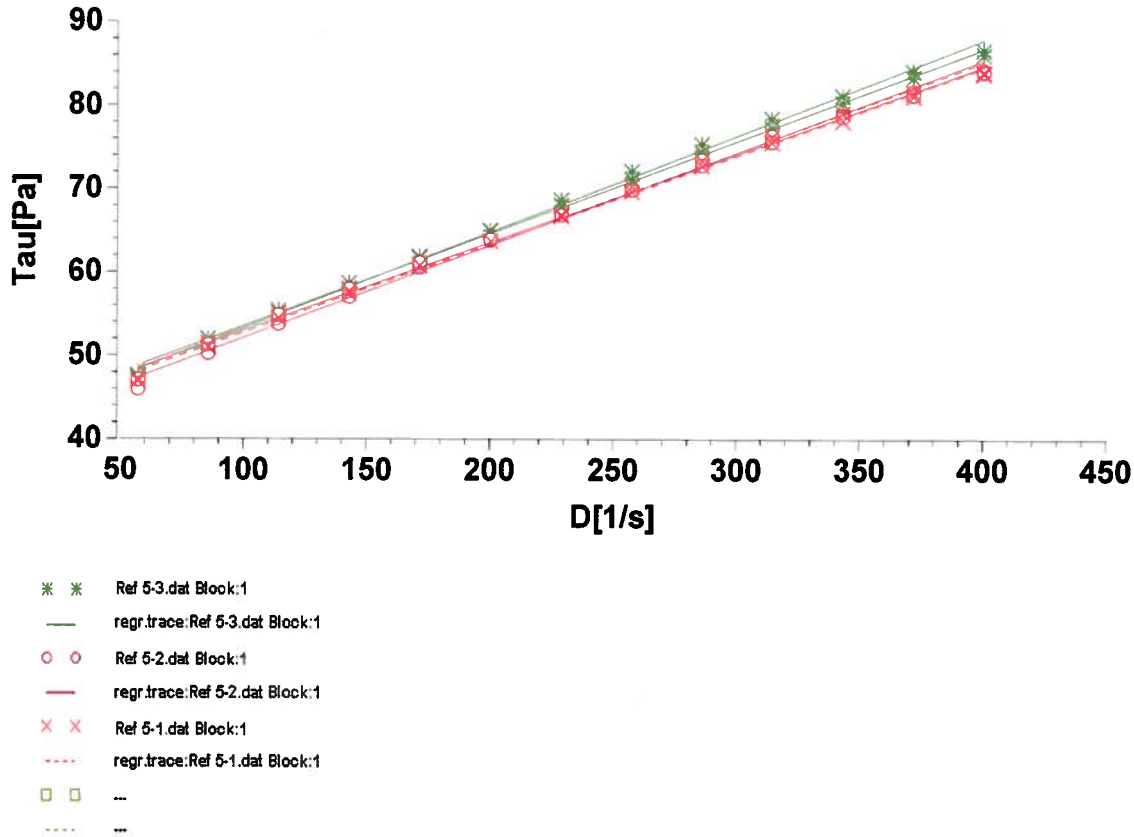


Analysis-results
Analysis data source: Ref 4-4.dat Block:1
filter activated: D[1/s]>40
step1: Bingham: Y=59.393+0.18076*X ;B=0.99367; S=1.68
step1: Bingham yieldstress[Pa]=59.3929
step1: Bingham viscosity[Pas]=0.1808
step2: Bingham: Y=61.972+0.17293*X ;B=0.99234; S=1.77
step2: Bingham yieldstress[Pa]=61.972
step2: Bingham viscosity[Pas]=0.1729

filter activated: D[1/s]>40
step1: Bingham: Y=61.583+0.18753*X ;B=0.99592; S=1.4
step1: Bingham yieldstress[Pa]=61.5831
step1: Bingham viscosity[Pas]=0.1875
step2: Bingham: Y=62.228+0.18368*X ;B=0.99414; S=1.64
step2: Bingham yieldstress[Pa]=62.2283
step2: Bingham viscosity[Pas]=0.1837

filter activated: D[1/s]>40
step1: Bingham: Y=61.901+0.17554*X ;B=0.99428; S=1.55
step1: Bingham yieldstress[Pa]=61.9007
step1: Bingham viscosity[Pas]=0.1755
step2: Bingham: Y=61.996+0.17298*X ;B=0.99285; S=1.71
step2: Bingham yieldstress[Pa]=61.9962
step2: Bingham viscosity[Pas]=0.173
End of report

15:34 29/11/10
Manual Report Analysis/Regression



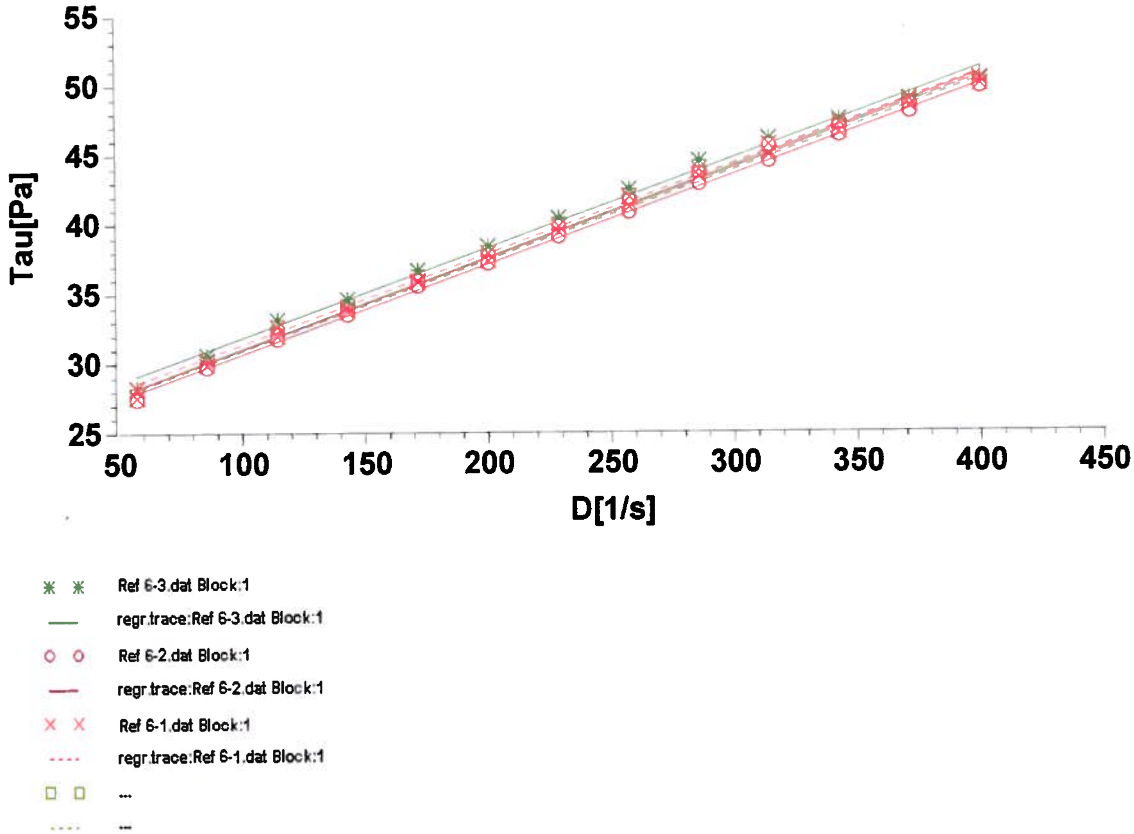
Analysis-results
Analysis data source: Ref 5-3.dat Block:1
filter activated: D[1/s]>40
step1: Bingham: Y=41.788+0.11516*X ;B=0.99792; S=0.61
step1: Bingham yieldstress[Pa]=41.788
step1: Bingham viscosity[Pas]=0.1152
step2: Bingham: Y=42.482+0.11073*X ;B=0.99844; S=0.508
step2: Bingham yieldstress[Pa]=42.4816
step2: Bingham viscosity[Pas]=0.1107

filter activated: D[1/s]>40
step1: Bingham: Y=41.038+0.11103*X ;B=0.9968; S=0.731
step1: Bingham yieldstress[Pa]=41.0379
step1: Bingham viscosity[Pas]=0.111
step2: Bingham: Y=42.462+0.10558*X ;B=0.99788; S=0.565
step2: Bingham yieldstress[Pa]=42.4617
step2: Bingham viscosity[Pas]=0.1056

filter activated: D[1/s]>40
step1: Bingham: Y=41.926+0.10809*X ;B=0.99806; S=0.554
step1: Bingham yieldstress[Pa]=41.9262
step1: Bingham viscosity[Pas]=0.1081
step2: Bingham: Y=42.163+0.1059*X ;B=0.99792; S=0.562
step2: Bingham yieldstress[Pa]=42.1628
step2: Bingham viscosity[Pas]=0.1059
End of report

multiple data sources

15:46 29/11/10
Manual Report Analysis/Regression



Analysis-results
Analysis data source: Ref 6-3.dat Block:1
filter activated: D[1/s]>40
step1: Bingham: Y=25.439+0.064397*X ;B=0.99557; S=0.5
step1: Bingham yieldstress[Pa]=25.4389
step1: Bingham viscosity[Pas]=0.0644
step2: Bingham: Y=24.51+0.065125*X ;B=0.99908; S=0.229
step2: Bingham yieldstress[Pa]=24.5102
step2: Bingham viscosity[Pas]=0.0651

filter activated: D[1/s]>40
step1: Bingham: Y=24.51+0.065574*X ;B=0.9973; S=0.397
step1: Bingham yieldstress[Pa]=24.5102
step1: Bingham viscosity[Pas]=0.0656
step2: Bingham: Y=24.254+0.064382*X ;B=0.9992; S=0.211
step2: Bingham yieldstress[Pa]=24.2537
step2: Bingham viscosity[Pas]=0.0644

filter activated: D[1/s]>40
step1: Bingham: Y=24.909+0.064856*X ;B=0.99832; S=0.31
step1: Bingham yieldstress[Pa]=24.9092
step1: Bingham viscosity[Pas]=0.0649
step2: Bingham: Y=24.422+0.064829*X ;B=0.9987; S=0.272
step2: Bingham yieldstress[Pa]=24.4225
step2: Bingham viscosity[Pas]=0.0648
End of report

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Asia	+ 86 21 6258 5522
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solutions@golder.com
www.golder.com

Golder Paste Technology Ltd.
1010 Lorne Street
Sudbury, Ontario, P3C 4R9
Canada
T: +1 (705) 524 5533

Golder PasteTec

Attachment 7

H3D Technical Description

Theoretical Basis

H3D is a three-dimensional time-stepping numerical model which computes the three components of velocity (*u*,*v*,*w*) on a regular grid in three dimensions (*x*,*y*,*z*), as well as scalar fields such as temperature and contaminant concentrations. The model uses the Arakawa C-grid (Arakawa and Lamb, 1977) in space, and uses a two level semi-implicit scheme in the time domain. H3D bears many similarities to the well-known Princeton Ocean Model (POM) (Blumberg and Mellor, 1987) in terms of the equations it solves, but differs in how the time-domain aspects are implemented. H3D uses a semi-implicit scheme, allowing relatively large time steps, and does not separately solve the internal and external models as POM does. It also uses a considerably simpler turbulence scheme in the vertical. These considerations combined allow H3D to execute complex problems relatively quickly.

The equations to be solved are:

Mass Conservation:

(A1)

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

At the end of each timestep equation, (A1) is used to diagnostically determine the vertical component of velocity (*w)* once the two horizontal components of velocity (*u* and *v*) have been calculated by the model.

X-directed momentum:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}+g\frac{\partial \eta}{\partial x}+\frac{1}{\rho_o}\frac{\partial}{\partial x}\int_z^{\eta}(\rho_w-\rho_o)gdz-fv-\frac{\partial}{\partial x}A_H\frac{\partial u}{\partial x}-\frac{\partial}{\partial y}A_H\frac{\partial u}{\partial y}-\frac{\partial}{\partial z}A_V\frac{\partial u}{\partial z}=0. \quad \text{(A2)}$$

Y-directed momentum:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}+g\frac{\partial \eta}{\partial y}+\frac{1}{\rho_o}\frac{\partial}{\partial y}\int_z^{\eta}(\rho_w-\rho_o)gdz+fu-\frac{\partial}{\partial x}A_H\frac{\partial v}{\partial x}-\frac{\partial}{\partial y}A_H\frac{\partial v}{\partial y}-\frac{\partial}{\partial z}A_V\frac{\partial v}{\partial z}=0. \quad \text{(A3)}$$

Water surface elevation determined from the vertically-integrated continuity equation:

$$\frac{\partial \eta}{\partial t} = -\frac{\partial}{\partial x}\int_{-H}^{\eta} u dz - \frac{\partial}{\partial y}\int_{-H}^{\eta} v dz. \tag{A4}$$

The effect of wind forcing introduced by means of the surface wind-stress boundary condition:

$$\left(A_V \frac{\partial u}{\partial z}, A_V \frac{\partial v}{\partial z} \right)_{z=\eta} = \frac{\rho_a}{\rho_w} C_{D,\,air} \vec{U}_{wind} \left| \vec{U}_{wind} \right|. \tag{A5}$$

The effect of bottom friction introduced by the bottom boundary condition:

$$\left(A_V \frac{\partial u}{\partial z}, A_V \frac{\partial v}{\partial z} \right)_{z=-H} = K_{bottom} \vec{U}_{bottom} \left| \vec{U}_{bottom} \right|. \tag{A6}$$

The bottom friction coefficient is usually understood to apply to currents at an elevation of one metre above the bottom. The bottom-most vector in H3D will, in general, be at a different elevation, i.e., at the midpoint of the lowest computational cell. H3D uses the 'law of the wall' to estimate the flow velocity at one metre above the bottom from the modelled near-bottom velocity.

The evolution of scalars, such as salinity, temperature, or suspended sediment, is given by the scalar transport/diffusion equation:

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} + w\frac{\partial S}{\partial z} - \frac{\partial}{\partial x} N_H \frac{\partial S}{\partial x} - \frac{\partial}{\partial y} N_H \frac{\partial S}{\partial y} - \frac{\partial}{\partial z} N_V \frac{\partial S}{\partial z} = Q\,. \tag{A7}$$

In the above equations:

$u(x,y,z,t)$: component of velocity in the x direction;

$v(x,y,z,t)$: component of velocity in the y direction;

$w(x,y,z,t)$: component of velocity in the z direction;

$S(x,y,z,t)$: scalar concentration;

$Q(x,y,z,t)$: source term for each scalar species

f: Coriolis parameter, determined by the earth's rotation and the local latitude;

$A_H\left(\partial u / \partial x, \partial u / \partial y, \partial v / \partial x, \partial v / \partial y\right)$: horizontal eddy viscosity;

$A_V \left(\partial u / \partial z, \partial v / \partial z, \partial \rho_{water} / \partial z\right)$: vertical eddy viscosity;

N_H: horizontal eddy diffusivity;

$N_V \left(\partial u / \partial z, \partial v / \partial z, \partial \rho_{water} / \partial z\right)$: vertical eddy diffusivity;

$C_{D,air}$: drag coefficient at the air-water interface;

$C_{D,bottom}$: drag coefficient at the water/sea bottom interface;

ρ_a: density of air;

$\rho_w(x,y,z,t)$: density of water;

ρ_o : reference density of water;

$\eta(x,y,t)$: water surface;

$H(x,y)$: local depth of water.

The above equations are formally integrated over the small volumes defined by the computational grid, and a set of algebraic equations results, for which an appropriate time-stepping methodology must be found. Backhaus (1983, 1985) presents such a procedure, referred to as a semi-implicit method. The spatially-discretized version of the continuity equation is written as:

$$\eta^{(1)} = \eta^{(0)} - \alpha \frac{\Delta t}{\Delta l}(\delta_x U^{(1)} + \delta_y V^{(1)}) - (1-\alpha)\frac{\Delta t}{\Delta l}(\delta_x U^{(0)} + \delta_y V^{(0)}) \qquad \text{(A8)}$$

where superscript *(0)* and *(1)* refer to the present and the advanced time, δ_x and δ_y are spatial differencing operators, and *U* and *V* are vertically integrated velocities. The factor α represents an implicit weighting, which must be greater than 0.5 for numerical stability. $U^{(0)}$ and $V^{(0)}$ are known at the start of each computational cycle. $U^{(1)}$, and similarly $V^{(1)}$, can be expressed as:

$$U^{(1)} = U^{(0)} - g\alpha\Delta t\eta_x^{(1)} - g(1-\alpha)\Delta t\eta_x^{(0)} + \Delta t X^{(0)} \qquad \text{(A9)}$$

where $X^{(0)}$ symbolically represents all other terms in the equation of motion for the u- or v-component, which are evaluated at time level *(0)*: Coriolis force, internal pressure gradients, non-linear terms, and top and bottom stresses,*)*. When these expressions are substituted into the continuity equation (A4), after some further manipulations, there results an elliptic equation for $\delta_{i,k}$, the change in water level over one timestep at grid cell *i*,*k* (respectively the *y* and *x* directions):

$$\delta_{i,k} - (ce\delta_{i,k+1} + cw\delta_{i,k-1} + cn\delta_{i-1,k} + cs\delta_{i+1,k}) = Z_{i,k} \qquad \text{(A10)}$$

where *ce*, *cw*, *cn*, and *cs* are coefficients depending on local depths and the weighting factor (α), and $Z_{i,k}$ represents the sum of the divergence formed from velocities at time level *(0)* plus a weighted sum of adjacent water levels at time level *(0)*.

Once equation (A10) is solved for $\delta_{i,k}$, the water level can be updated:

$$\eta_{i,k}^{(1)} = \eta_{i,k}^{(0)} + \delta_{i,k} \qquad \text{(A11)}$$

and equation (A9) can be completed.

At the end of each timestep, volume conservation is used to diagnostically compute the vertical velocity *w(j,i,k)* from the two horizontal components *u* and *v*.

Grid Geometry

In the vertical, the levels near the surface are typically closely spaced to assist with resolving near-surface dynamics. In addition, the model is capable of dealing with relatively large excursions in overall water level as the water level rises and falls in response to varying inflows and outflows, by allowing the number of near-surface layers to change as the water level varies. That is, as water levels rise in a particular cell, successive layers above the original layer are turned on and become part of the computational mesh. Similarly, as water levels fall, layers are turned off. This procedure has proven to be quite robust, and allows for any reasonable vertical resolution in near-surface waters. When modelling thin river plumes in areas of large tidal range, the variable number of layers approach allows for much better control over vertical resolution than does the σ-coordinate method.

In addition to tides, the model is able to capture the important response, in terms of enhanced currents and vertical mixing, to wind-driven events. This is achieved by applying wind stress to each surface grid point on each time step. Vertical mixing in the model then re-distributes this horizontal momentum throughout the water column. Similarly, heat flux through the water surface is re-distributed by turbulence and currents in temperature simulations.

Turbulence Closure

Turbulence modelling is important in determining the correct distribution of velocity and scalars in the model. The diffusion coefficients for momentum (A_H and A_V) and scalars (N_H and N_V) at each computational cell are dependent on the level of turbulence at that point. H3D used a shear-dependent turbulence formulation in the horizontal, (Smagorinsky, 1963). The basic form is:

$$A_H = A_{Ho}\, dx\, dy \sqrt{\left(\frac{du}{dx}\right)^2 + \left(\frac{dv}{dy}\right)^2 + \frac{1}{2}\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2} \qquad \text{(A12)}$$

The parameter A_{H0} is a dimensionless tuning variable, and experience has shown it to lie in the range of 0.25 to 0.45 for most water bodies such as rivers, lakes and estuaries.

A shear and stratification dependent formulation, the Level 2 model of Mellor and Yamada (1982), is used for the vertical eddy diffusivity. The basic theory for the vertical viscosity formulation is taken from an early paper, Mellor and Durbin (1975). The evaluation of length scale is based on a methodology presented in Mellor and Yamada (1982).

For scalars, both horizontal and vertical eddy diffusivity are taken to be similar to their eddy viscosity counterparts, but scaled by a fixed ratio from the eddy viscosity values. Different ratios are used for the horizontal and vertical diffusivities. If data is available for calibration, these ratios can be adjusted based on comparisons between modelled and observed data. Otherwise, standard values based on experience with similar previously modelled water bodies are used. For the Site C model, the ratio of vertical eddy diffusivity to vertical eddy viscosity was 0.75 and the ratio between horizontal eddy diffusivity and horizontal eddy viscosity was 1.0.

Scalar Transport

The scalar transport equation implements a form of the flux-corrected algorithm (Zalesak, 1979), in which all fluxes through the sides of each computational cell are first calculated using a second-order method. Although generally more accurate than a first order method, second order flux calculations can sometimes lead to unwanted high frequency oscillations in the numerical solution. To determine if such a situation is developing, the model examines each cell to see if the computed second order flux would cause a local minimum or maximum to develop. If so, then all fluxes into or out of that cell are replaced by first order fluxes, and the calculation is completed. As noted, the method is not a strict implementation of the Zalesak method, but is much faster and achieves very good performance with respect to propagation of a Gaussian distribution through a computational mesh. It does not propagate box-car distributions as well as the full Zalesak method, but achieves realistic simulations of the advection of scalars in lakes, rivers and estuaries, which is the goal of the model. This scheme as implemented is thus a good tradeoff between precision and execution time, important since in many situations, where more than one scalar is involved, the transport-diffusion algorithm can take up more than half the execution time.

Heat Flux at the Air-Water Interface

The contribution of heat flux to the evolution of the water temperature field can be schematized as:

$$\frac{dT}{dt} = \frac{\Delta Q}{\rho * c_p * h}$$

where ΔQ is the net heat flux per unit area retained in a particular layer, ρ is the density of water, c_p is the heat capacity of water and h is the layer thickness.

Heat flux at the air-water interface incorporates the following terms:

Q_{in} : incident short wave radiation. Generally, this is not known from direct observations. Values for albedo as a function of solar height are taken from Kondratyev (1972).

Q_{back}: long wave back- radiation, calculated according to Gill (1982), involving the usual fourth power dependence on temperature, a factor of 0.985 to allow for the non-black body behaviour of the ocean, a factor depending on vapor pressure to allow for losses due to back radiation from moisture in the air, and a factor representing backscatter from clouds.

Q_L and Q_H: latent and sensible heat flux. Latent heat flux (Q_L) is the heat carried away by the process of evaporation of water. Sensible heat flux (Q_S) is driven by the air-water temperature difference and is similar to conduction, but assisted by turbulence in the air. Latent and sensible heat flux is described by:

$$Q_L = 1.32e^{-3} * L * windspeed * (q_{obs} - q_{sat}) * latent\_factor$$

$$Q_S = 1.46e^{-3} * \rho_{air} * c_p * windspeed * (T_{air} - T_{water}) * sensible\_factor$$

Where q_{obs} and q_{sat} are the observed and saturated specific humidities, T_{air} and T_{water} are the air and water temperatures, L is the latent heat of evaporation of water, and c_p is the heat capacity of water. '*latent_factor*' and '*sensible_factor*' are scaling factors introduced to account for local factors, and can be adjusted, when needed, to achieve better calibration of the model. Typically, the only adjustment is that *Sensible_factor* is doubled when the air temperature is less than the water or ice surface temperature to account for increased turbulence in an unstable air column.

Light absorption in the water column. As light passes through the water column it is absorbed and the absorbed energy is a component of the energy balance that drives water temperature. H3D assumes that light attenuation follows an exponential decay law:

$$E(z) = E(z_0) * e^{-k*(z-z_0)}$$

The model computes the energy at the top and bottom of each layer and the difference is applied to the general heat equation in that layer. The extinction coefficient (k) is related to the Secci depth (D_s) by

$$k = \frac{2.1}{D_s}$$

Temperate is treated like any other scalar as far as advection and diffusion are concerned. Heat flux at the water-sediment interface is not currently included in H3D.

Ice

The ice model is generally based on processes described in Patterson and Hamblin (1988). The ice cover is characterized by a thickness, a fraction of the cell covered, and an ice surface temperature. The temperature of the bottom of the ice is assumed to be the temperature of melting, usually 0^o C. The strategy is to compute the differences in heat flux at the top and bottom of the ice layer and use this difference to determine the growth or decay rate and the change in temperature of the ice. The heat flux at the bottom of the ice layer is dependent on lake temperature and water velocity. The heat flux at the top is dependent on meteorological processes and the surface temperature of the ice. The surface heat flux to the top of the ice sheet is calculated in a similar way as for open water, except that latent heat flux term (Q_L) also includes the heat of fusion. Albedo is also altered to account for ice/snow cover.

In order to start ice formation, once the surface water temperature drops below 3^o C in a particular cell, a test ice layer of thickness 1 cm is initialized. If the test thickness melts in one time step, then the system cannot support ice cover in that cell at that time. If it survives, then the amount of ice in that cell is converted to a 1 cm thick region with coverage calculated from the mass of ice formed. In this way, a relatively robust start is made to ice formation.

The frictional interaction between the bottom of the ice and the immediately adjacent water is parameterized according to Nezhikhovskiy (1964).

Validation

Three validations are discussed below.

Strait of Georgia/Point Atkinson Tide: Wave Propagation

A fundamental concern with a circulation model such as H3D is how well it propagates waves, the carriers of information through the system. Figure A-1 presents results of a simulation of tides in the Strait of Georgia and Juan de Fuca Strait, with tidal elevations prescribed at the entrance to Juan de Fuca Strait and at a section north of Texada Island in the Strait of Georgia. The complex dynamics of the northern passes, such as Discovery Passage and Seymour Narrows, are thus avoided, allowing a test of H3D's wave propagation capabilities. The figure plots the modelled water level at Point Atkinson in red, and the observed water level in black. There is nearly perfect agreement, with the slight difference resulting from small storm surge events. This validation demonstrates that the selection of grid schematization (Arakawa C-grid) and the semi-implicit time-stepping approach have produced a system than can accurately propagate information through a water body.

Okanagan Lake Temperature Profiles

Obtaining good reproduction of the seasonally–evolving temperate structure of a lake indicates that the heat flux across the air-water interface is accurately parameterized and that the transport-diffusive processes operating in the water column are also accurately reproduced by the model. Figure A-2 presents a comparison of observed and computed temperature profiles at the northern end of Okanagan Lake near Vernon, in April, August, October and December of 1997. The agreement is very good as the model reproduced the transition from a well-mixed condition in the spring to the development of a strong thermocline in the summer, the deepening of the upper layer during the fall cooling period, and a return to isothermal conditions in winter. There is little doubt that H3D can compute accurate temperature distributions in water bodies, as long as adequate meteorological data is available. For this simulation, the meteorological data was obtained from Penticton Airport: winds, rotated to follow the thalweg of the valley; cloud cover, air temperature and relative humidity.

Thermistor Response: Okanagan Lake

Okanagan Lake is subject to significant fluctuations in the vertical thermal structure during the summer stratified period. Figure A-3 shows a temperature time-series at a site on the north side of the William R. Bennett Bridge which exhibits significant temperature excursions at periods of about 60 hours, or 2.5 days. Figure A-4 shows the modelled time series of temperature at three selected depths, 51 m, 21 m and 9 m. The occurrence and magnitude of the temperature fluctuations is generally predicted by the model, but the reproduction is not perfect: the occurrence and timing of the temperature events is quite good, but the modelled peaks appear to be generally somewhat broader in time. . It was found that there were considerable differences in the simulated behaviour depending on whether winds at Kelowna Airport, which is situated in a side-valley, were included in the model or not. It is also clear that H3D can generally reproduce internal seiches in a lake, as long as adequate spatial resolution is used. This is particularly apparent when the coherent internal waves that propagate up and down the lake are examined in a longitudinal section, illustrated in two snapshots from a model simulation of such an event in Figure A-5.

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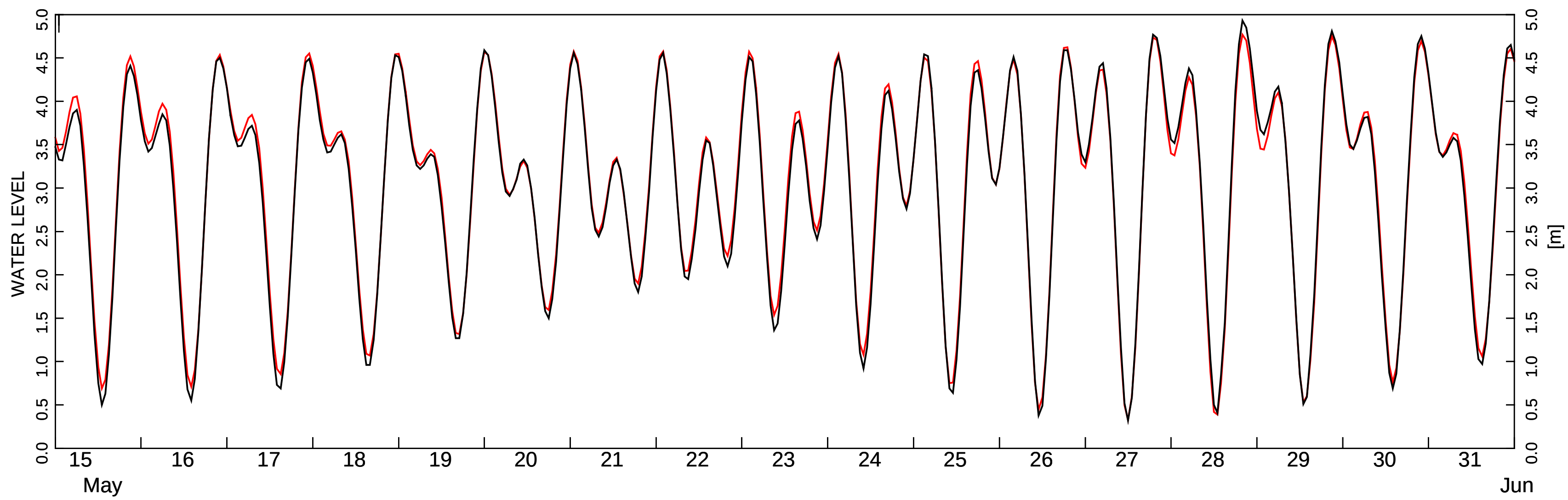
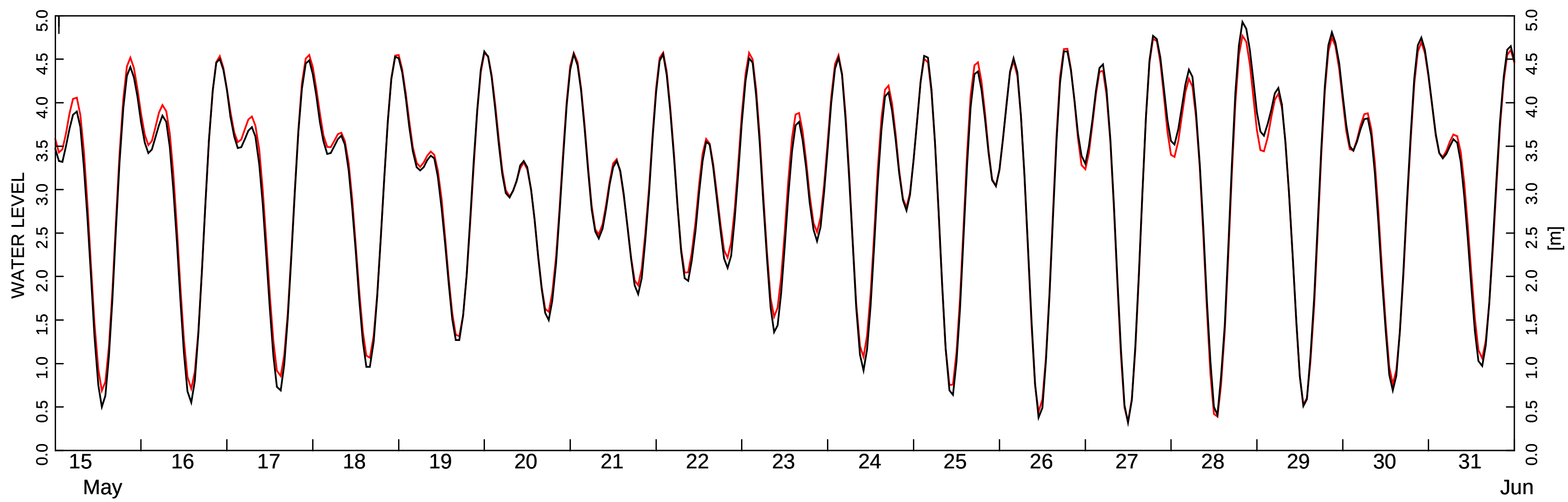




NOTES

MODELLED POINT ATKINSON DATA

OBSERVED POINT ATKINSON DATA

STATUS
ISSUED FOR REVIEW

CLIENT

BC HYDRO

A TETRA TECH COMPANY

Validation Example

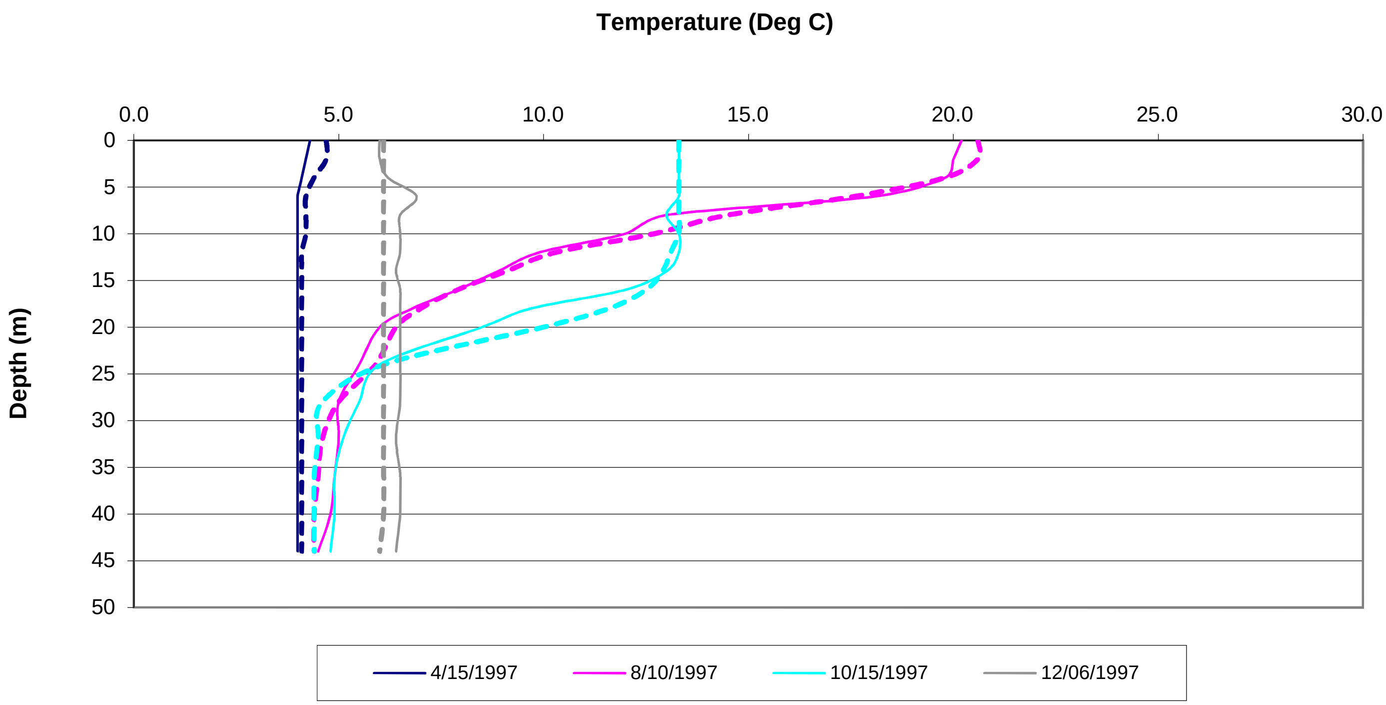
H3D VALIDATION
TIDAL REPRODUCTION

PROJECT NO.	DWN	CHK	APVD	REV
V13201131	EW	JAS	JAS	0

OFFICE	DATE
EBA-VANC	August 2011

Figure A-1

Tue Aug 02 15:16:16 2011:v:\V13201028 Fraser River Class C Study\working\EW\H3D-SOG\Run068\tsplot



LEGEND

- Solid lines represent observed profiles
- Dash lines represent modelled profiles

NOTES

STATUS

CLIENT

BC Hydro

EBA A TETRA TECH COMPANY

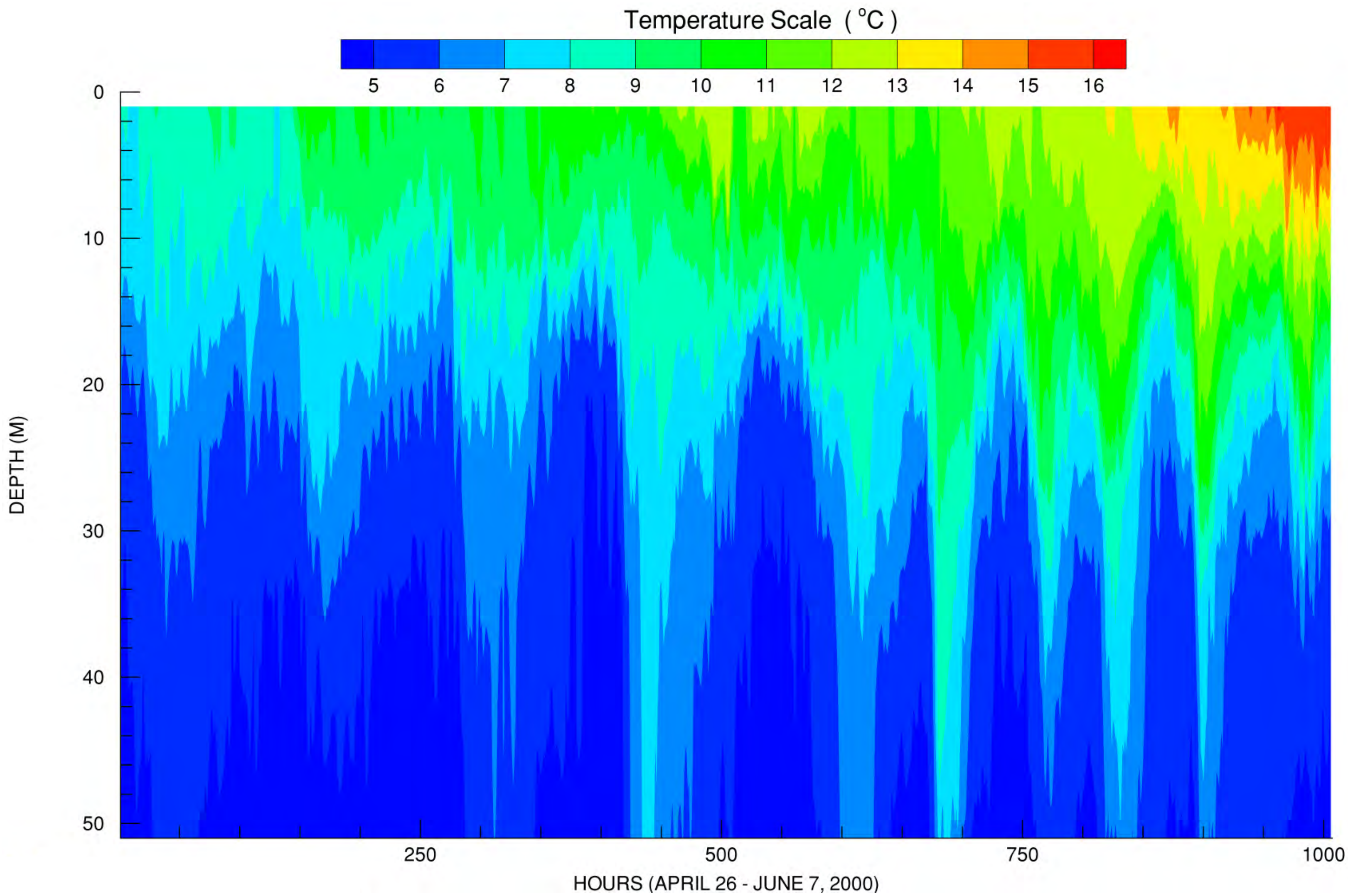
Validation Example

H3D Validation
Comparison of Observed and Modelled Temperature Profiles at Vernon

PROJECT NO.	DWN	CKD	APVD	REV
V13201131	AL	JAS	JAS	001

OFFICE	DATE
EBA-VANC	August , 2011

Figure A-2



LEGEND

NOTES

STATUS
ISSUED FOR REVIEW

CLIENT

BC Hydro

A TETRA TECH COMPANY

Validation Example

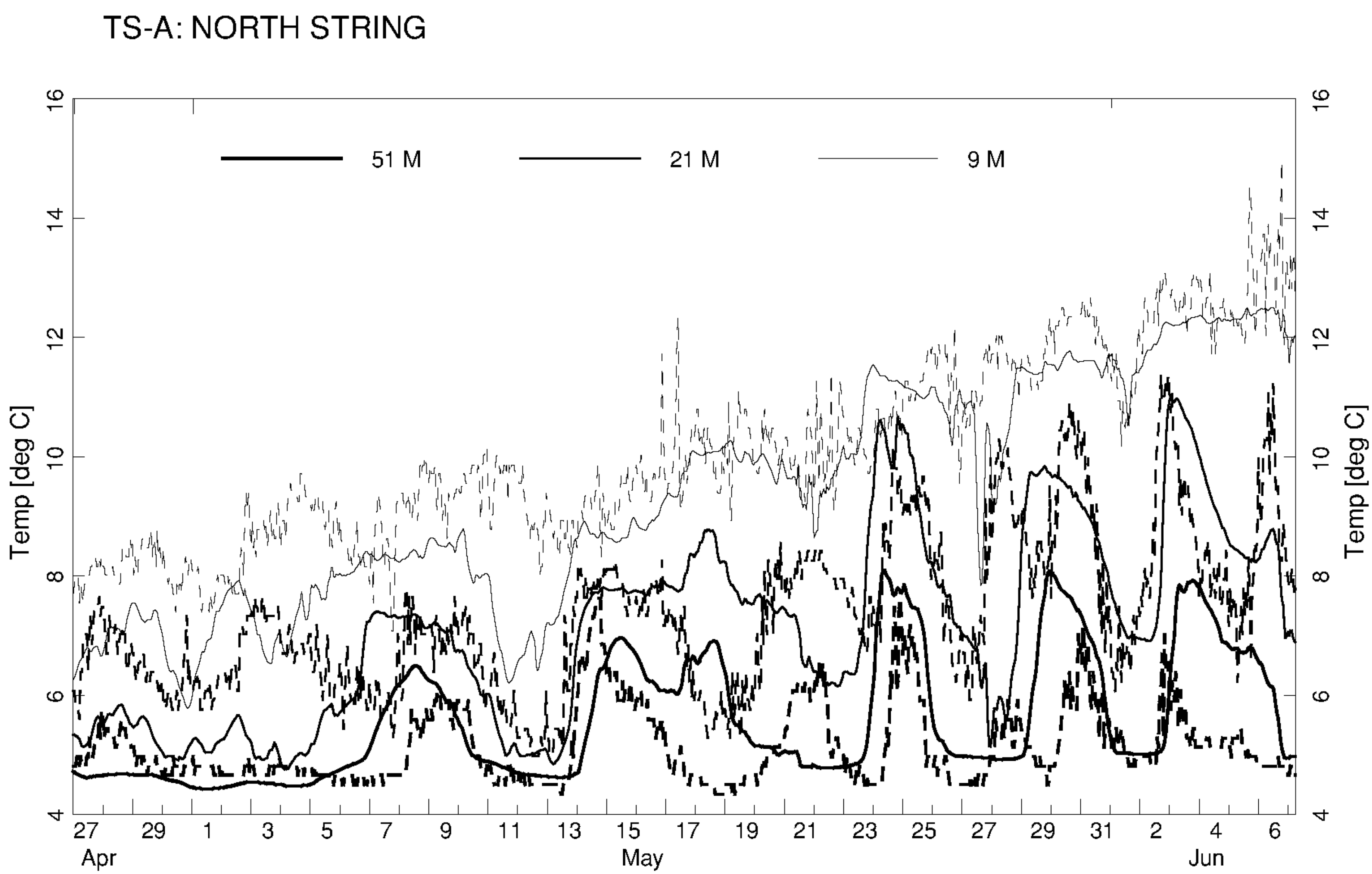
H3D VALIDATION SEICHES IN OKANAGAN LAKE (OBSERVED DATA)

PROJECT NO.	DWN	CKD	APVD	REV
V13201131	EW	JAS	JAS	0

OFFICE	DATE
EBA-VANC	August 2, 2011

Figure A-3

C:\Users\tara.schmidt\AppData\Local\Microsoft\Windows\Temporary Internet Files\Content.Outlook\4YICWR67\figureA3.doc



LEGEND

Dashed Lines: Observed Temperature
Solid Lines: Modelled Temperature

NOTES

STATUS
ISSUED FOR REVIEW

CLIENT

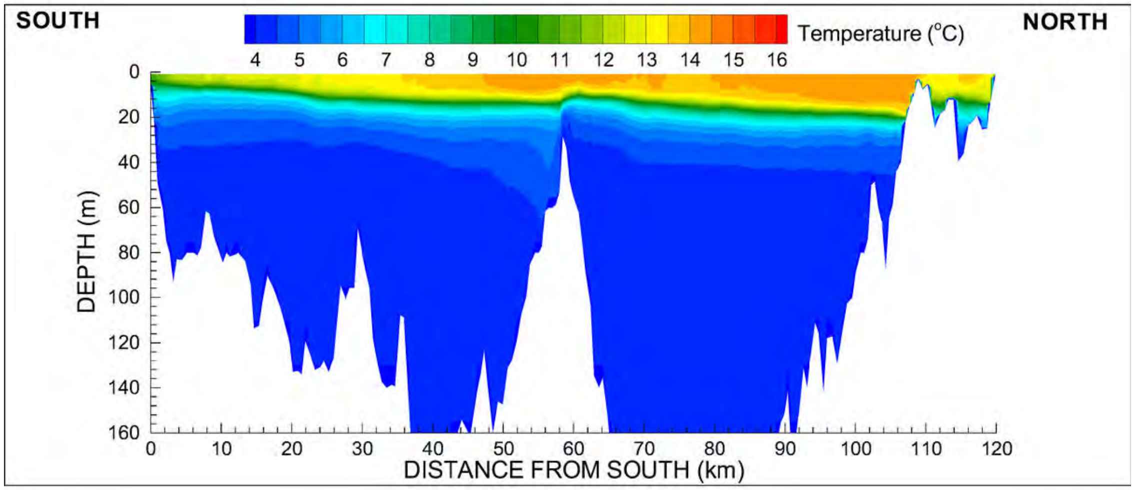
BC Hydro

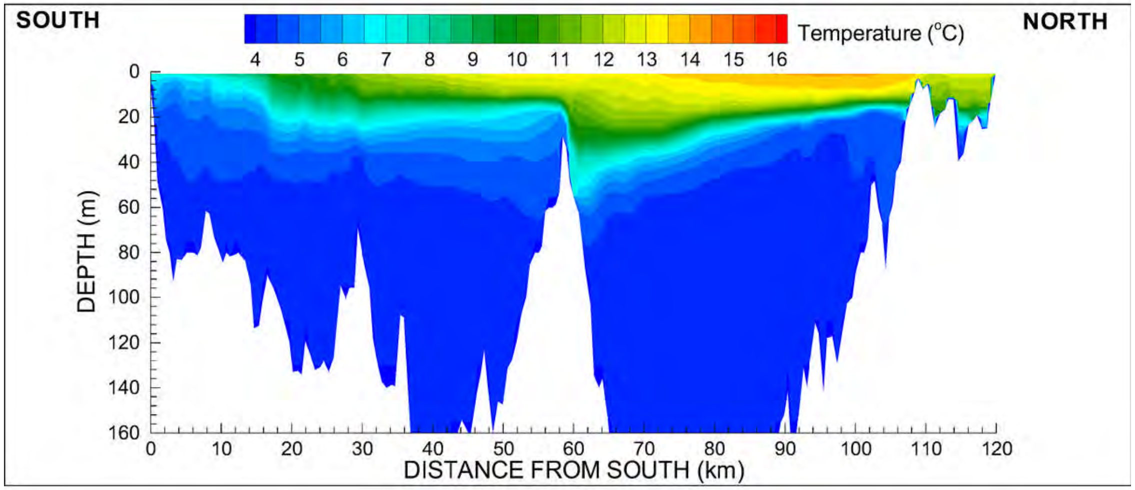
A TETRA TECH COMPANY

Validation Example

H3D VALIDATION
INTERNAL SEICHE DYNAMICS
OKANAGAN LAKE

PROJECT NO.	DWN	CKD	APVD	REV	
V13201131	EW	JAS	JAS	0	**Figure A-4**
OFFICE	DATE				
EBA-VANC	August 2, 2011				





LEGEND

NOTES

STATUS
ISSUED FOR REVIEW

CLIENT
BC Hydro

A TETRA TECH COMPANY

Validation Example

H3D VALIDATION
INTERNAL SEICHE DYNAMICS
OKANAGAN LAKE

PROJECT NO.	DWN	CKD	APVD	REV
V13201131	EW	JAS	JAS	JAS

OFFICE	DATE
EBA-VANC	August 2, 2011

Figure A-5

Attachment 8

RADIOACTIVITY PATHWAYS ASSESSMENT FOR THE THOR LAKE PROJECT, NORTHWEST TERRITORIES

Prepared For:

Avalon Rare Metals Incorporated

Prepared By:

SENES Consultants Limited

July 2011

AVALON
RARE METALS INC.

SENES Consultants Limited
Specialists in Energy, Nuclear and Environmental Sciences

FINAL

RADIOACTIVITY PATHWAYS ASSESSMENT FOR THE THOR LAKE PROJECT, NORTHWEST TERRITORIES

Prepared for:

Avalon Rare Metals Incorporated
130 Adelaide Street West
Suite #1901
Toronto, Ontario
M5H 3P5

Prepared by:

SENES Consultants Limited
121 Granton Drive, Unit 12
Richmond Hill, Ontario
L4B 3N4

July 2011

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Prepared for:

Avalon Rare Metals Incorporated
130 Adelaide Street West
Suite #1901
Toronto, Ontario
M5H 3P5

Prepared by:

SENES Consultants Limited
121 Granton Drive, Unit 12
Richmond Hill, Ontario
L4B 3N4

Stacey Fernandes, M.A.Sc., P.Eng.
Senior Environmental Engineer

Claire Brown, B.Sc., GIT
Environmental Scientist

Douglas B. Chambers, Ph.D.
Director of Risk and Radioactivity Studies

July 2011

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1.0 INTRODUCTION

SENES Consultants Limited (SENES) has been contracted by Avalon Rare Metals Incorporated (Avalon) to conduct a Radioactivity Pathways Assessment of the Thor Lake Project, a proposed rare earth mineral mine and processing facility on Great Slave Lake, Northwest Territories. The screening level pathways assessment examined the potential exposure of human and ecological receptors to radioactivity from the Thor Lake Project.

An exposure pathways analysis was conducted to evaluate contaminant sources, assess the environmental fate of released radioactive species, estimate doses to workers (not directly involved in mining), people who hunt, fish or live in the area, and to non-human biota (aquatic and terrestrial systems). Using findings of baseline studies of environmental media and receptors (Stantec 2010a-f), test-run laboratory results of mine wastes (SGS 2010a), mathematical modelling of air (RWDI 2011) and water (EBA 2011), and known Toxicity Reference Values (TRVs), potential risks to both the human and ecological populations were determined. This report exclusively examines pathways of radiological exposure, and does not assess other potential contaminants (e.g. metals, organic compounds). Human radiation exposure focussed on radiation pathways to First Nations peoples using adjacent lands and Thor Lake Project workers employed in support positions (e.g. camp cook, security guard). The assessment of radiation pathways and exposures to workers in mining occupations (e.g. driller, mill worker), is provided under separate cover (SENES 2011).

For the current work program, the environmental modelling and pathways analyses were performed at a screening level and, as such, simplifying assumptions were made. Air and water dispersion modelling was conducted to provide an estimate of radionuclides in these media. Environmental modelling estimated the steady-state (long-term) concentrations of the COPC in the environmental media of interest (e.g. vegetation, fish). Pathways modelling combined the receptor characteristics (ingestion rate, body weight, time at site, etc.) with the estimated environmental media concentrations of Constituents of Potential Concern (COPC) to estimate exposure of each receptor. For this screening level assessment, a spreadsheet pathways model was used. This spreadsheet model was built on the INTAKE pathways model, which calculates exposures and doses to ecological and human receptors. The INTAKE model has been applied to several uranium mining projects in northern Saskatchewan to simulate radiological and non-radiological constituent fate and transport in the environment and the subsequent evaluation of exposures to ecological species and humans. The dose estimates are then compared to dose limits in the risk assessment to identify any areas of concern.

Potential radiological impacts to the human and ecological systems were assessed based on the proposed mine plan as presented within the Project Description Report (Avalon 2010a). The document, as submitted by Avalon to the Mackenzie Valley Land and Water Board in April 2010, served as the primary guidance document of projected land use and mine planning. The sole exception is the tailings management plan for the Hydrometallurgical Plant Site, reported within the separate December 2010 Updated Hydrometallurgical Plant Tailings Management Plan (Knight Piésold 2010). Further revisions to the tailings management plan were also recommended, as identified in the January 2011 Knight Piésold Pine Point Hydrometallurgical Site Clarification Memorandum (Knight Piésold 2011).

1.1 PROJECT BACKGROUND

The Thor Lake Project is a proposed rare earth mineral mine with two infrastructure sites: the Nechalacho Mine and Flotation Plant Site, and the Hydrometallurgical Plant Site. The Nechalacho Mine is located on Thor Lake, 5km from the northern shore of the Hearne Channel of Great Slave Lake. 100% owned by Avalon, the property is within the Mackenzie Mining District, approximately 100 km southeast of Yellowknife, 100 km southwest of Lutsel K'e, and 225 km northeast of Hay River. The Thor Lake property hosts a total of six metal bearing mineral deposits, with the Nechalacho deposit the largest and covering an approximate area of two square kilometres (Avalon 2010a). The ore extracted from the Nechalacho Mine will be processed into Rare Earth Element (REE) concentrate through underground crushing and processing within the Flotation Plant (conventional grinding, crushing, and flotation). The concentrate is to be shipped by barge to the Hydrometallurgical Plant Site for further processing.

The Hydrometallurgical Plant Site is situated at the former Pine Point Lead/Zinc Mine, approximately 165 km southwest of the Nechalacho Mine and 10 km south of the southern shore of Great Slave Lake. The now decommissioned lead/zinc mine is classified as a brownfield site. Following processing of the Nechalacho Mine ore at the Hydrometallurgical Plant Site, the finished ore will be shipped by rail to southern markets for sale.

Figure 1.1 below provides an overview of the location of the Nechalacho Mine/Flotation Plant and the Hydrometallurgical Plant.

FIGURE 1.1 OVERVIEW OF THE THOR LAKE PROJECT LOCATION

Source: Map adapted from Avalon Rare Metals Inc., Figure 1.0-1, April 2010

1.2 REPORT STRUCTURE

The report has been structured into sections describing specific aspects of the risk assessment. These aspects include:

Section 1 – Introduction: Provides a frame of reference for the Thor Lake Project and Pathways Assessment.

Section 2 – Conceptual Site Model: Provides a description of the site, characteristics of the surrounding environment, the project description, and selection of the VECs and COPC.

Section 3 – Receptor Characterization: Identifies the relevant characteristics of the ecological and human receptors selected for inclusion in the pathways assessment.

Section 4 – Assessment Methodology: Describes the existing conditions in the immediate project area, and pathways model inputs used to predict the fate of radiological constituents in the environment.

Section 5 – Hazard Assessment: Details the endpoints used in the assessment for each of the COPC to characterize the risks of potential effects on the health of ecological species and humans.

Section 6 – Results: Presents the results of the pathways modelling and assessments for the Thor Lake Project, both for human health and ecological effects.

Section 7 – Summary: Provides a summary of the assessment and the critical conclusions.

Section 8 – References: Lists the reference sources used in this study.

2.0 CONCEPTUAL SITE MODEL

2.1 SITE DESCRIPTION

The following report sections describe the natural environment at the Nechalacho Mine and Flotation Plant (within the East Arm of Great Slave Lake), and the Hydrometallurgical Plant (southern shore of Great Slave Lake).

2.1.1 Nechalacho Mine Site

The Nechalacho Mine site is located within the Sub-Arctic Climatic Zone, which is characterized by short cool summers and long cold winters. On the basis of historical weather data collected between 1971-2000 from the nearest weather station (i.e. Yellowknife), the average daily temperature ranges from -26.8°C in January to 16.8 °C in July. The average annual precipitation is 280.7 mm, with 164.5 mm annual rainfall and 151.8 cm annual snowfall (Environment Canada 2011). Climate monitoring at the Nechalacho Mine area has been ongoing since June 2008, with a meteorological station measuring temperature, rainfall, wind direction/speed, barometric pressure, relative humidity and snow depth (Stantec 2010a). Results were approximately consistent with Yellowknife and Lutsel K'e climate statistics, with similar seasonal trends observed.

The landscape of the Nechalacho Mine and Flotation Plant is dominated by bedrock (covering approximately 43% of ground surface). Topography rises from 235 m above sea level (m.a.s.l.) at the shore of Thor Lake, to 265 m.a.s.l. on surrounding bedrock knolls. The topography decreases to a low of 156 m.a.s.l. at Great Slave Lake. Glacial deposits are also common in the Thor Lake Area, with thin veneers (<1 m thick) and blankets (>1 m thick) overlying the bedrock. The Nechalacho Mine lies within the discontinuous permafrost zone, and the active layer thickness ranges from 40-200 cm (Stantec 2010d).

The Thor Lake watershed covers an area of approximately 2,100 ha (Figure 2.1). Water velocity measurements revealed that while flow periodically reverses between Thor and Long Lakes, water does flow from Thor Lake to Fred Lake through a small defined channel. Thor Lake water reaches Great Slave Lake through a series of small lakes and wetlands, flowing approximately 20 km in a west/southwest direction. As part of the Baseline Study, surface water and sediment data were collected at a total of 23 study lakes. Water was neutral to basic (mean pH from 7.07 to 8.62), varied greatly in conductivity and hardness, and nutrient levels were generally low (Stantec 2010c).

Hydrogeology at the Nechalacho Mine is assumed to be dominated by a shallow and almost completely disconnected, aquifer in the areas of Thor and Long Lake. The shallow aquifer is very near the surface, varying from 0.7 m to 4.5 m below ground surface (b.g.s) and perched on permafrost (Stantec 2010b).

The Nechalacho Mine and Flotation Plant site is located within the Great Slave Upland High Boreal Ecoregion, a subdivision of the more extensive Taiga Shield High Boreal Ecoregion (Ecosystem Classification Group 2008). A total of 14 different vegetated ecosystems were mapped in the project area by Stantec. The most common ecosystem unit was lichen-bearberry woodland, followed by spruce-paper birch –toad flax forest (Stantec 2010e).

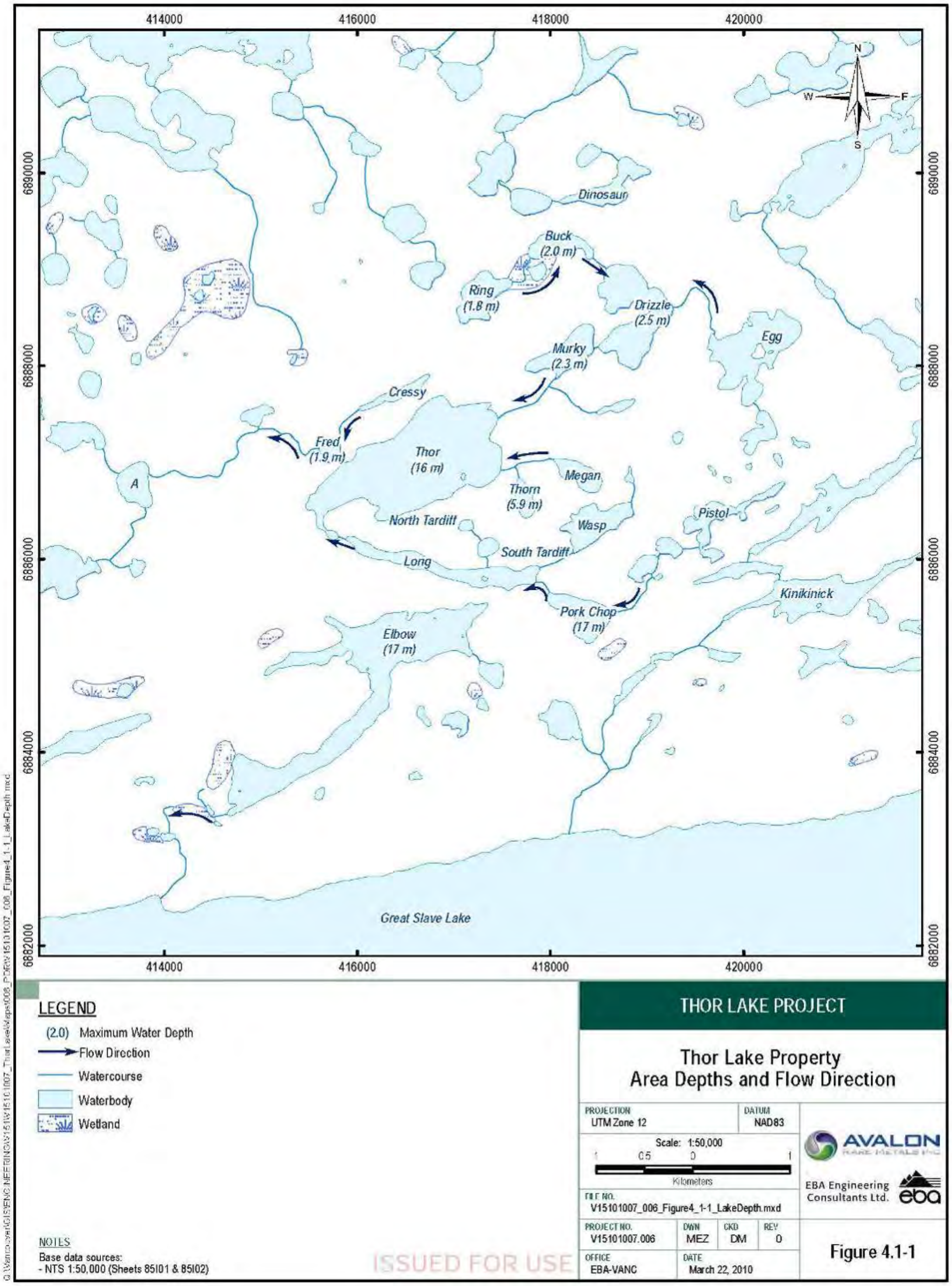
Both boreal and tundra animal species frequent the Nechalacho Mine and Flotation Plant area. A total of 26 species of mammals were identified to possibly visit this region, including: barren-ground caribou, beaver, black bear, gray wolf, moose, red squirrel and snowshoe hare (Stantec 2010f).

The Nechalacho Mine is host to a wide variety of bird species, and while some species may be present year round, the majority are migratory and only present at the site during their reproductive phases (April-October). Results of the Wildlife Assessment (Stantec 2010f) indicate a total of 49 passerine species, 16 raptor species, and 35 waterbird species may be present in the Nechalacho Mine Area (e.g. raven, bald eagle, peregrine falcon, grouse, mallard, merganser, and scaup).

Fisheries studies were conducted in 19 lakes within the Thor Lake watershed, with eight found to be devoid of fish (Buck, Cressy, Drizzle, Megan, North Tardiff, Ring, South Tardiff, and Thorn). Under the Fisheries Act, these lakes are not classified as fisheries habitat. The most common species found in the 11 fish bearing water bodies were northern pike, lake whitefish, lake cisco, slimy sculpin and ninespine stickleback. These five species were present in Thor, Long, Elbow, A and Redemption lakes. Lake trout was observed in the larger deeper lakes (Carrot and Great Slave Lake), and lake chub within Kinnickinnick Lake (Stantec 2010c).

Species protected under the Species at Risk Act (SARA) as well as those under consideration by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) were considered in the assessment where appropriate. Species which may have a range overlapping the Nechalacho Mine and Flotation Plant site include the following species: rusty blackbird, common nighthawk, olive-sided flycatcher, yellow rail, horned grebe, short-jaw cisco, short eared owl, wolverine, and peregrine falcon. Olive-sided flycatcher, peregrine falcon, common nighthawk, short-eared owl and horned grebe have been identified in the Nechalacho Mine area (Stantec 2010f). The Radioactivity Pathways Assessment has selected a number of receptors with similar dietary components that would encompass the characteristics of these species.

FIGURE 2.1 SURFACE HYDROLOGICAL REGIME AT THE NECHALACHO MINE AND FLOTATION PLANT SITE



Source: Avalon, 2010a

2.1.2 Hydrometallurgical Plant Site

Detailed baseline studies have not been conducted at the Hydrometallurgical Plant Site, owing to previous disturbance as part of the former Pine Point Lead/Zinc Mine. Baseline information obtained from the Project Development Report (Avalon 2010a) is largely sourced from studies conducted in support of the proposed re-activation of the Pine Point Mine by Tamerlane resources.

The Hydrometallurgical Plant site is also located within the Sub-Arctic Climatic Zone. The nearest weather station (Hay River, NT), reports average daily temperatures from -23.1^{o}C in January to 15.9^{o}C in July. The average annual precipitation is 320.4 mm, with 203.1 mm annual rainfall and 125 cm annual snowfall (Environment Canada 2011).

Topographic elevations at the Hydrometallurgical Plant Site range from approximately 156 m.a.s.l. at Great Slave Lake, to a maximum of 220 m.a.s.l. at the proposed plant site. Topography is more gradual than observed at the Nechalacho Mine site. Located at the northern boundary of the sporadic discontinuous permafrost zone, permafrost is not pervasive across the site. Organic soils <50 cm in depth are observed in upland areas, with sand and gravel deposits in east-west ridges transecting the site. Underlying the surficial topsoil is glacial till, up to 40 m in thickness (Knight Piésold 2010).

Flat lacustrine plains overlain by peatlands (poorly drained muskeg up to 3 m deep) cover much of the area north of the proposed Hydrometallurgical Process Plant area and south of Great Slave Lake. Shallow wetlands occur throughout this area, although no other connected surface water features are observed at the site (Knight Piésold 2010).

Regional groundwater flow is hypothesized to originate in the Caribou Mountains, 200 km south and 600 m topographically higher than the Hydrometallurgical Plant Site. The southern shores of Great Slave Lake serve as a groundwater discharge area, as observed by sulphurous springs and high specific conductance in surface water systems. Local groundwater flow is primarily within the Presqui'ile aquifer, and despite high permeability within the aquifer, flow velocities are expected to be slow due to low hydraulic gradients in the Pine point area and slow recharge through the low permeability glacial till (Knight Piésold 2010).

The area of interest is located in the Great Slave Lowlands Mid-Boreal Ecoregion of the Taiga Plains Ecozone (Ecosystem Classification Group 2007). A 2005 field program conducted by EBA Engineering identified eight naturally vegetated ecosystem units, the most common of which was the Labrador tea – mesic ecosite in drier upland areas, and shrubby/treed fens in the lower wetland areas (EBA 2009).

During a 2009 literature review and a 2005 field program, the following mammal species were observed or documented to occur in the Pine Point Area: snowshoe hare, red squirrel, American beaver, common porcupine, coyote, gray wolf, black bear, ermine, mink, lynx, woodland caribou, moose and wood bison. A total of 40 mammal species have home ranges that may overlap the Pine Point site (cited in EBA 2009).

Upwards of 32 bird species were identified at the Pine Point site. The most frequently observed bird species include the following: American robin, tundra Swans, white-winged scoter, gray jay, common raven, spruce grouse, and bohemian waxwings (cited in EBA 2009).

There are no streams or significant natural water bodies located near the site of the Hydrometallurgical Plant, and thus no fish populations are expected to reside within the area. The proposed location of the Tailings Management Area (TMA), within an abandoned former pit of the Pine Point Mine, is likely not hydrologically connected to the wetland systems and is approximately 10 km to Great Slave Lake.

SARA protected and COSEWIC assessed species which may have a range overlapping the Hydrometallurgical Plant site include the following: whooping crane, wood bison, woodland caribou, rusty blackbird, common nighthawk, olive-sided flycatcher, yellow rail, horned grebe, short-jaw cisco (in Great Slave Lake), short-eared owl, wolverine, and peregrine falcon (Environment Canada 2010).

2.2 DETAILED PROJECT DESCRIPTION

Avalon proposes to mine and mill rare earth carbonates and oxides, zirconium, niobium and tantalum oxides from the Nechalacho deposit. The deposit is approximately 2% rare earth oxides (REO), and will be mined at a rate of 2000 tons per day (t/d). An estimated 9 million tons of indicated resources are to be mined from the Nechalacho deposit alone. Construction of the mine and associated infrastructure is projected to require 2 years, followed by 18 years of active mining, and 3 years to implement the closure plan.

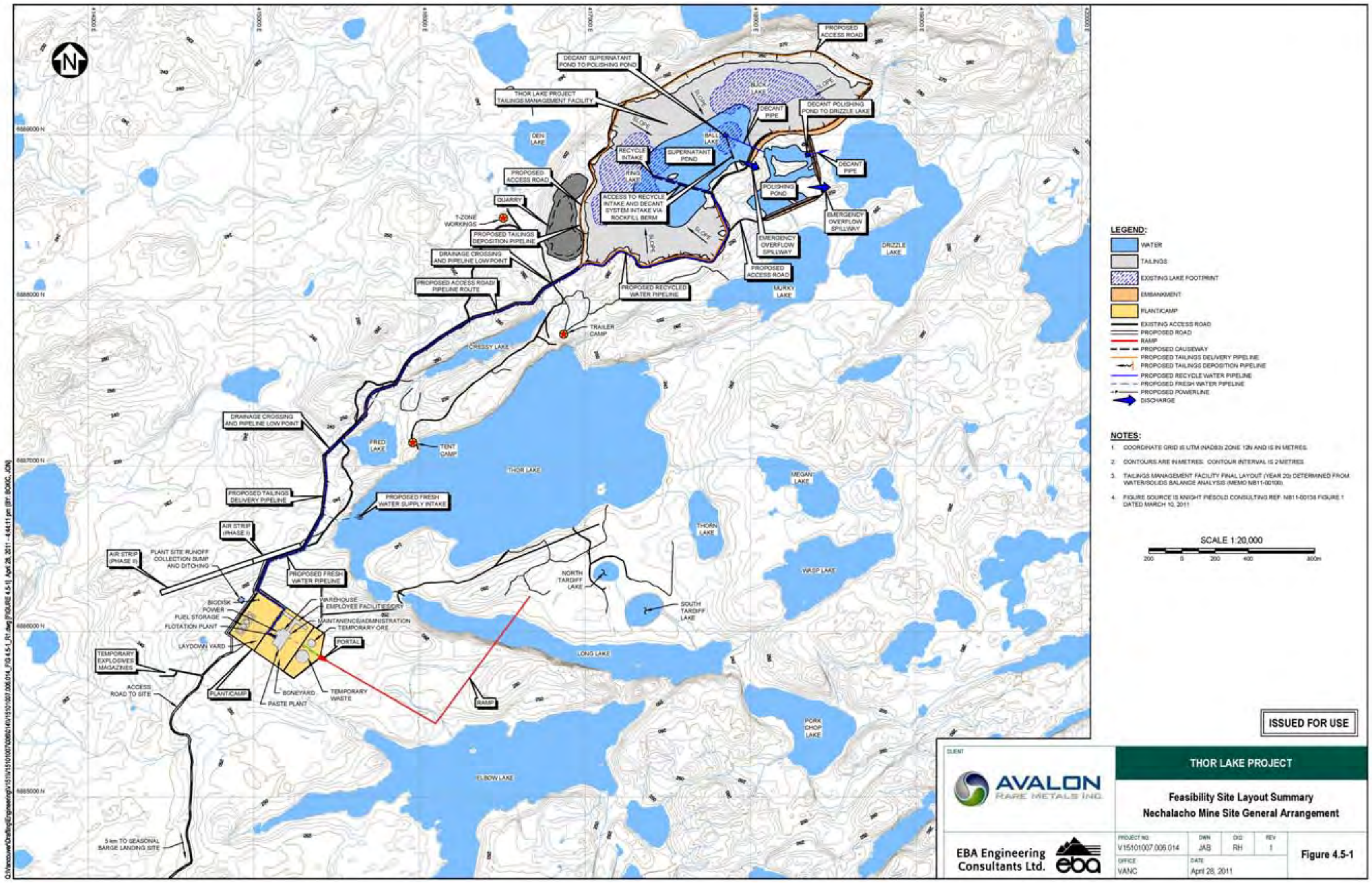
2.2.1 Nechalacho Mine and Flotation Plant Site (Thor Lake Area)

The following section is a summary of the proposed operations at the Nechalacho Mine and Flotation Plant as provided within the Project Description Report (Avalon 2010a). Figure 2.2 below shows the proposed location of site infrastructure. The Nechalacho Mine is a remote site with no road access, and may be reached by boat, helicopter, snowmobile, or plane (float or skis, and wheels upon completion of the runway). The infrastructure and processes outlined below form the basis of the Conceptual Site Model (CSM) and exposure pathway analyses:

- *Underground Operations*: The Nechalacho Deposit will be mined underground to an anticipated depth of 200 m, using a 1,600 m long decline ramp to access the ore zone. Under normal operating conditions, approximately 2,000 t/d of ore will be extracted from the mine. The underground crushing circuit will include primary and secondary crushing as well as screening, with the ore conveyed to the surface for further processing.

- *Flotation Plant*: The Flotation Plant will process the ore using traditional methods of ore concentration, incorporating rod mill/ball mill grinding, desliming, magnetic separation, flotation concentrate, and pressure filtration of the gravity concentrate. To prevent losses to the atmosphere, ore processing will be a wet process. Processing approximately 2,000 t/d of ore, it is expected the flotation plant will produce 360 t/d of ore concentrate. Concentrate will be barged off-site for further processing at the Hydrometallurgical Plant and tailings will be discharged to the Nechalacho Tailings Facility or used as paste backfill.
- *Nechalacho Tailings Management Facility:* A total of 3.5 million tonnes of tailings are expected be discharged to the Nechalacho Tailings Facility. The Tailings Facility will be located up slope from the Flotation Plant, northeast of Thor Lake, in the local catchment of Ring and Buck lakes. The tailings slurry will be discharged to a number of locations surrounding Ring Lake, developing a relatively flat tailings beach and centralized supernatant pond to maximize tailings storage efficiency. Discharge from the supernatant pond is to be first treated in a polishing pond and then diffused into Thor Lake via Drizzle and Murky Lakes.
- *Dock and Ore Concentrate Transport*: Ore concentrate will be containerized into half-height intermodal containers, and transported from the Flotation Plant to the dock area for barging to the Hydrometallurgical Plant, or for winter storage in a designated stacking area.
- *Airstrip*: Constructed in the summer of 2010, the airstrip will be extended to a total length of 1000m, permitting larger aircraft (e.g. Dash 8 and Buffalo), and will serve as the primary transport mechanism for employees.
- *Roadways*: Access roads throughout the mine area, and leading to the dock area, will be upgraded for transport of ore concentrate, supplies, and staff. These roadways are expected to be constructed of aggregate (likely wasterock).
- *Power and Fuel*: Power requirements for the Nechalacho Mine and Flotation Plant are projected at 8.4 MW, with all power generation by diesel powered generators.
- *Camp*: Camp facilities are required to support staff of approximately 150. The camp site will be located beside the Flotation Plant. The mine is expected to operate 365 days per year on a 24/7 schedule, with individual employees working 12 hour shifts on a 3 week in/3 week out rotation.
- *Water Supply*: Fresh and process water for camp and mine purposes will be supplied from Thor Lake. Tailings water will pass from the Nechalacho Tailings Facility, to the polishing ponds, Drizzle and Murky Lakes, and finally back into Thor Lake. A piping system is planned to permit water management within the lakes.

FIGURE 2.2 PROPOSED NECHALACHO MINE AND FLOTATION PLANT SITE



Source: Avalon 2010a

2.2.2 Hydrometallurgical Plant Site

The Hydrometallurgical Plant at the former Pine Point Mine will further process the REE concentrates from the Nechalacho Mine and Flotation Plant site. The Pine Point Mine was a large scale lead/zinc mine operating from 1964 to 1986, during which time approximately 40 open pits were mined. The Pine Point Abandonment and Remediation Plan was completed in 1991, including the removal of the town site and railway (GNWT 2007); however, the site is still accessible by a maintained four-season Territorial roadway.

The following section is a summary of the proposed development and processes at the Hydrometallurgical Plant Site, as provided within the most current project description reports (Avalon 2010a, Knight Piésold 2010, Knight Piésold 2011). The infrastructure and processes outlined below form the basis of the CSM and exposure pathway analyses:

- *Hydrometallurgical Plant:* The proposed Hydrometallurgical Plant will further process the REE concentrates, with an input rate of 360 t/d. The process will include acid baking, water washing, filtration, caustic regeneration and evaporation, double salt precipitation, solvent extraction and product drying facilities to produce the final concentrate product.
- *Hydrometallurgical Tailings Facility:* The Hydrometallurgical Tailings Facility is to be located within the former L-37 Pit of the Pine Point Mine, with excess water to be pumped to the N-42 Pit (Knight Piésold 2011). The L-37 Pit volume is approximately 5 million m^3 with tailings to be deposited into the dry pit and will not have direct contact with aquifer water (Knight Piésold 2010).
- *Water Supply:* Process water for the Hydrometallurgical Plant will be obtained from the T-37N Pit (an existing nearby open pit lake), and treated on-site.
- *Dock and Ore Concentrate Transport:* Barges containing ore concentrate from the Nechalacho Mine will dock at a temporary dock facility constructed of two barges. An existing access road (~8.5 km in length) will be upgraded to permit truck travel from the dock area, south to the Hydrometallurgical Plant.
- *Power and Fuel:* Power requirements at the Thor Lake Project are estimated at approximately 16 MW, provided from the existing Northwest Territories Power Corporation (NTPC) grid. Secondary and backup power at the facility will be provided by diesel generators.
- *Final Product Export:* Final ore concentrate products will be produced at a rate of 160 t/d. The ore will be packaged as per Transport Canada regulations and trucked to Hay River for transport to the railhead, or for shipment to southern markets.
- *Camp:* The Hydrometallurgical Plant will operate with a staff of 88 during operation (100-200 during construction), with schedule of 351 days/year, 24 hours/day, 7 days/week, and a yearly 14 day maintenance shut-down. Workers will be bussed daily from either Hay River or Fort Resolution, and thus camp facilities are limited to administrative and day facilities (e.g. lunch room, offices).

FIGURE 2.3 PROPOSED HYDROMETALLURGICAL PLANT SITE

Source: Knight Piésold 2011

2.3 SELECTION OF VECS

Valued Ecosystem Components (VECs) in the natural environment are environmental attributes or components identified as having a "legal, scientific, cultural, economic or aesthetic value". VECs are usually individual valued species or represent important groups of species within food webs.

2.3.1 Human Receptors

Human receptors were selected for evaluation due to potential exposure to COPC, and include a working member of the public (e.g. camp cook) and members of the local First Nations population. It was assumed that workers are prohibited from hunting or gathering food directly from the site during operation; however, nearby First Nations groups may obtain food from the downgradient environment. Table 2.1 provides a summary of the human receptors and the rationale for selection. The rationale indicates the reason for VEC selection, and does not indicate exposure at hazardous concentrations.

TABLE 2.1 LIST OF SELECTED HUMAN RECEPTORS

Environmental Components	Sub-components	Relevant human receptors	Rationale
Radiation/ Radioactivity	Human	• Camp cook • First Nations	• Humans on-site could be exposed to increased radiation and/or radon • First Nations may be exposed to increased radon
Atmospheric Environment	Air Quality	• Camp cook • First Nations	• Humans on-site could be affected by increased radionuclide releases to air in the form of fugitive dust. • First Nations people using surrounding lands could also be exposed to fugitive dust.
Aquatic Environment	Water Quality/ Sediment Quality	• Camp cook • First Nations	• Humans on-site will be consuming Thor Lake water • First Nations people may consume water from sources downstream of the Nechalacho Mine
Terrestrial Environment	Soil Quality	• First Nations	• First Nations using surrounding lands could ingest vegetation (or animals which may have consumed vegetation) which may have been exposed to fugitive dust

2.3.2 Ecological Receptors

All environmental components were assessed with respect to specific features of the natural environment (e.g. water quality or air quality) and their roles in providing pathways and mechanisms for effects on the VECs based on the inter-relationships of the environmental components.

Generally, VEC selection considers the following:

- Abundance in the Site, Local and Regional Study Areas;
- Ecological importance - position in the food web and relative contribution to productivity;
- Baseline data availability - sufficient information should be available to allow a reasonable evaluation of effects;
- Native species, without setting aside the possibility to consider exotic species;
- Exposure - the VEC should have some degree of exposure to the “stressors” produced by the project Works and Activities;
- Sensitivity - the VEC should be sensitive to the “stressors” produced by the Project Works and Activities;
- Ecological health – potential to affect the growth or sustainability of biota;
- Human health – potential to affect human health (e.g. as a food source);
- Socio-economic importance – e.g. value as commercial, recreational or subsistence; inherent aesthetic value, including being of educational or scientific interest;
- Conservation status of Species at Risk - specifically protected by law, designated as rare, threatened, endangered, or of special concern;
- Traditional and current importance to First Nations people; and,
- Cultural and heritage importance to society.

Using the VEC selection criteria, the findings of the Baseline Wildlife Studies (Stantec 2010f), wildlife species with special conservation status (under SARA or COSEWIC), and species known to have particular importance (as a food source or of cultural significance) to local First Nations communities, VECs were identified for the Thor Lake Project (Table 2.2).

The species selected to represent the ecological receptor categories, and for inclusion in the assessment include the following:

- Aquatic biota (including aquatic plants, benthic invertebrates, predatory and forage fish, etc.);
- Waterfowl (mallard, merganser, and scaup);
- Predatory birds (peregrine falcon);
- Non-predatory terrestrial birds (spruce grouse);
- Small mammals (snowshoe hare);
- Predatory large mammals (wolf and black bear); and,
- Non-predatory large mammals (barren-ground caribou and moose).

TABLE 2.2 LIST OF SELECTED ECOLOGICAL RECEPTORS

Environmental Components	Sub-components	Relevant Receptors	Rationale
Surface Water Quality	Water Quality	Water and sediment quality	• Exposure of receptors to increased radionuclides from the upstream tailings ponds
Aquatic Environment	Aquatic Biota	Forage and Predator Fish	• Components of aquatic food webs (bottom feeder) and consumed by other ecological receptors. • Sensitive to changes in water quality. • Biota may be affected by water discharge, with fish known to be present in Thor Lake.
		Benthic Invertebrates, Aquatic Plants, Phytoplankton and Zooplankton	• Components of aquatic food webs. Consumed by other ecological receptors. • Sensitive to changes in water and sediment quality. • Biota may be affected by water discharge and site runoff.
		Aquatic Birds (waterfowl)	• Components of the aquatic food web. Consumed by other ecological receptors. • Sensitive to changes in water and sediment quality. • Biota may be affected by water discharge and site runoff.
Terrestrial Environment	Wildlife	Terrestrial-Based Mammals and Birds	• Components of terrestrial food webs. Consumed by other ecological receptors. • Sensitive to changes in air and water quality. • Biota may be affected by air and/or water releases, increasing radiation doses from the environment and from food sources • Food source for people

2.4 CONCEPTUAL SITE MODEL

To evaluate the pathways of radiation exposure, a conceptual site model (CSM) was developed for the Thor Lake Project. CSMs graphically display an overview of the relationship between the receptors, and of the physical-chemical processes that are occurring that affect the fate and transport of COPC. It also illustrates the major food web links between receptors.

2.4.1 Nechalacho Mine and Flotation Plant Site

A CSM was developed for the Nechalacho Mine and Flotation Plant site, identifying pathways of potential radiation exposure. COPC may be introduced to the water and sediment through the use of the Thor Lake water system as part of the Nechalacho Tailings Facility. Ore extraction, transfer, and processing may introduce radiological COPC to the air as suspended particulate, which may be respired by receptors, or fall as dust to enter the soil profiles and be taken up by vegetation. Radioactivity pathways to human and ecological receptors were determined using conservative assumptions, and are provided in Figure 2.4 and in Table 2.3.

Several key assumptions guided the determination of exposure scenarios for the Nechalacho Mine and Flotation plant.

- Thor Lake is the source of potable water for mine employees, and has been modelled as the water source for First Nations (although would more likely source drinking water from a larger downstream water body).
- Mine employees will not be permitted to hunt, fish, or consume vegetation from the Nechalacho Mine site.
- Fish consumed by First Nations is sourced from Thor Lake, a highly conservative assumption due to the low level of fish present (Stantec 2010c) and the availability of abundant fish in Great Slave Lake. Terrestrial food sources (vegetation, caribou, moose, hare, and waterfowl) consumed by First Nations people was also conservatively modelled from the Thor Lake area.
- It is assumed that the abundance of personnel and the significant noise associated with mining and milling would deter large mammals from inhabiting the immediate mine area for any appreciable quantity of time. When these receptors are on site, it is assumed that they will remain primarily near Thor Lake.

2.4.2 Hydrometallurgical Plant Site

At the Hydrometallurgical Plant site, there were no pathways identified that could lead to a significant incremental increase in radioactivity exposure for receptors. Ore is to be containerized while mobilizing to and from the site, and hydrometallurgical processing is within an enclosed facility. Results of air quality modelling for the proposed site indicated there is will be no significant increase to suspended particulate or dustfall due to the Hydrometallurgical Plant (RWDI 2011), with no subsequent loadings to the air, soil, or vegetation. The tailings slurry will be discharged to the L-37 pit (former pit within the brownfield site), and excess water to the N-42 pit. The pits are isolated from the surface hydrological regime and tailings water will discharge to the groundwater system. Due to the low hydraulic gradient, it is anticipated that it would take over 100 years for groundwater to reach Great Slave Lake. The residence time, dilution factors, and processes of natural attenuation in flow through porous media, eliminate the groundwater pathway as a source of radiological concern. **There are consequently no pathways of incremental radioactivity due to the Hydrometallurgical Plant site, and the site was removed from the assessment.**

FIGURE 2.4 CONCEPTUAL SITE MODEL FOR THE NECHALACHO MINE AND FLOTATION PLANT SITE

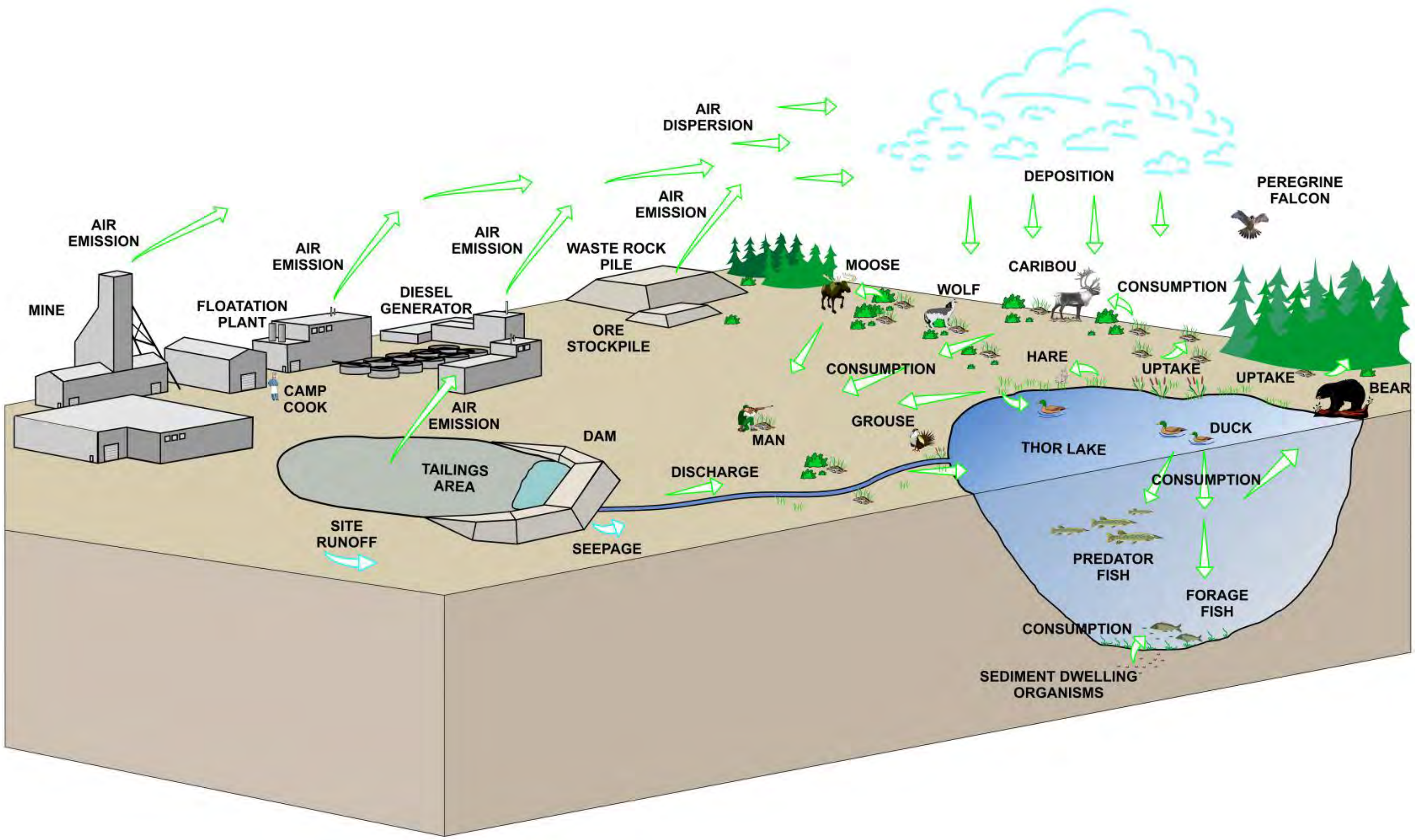


TABLE 2.3 NECHALACHO MINE AND FLOTATION PLANT PATHWAYS

Receptor	EXPOSURE PATHWAYS					
	Intake of Water [A]	Intake of Terrestrial Vegetation [B]	Inhalation of Dust[+ B]	Radon [B]	Consumption of Aquatic Biota [A]	Consumption of Game (waterfowl, hare, caribou, moose, fish) [A,B]
Aquatic Biota	Y	N	N	N	Y	N
Waterfowl	Y	N	N	N	Y	N
Predatory Birds	Y	N	N	N	Y	Y
Non-Predatory Terrestrial Birds	Y	Y	N	N	N	N
Small Mammals	Y	Y	N	N	N	N
Large Predators	Y	N	N	N	Y	Y
Non-Pred. Large Animals	Y	Y	N	N	Y	N
Camp Cook*	Y	N	Y	Y	N	N
First Nations**	Y	Y	Y	Y	Y	Y

Conservative assumptions made for all receptors. Receptors placed in the location of maximum possible exposure.
N=Not a significant route of exposure
Y=Exposure possible, quantified in assessment
*=Workers are not permitted to hunt or consume local biota while on site
**=Members of First Nations groups are not expected to occupy the main mine area, but are assessed at this location as a conservative assumption
[+]=Dust was conservatively assessed assuming 100% ore.
A=Thor Lake
B=Nechalacho Mine/Camp Area

2.5 SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN

The list of radioactive COPC is populated from the analysis of ore, test run tailings solutions, and specific concerns raised in the Mackenzie Valley Review Board Environmental Assessment Terms of Reference (MRVB 2010).

Radionuclides of potential concern include the thorium series radionuclides (including thorium-232, radium-228 and thorium-228) and the uranium series radionuclides (including uranium-238, thorium-230, radium-226, lead-210 and polonium-210). Concentrations of uranium and thorium in mine materials are provided in Table 2.4. Thor Lake has uranium levels higher than an average granite but far below those of even very low grade uranium deposits. The thorium levels in the Nechalacho deposit are elevated, although the dose from the thorium series radionuclides would be about one quarter of that from uranium series at the same concentration level. Given the lower radioactivity equivalency of thorium relative to uranium, the overall effect of typical Nechalacho mineralization as a rock mass is predicted to be similar to the very lowest grade uranium deposits.

TABLE 2.4 URANIUM AND THORIUM CONCENTRATIONS IN NECHALACHO MINE MATERIALS

Samples	Mean U (ppm)	Mean Th (ppm)	Th/U Ratio	Range U(ppm)	Range Th(ppm)
Nechalacho Basal Zone mineralization	29	160	-	1 - 269	2 – 1060
SRC (4 samples)	32	254	1 to 10	19 - 46	23 – 419
SRC (5 samples)	260	207	<1 to 10	19 - 1172	20 – 419
SGS (rock)	37	109	1.8 to 4.5	22-51	81-140
Multiple Ore Samples (Mercer, 2010b)	41	190	0.2-95	4.7-1,400	25-2000
Avalon (pers. comm., Feb 2011)*	24	130	-	-	-

<u>Notes:</u>
Nechalacho and SRC results from Mercer (2010a)
SRC (4 sample) excludes one elevated sample (>1000ppm U)
SGS from SGS (2010b, Table 11)
* Based on the results from a large numbers of samples (> 4000)

The crushed ore will be concentrated at the mine site using flotation processes to develop a gravity concentrate. The uranium and thorium are expected to follow the REE to the heavier fraction resulting in higher concentrations in the ore concentrate and lower concentrations in the flotation tailings. Uranium and thorium is predicted to be enriched by approximately five times in the flotation concentrate, relative to the raw ore (Mercer 2010b).

The potential radiation dose depends on the concentrations of the uranium and thorium series radionuclides. Prior to chemical separation, these radionuclides will normally be in secular equilibrium (constant in time) with the parent radionuclide. This was confirmed by SGS (2010a) measurements of rock, tailings and concentrate; indicating the SGS data on a limited number of measurements tends to support the expected equilibrium assumption. The activity concentrations can be determined from the mass concentration using Table 2.5. This allows for radioactivity to be calculated from the mass concentrations of uranium and thorium.

TABLE 2.5 MASS/RADIOACTIVITY CONVERSION FACTORS FOR URANIUM AND THORIUM

	Uranium	**Thorium**
Radionuclide Conversion (Bq U-238 or Th-232/g per ppm)	0.01235	0.00406
ppm per 1 Bq/g of parent	81	246

Secular equilibrium may not be present after chemical separation, as the different radioactive chemicals may report differently to the product and waste. This may affect the predicted behaviour of environmental releases including the effects of tailings from the REE mill.

3.0 RECEPTOR CHARACTERIZATION

One of the key considerations to define the scope of a risk assessment is the selection of ecological and human receptors. In selecting receptors it is important to identify plants, animals and people that are likely to be most exposed to the effects of the project as well as those that may be important for other ecological or social reasons. The receptors selected for this assessment were identified in Section 2.3. This section details the characteristics of the ecological (aquatic and terrestrial) species and human receptors, thus defining exposure pathways.

3.1 ECOLOGICAL RECEPTORS

In this assessment, exposure of ecological receptors to radioactivity was considered in both the aquatic and terrestrial environment. Receptors in the aquatic environment were selected to capture radiation exposure through water consumption, and through the consumption of fish, benthic invertebrates and aquatic vegetation. Terrestrial receptors were chosen in consideration of radiation through direct sources (i.e. radon), inhalation of fugitive dust, intake of water, and consumption of food sources.

Ecological receptor characteristics were assumed to represent a reasonable maximum exposure scenario, in that cautious assumptions were made regarding the receptor’s behaviour and home range. Receptors were assumed to spend all or much of their time in areas of mine infrastructure (e.g. Thor Lake), when in actuality, most species have a larger home range and would only occupy such areas for a portion of time (e.g. caribou migratory routes).

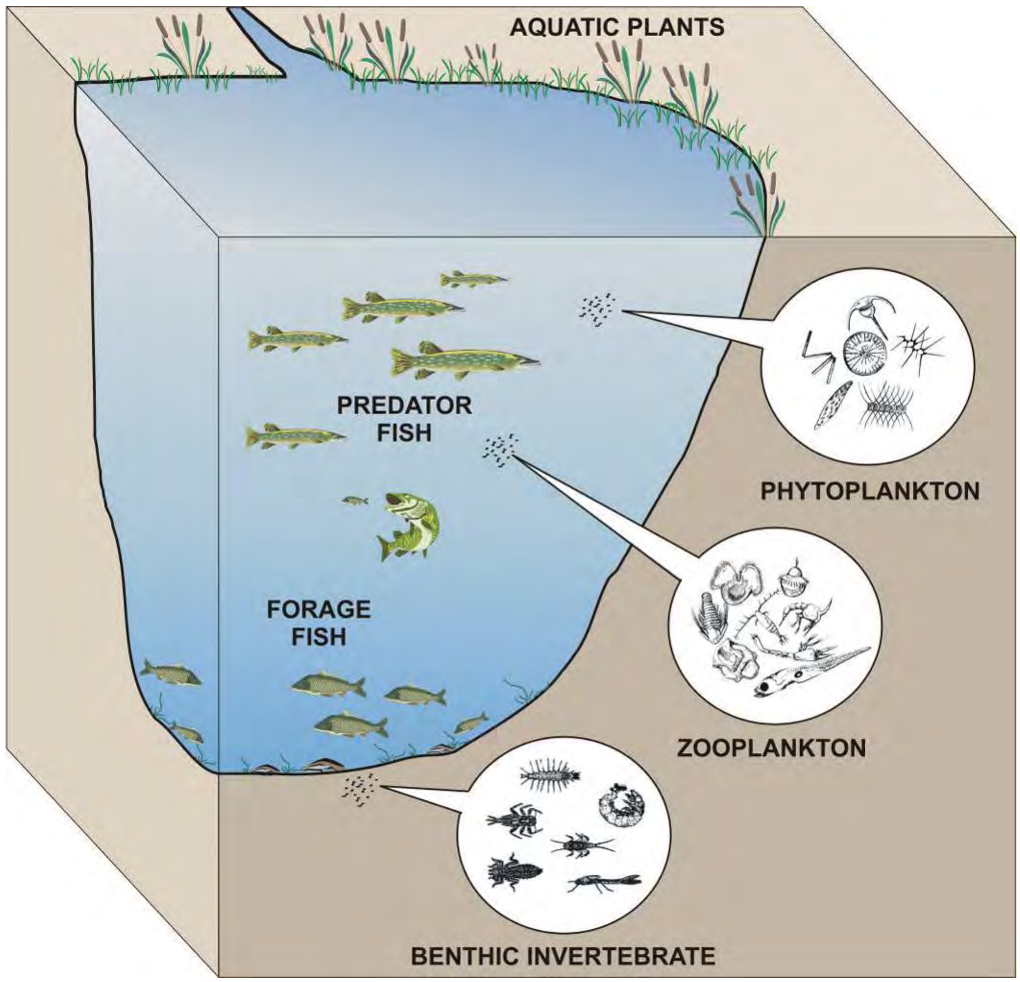
3.1.1 Aquatic Receptors

All trophic levels were included in the assessment of the Nechalacho Mine and Flotation Plant site, using Thor Lake as the location of all receptors (Figure 3.1). Thor Lake was selected as it is the first fish bearing water body downstream of the proposed Nechalacho Tailings Facility (within Ring and Buck Lakes).

Primary Producers - Primary producers occupy the lowest level in the food chain. These organisms are generally plants that use the sun and inorganic molecules to produce food.

Aquatic plants in most lake ecosystems usually constitute the majority of the primary producer biomass. Aquatic plants are often consumed by moose, muskrat and other animals, thereby forming a link between aquatic and terrestrial ecosystems. Besides being an important food resource, aquatic plants also provide habitat to aquatic organisms.

FIGURE 3.1 AQUATIC RECEPTORS IN THE THOR LAKE PROJECT PATHWAYS ASSESSMENT



Phytoplankton are also part of the first level in the aquatic food chain. Members of the division *Chlorophyta* have been studied extensively and are present in most northern aquatic ecosystems. Even though the overall contribution of *Chlorophyta* to northern aquatic ecosystems is relatively small, they are a primary food resource for grazing zooplankton. *Chlorophyta* is included in the pathways assessment.

Primary Consumers - Primary consumers occupy the second level in the food chain. These organisms generally eat plant material such as phytoplankton.

Zooplankton such as *Cladocerans* are found in most northern aquatic ecosystems. Although *Cladocerans* may be seasonally quite abundant, their overall contribution to northern aquatic ecosystems is relatively small.

Benthic invertebrates both live and feed within sediments and provide a link between aquatic and terrestrial ecosystems. For example, *Chironomidae* (midge) larvae are usually the most abundant benthic invertebrate taxa present in aquatic ecosystems in the northern climate. Many species feed on decaying organic matter and thereby form an important link between the decomposer and primary consumer levels. Furthermore, midge larvae are a main food source for small/juvenile fish and larger omnivorous fish. The adults are capable of flight and are frequently consumed by birds and bats. This life stage provides an important link between aquatic and terrestrial ecosystems in the region. *Cladocerans* and *Chironomidae* have been included in the pathways assessment.

Secondary Consumers - Ecological receptors at the secondary consumer level include forage fish that feed primarily on benthic invertebrates and smaller individuals, and are an important food source for larger predatory fishes. Examples of forage fish are cisco, yellow perch, and whitefish. Whitefish has been included in the pathways assessment as it is documented to occur in Thor Lake (Stantec 2010c) and represents an important part of the human food chain.

Tertiary Consumers - Tertiary consumers are found at the top end of the aquatic food chain and consist of larger predatory fish species that consume other fish species. Examples include lake trout, and pickerel. Both forage and predatory fish are an important component of the diet of piscivores (e.g. merganser and eagle) and omnivores (e.g. bear). Lake trout is also an important component in the human food chain and has been included in the pathways assessment.

3.1.2 Terrestrial Receptors

The terrestrial receptors chosen for the current assessment are presented in Figure 3.2, and pathways of exposure summarized in Figure 3.3 (terrestrial herbivores), Figure 3.4 (waterfowl), and Figure 3.5 (terrestrial omnivores and carnivores). Detailed receptor characteristics are provided in Appendix A. To estimate exposure it was conservatively assumed that the terrestrial species spend a maximum quantity of time at the site, with consideration of species specific home ranges. Due to the large habitats of the caribou, moose, bear and wolf, these receptors were assumed to spend less than 100% of their time on site. Additionally, because of the migratory nature of the avian species, it was assumed that the eagle, merganser, scaup and mallard spend less than half of their time at the site.

The receptors for this assessment were selected to represent a wide range of exposures and include:

Herbivores - Herbivores convert vegetable matter to animal protein, and in turn are consumed by omnivores and carnivores. They are also trapped or hunted for fur and food. Snowshoe hare, moose and barren-ground caribou are herbivores selected for the assessment.

Hare – Hare consume browse and herbaceous vegetation. They are an important source of food for larger predatory species and thus are an appropriate species to consider in predicting food chain effects. Snowshoe hare, or evidence of their presence, have been observed in the area of the Nechalacho Mine during previous site visits (Stantec 2010f).

Moose – The moose is the largest herbivore selected as a receptor in this assessment. Moose consume forage and aqueous vegetation. The moose has a large home range, and as such is assumed to be on site approximately 30% of the time.

Barren-ground caribou - Barren-ground caribou, or evidence of their presence, have been observed in the Thor Lake area (Avalon 2010a). Similar to the moose, caribou have a home range significantly larger than the Thor Lake Project site and thus the barren-ground caribou are assumed to be present in the area 10% of the time, a very conservative estimate given the large migratory route of these species.

Omnivores - Omnivores consume both plant and animal matter. Species of omnivorous ecological receptors selected for this assessment include waterfowl and bear.

Waterfowl (i.e., scaup, mallard and merganser) – Waterfowl are often the most exposed ecological receptors, since their diet is almost entirely obtained from the aquatic environment. Given their vulnerability to impacts from the aquatic environment, they have been included in this assessment. The three species chosen are representative of a wide range of other waterfowl that are present in the area, as their diets differ greatly. The merganser consumes mainly fish, the scaup feeds primarily on benthic matter, and the mallard's diet includes benthic organisms as well as terrestrial and aqueous vegetation. Waterfowl are migratory birds; and are typically present in the northern latitudes for approximately 4 months of the year. As a conservative estimate, the three waterfowl species have been assumed present in Thor Lake for six months of the year.

Black Bear – The black bear consumes a varied diet of berries, forage and fish. Because the bear has a home range larger than the site being assessed, it is assumed that they would spend approximately 30% of the time in the vicinity of Thor Lake.

Carnivores - Predators represent the top level of the food chain. The wolf and peregrine falcon are carnivorous species included in this assessment.

Wolf – The wolf's diet consists of small and large mammals such as hare, moose and caribou. Due to an extensive home range, the wolf is assumed to be in the area of the site for 10% of the time. Wolves and/or wolf sign have been observed in the Thor Lake area (Avalon 2010a).

Peregrine Falcon – The peregrine falcon is designated a threatened avian species under the *Species At Risk Act* (SARA), and has a range encompassing the Thor Lake Project area. The species is a crow-sized falcon that hunts medium-sized birds and small mammals, and is included in the ecological risk assessment to represent threatened species in the area.

FIGURE 3.2 TERRESTRIAL RECEPTORS INCLUDED IN THE THOR LAKE ASSESSMENT

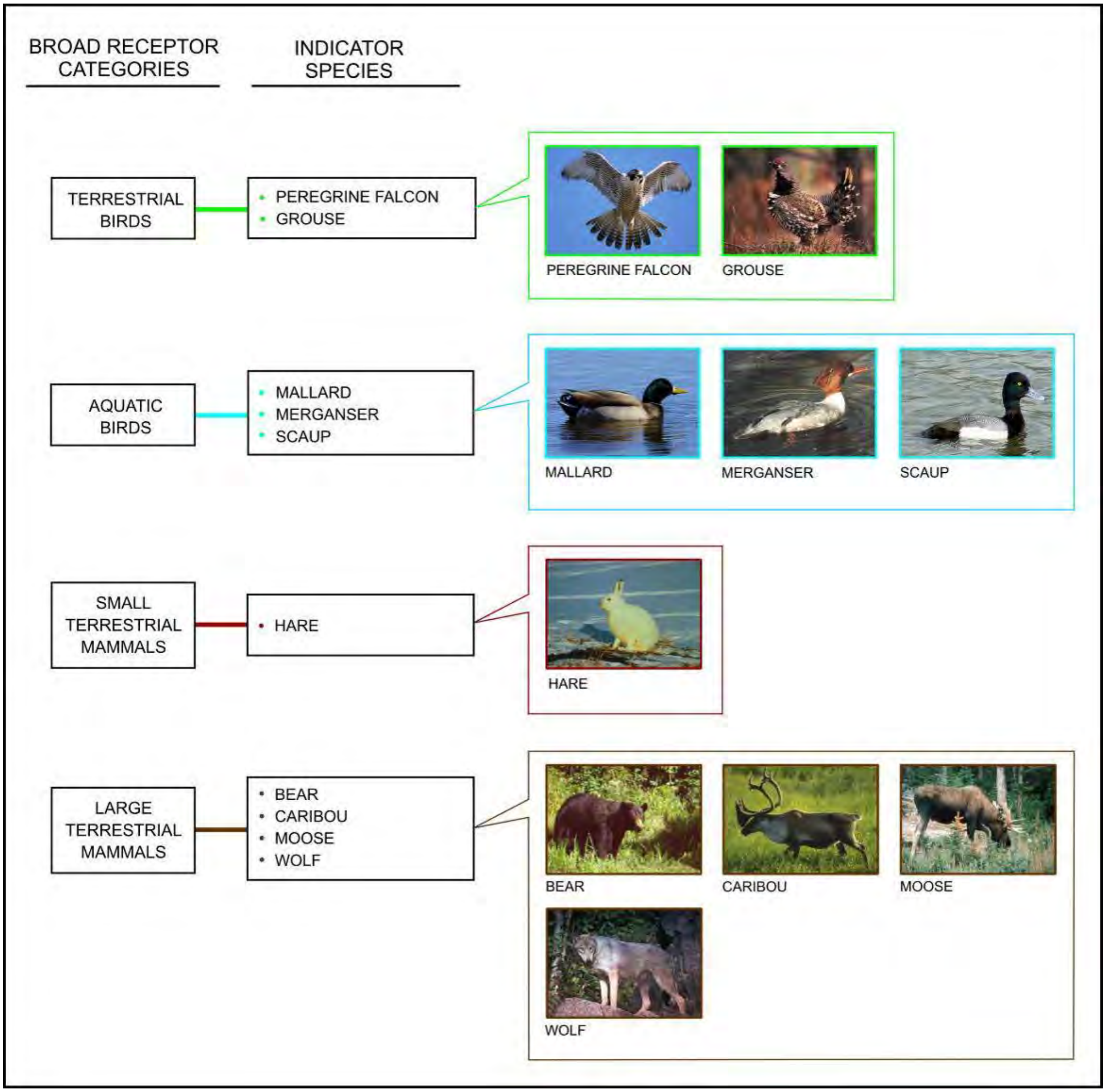


FIGURE 3.3 TERRESTRIAL HERBIVORE RECEPTOR EXPOSURE PATHWAYS

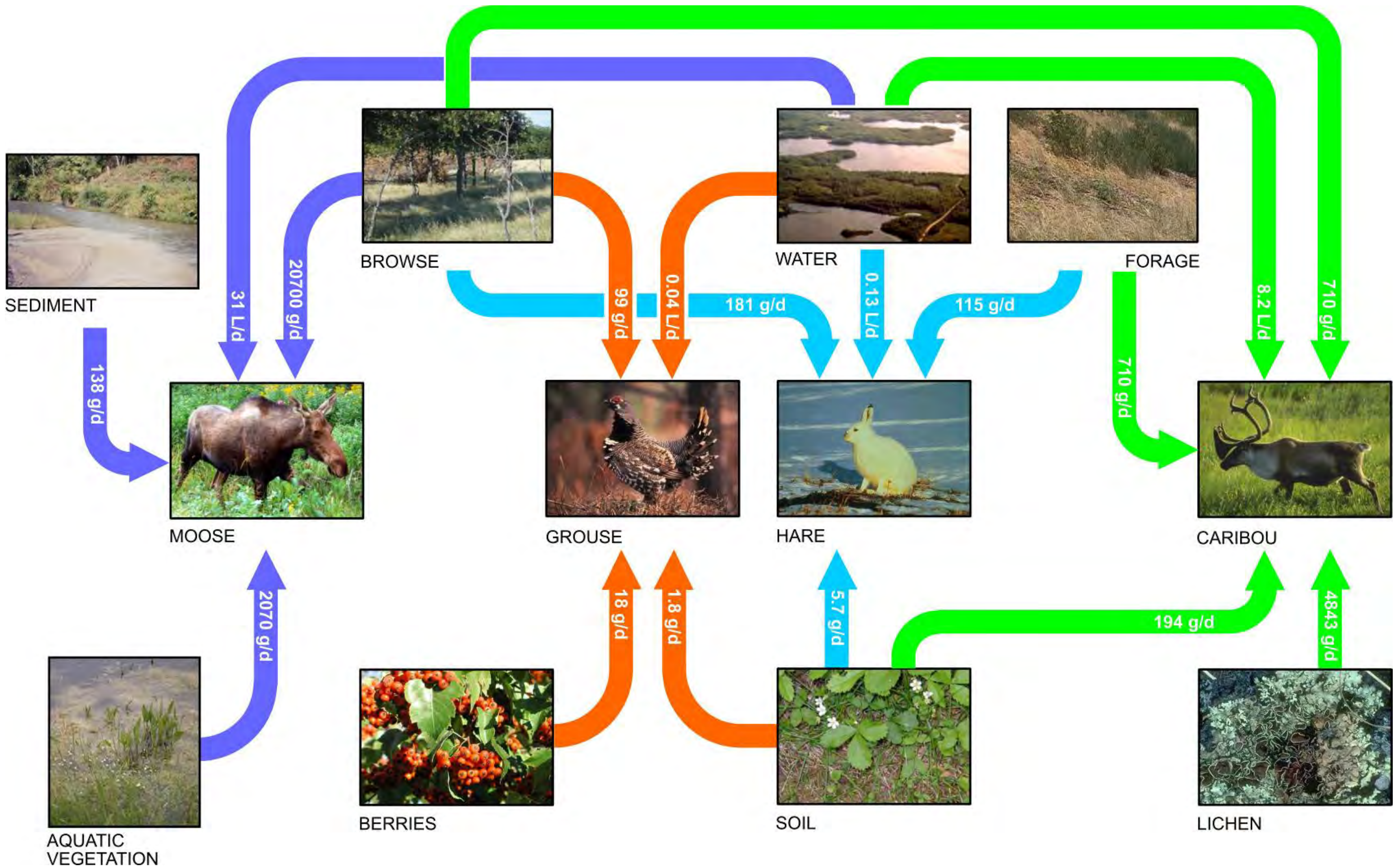


FIGURE 3.4 WATERFOWL RECEPTOR EXPOSURE PATHWAYS

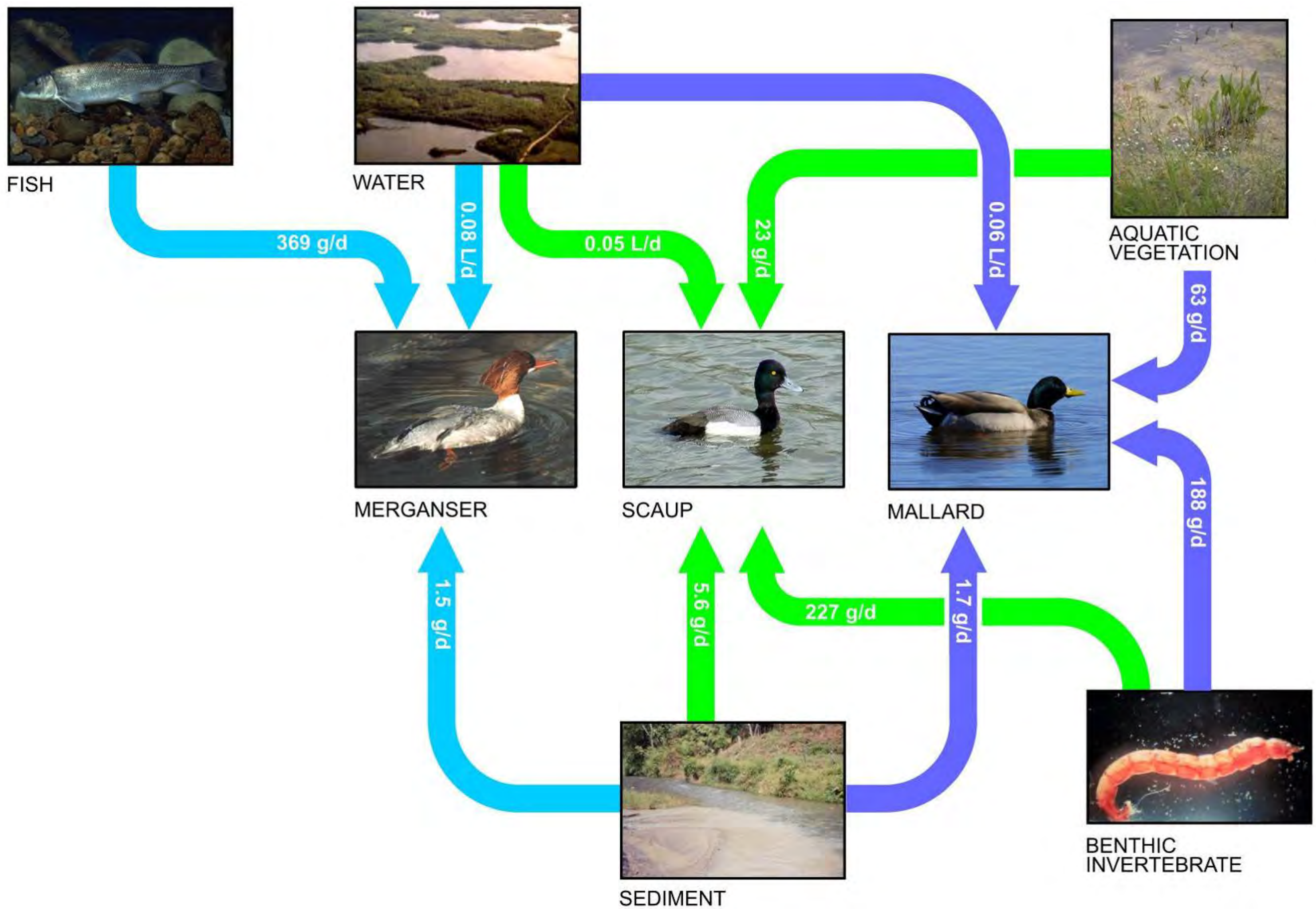
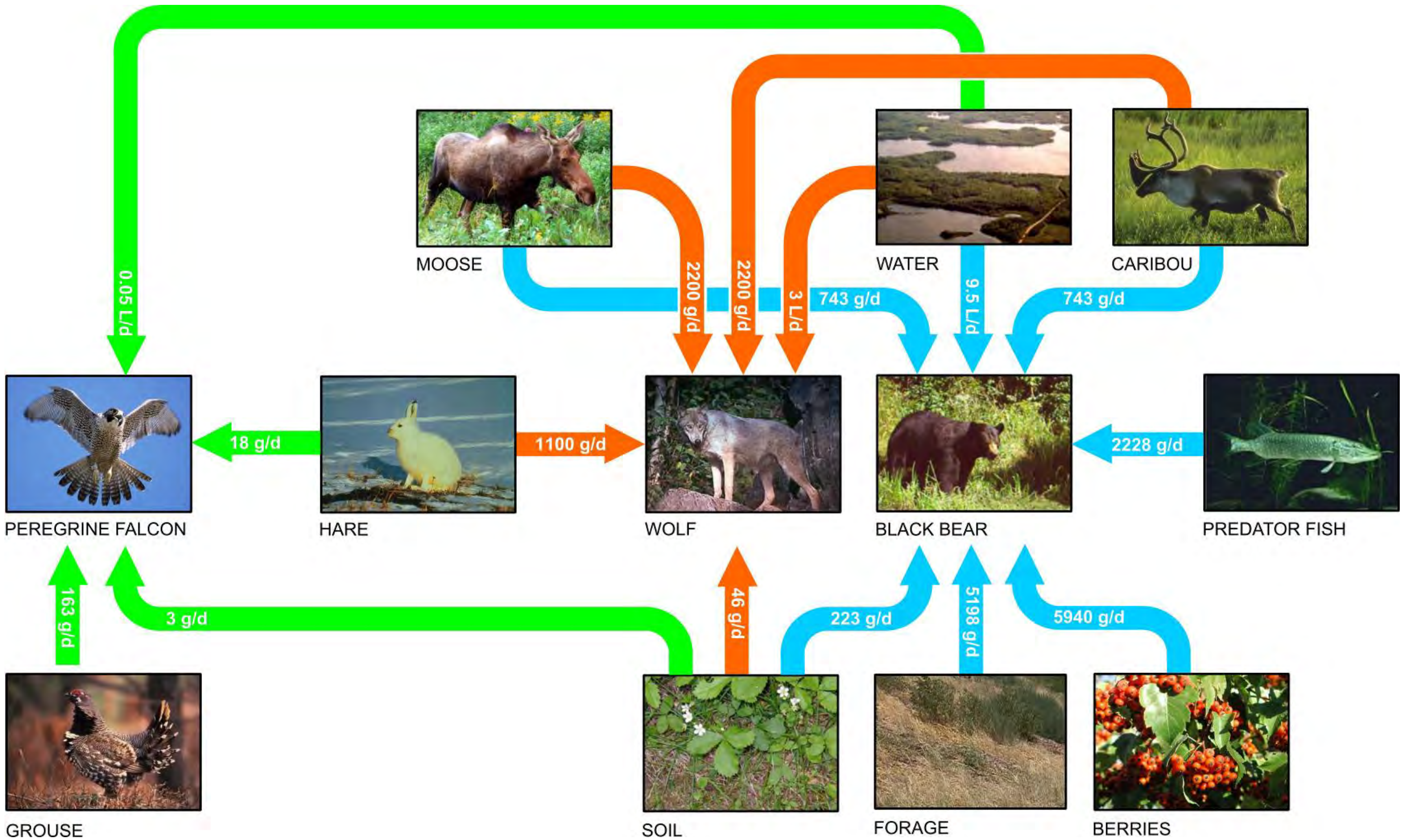


FIGURE 3.5 TERRESTRIAL OMNIVORE AND CARNIVORE RECEPTOR EXPOSURE PATHWAYS



3.2 HUMAN RECEPTORS

The humans selected as receptors for the Thor Lake Project area are workers not directly involved in the mine operations (e.g. site cook) and First Nations members using land surrounding the Nechalacho Mine and Flotation Plant. It is assumed that the site cook receptor will not consume food from the area but may be exposed to impacted media (soil, water and air). As a conservative assumption, the First Nations receptor was modeled at Thor Lake, receiving maximum concentrations of radiation exposure in water, air, and soil pathways. In reality, the First Nations receptor is not expected to be present on site during mining and ore processing operations, but may obtain food and water resources from the downstream environment. Exposure pathways considered in the assessment of the human receptors affected by the Nechalacho Mine and Flotation plant are summarized in Table 3.1.

TABLE 3.1 HUMAN EXPOSURE PATHWAYS INCLUDED IN THE THOR LAKE PROJECT ASSESSMENT

Pathway	Nechalacho Mine and Flotation Plant Site	
	Site Cook	First Nations Member
Inhalation of Radon	Y	Y
Soil		
Inhalation	Y	Y
Ingestion	Y	Y
Air		
Inhalation of dust	Y, Thor Lake levels	Y, Thor Lake levels
Water		
Ingestion	Y, Thor Lake water	Y, Thor Lake Area
Ingestion of wildlife and vegetation affected by the site	-	Y, food sources from Thor Lake Area

Intake rates associated with the pathways and characteristics of the selected human receptors associated with the pathways are provided in Table 3.2. First Nation receptor intakes are based on studies examining the dietary habits of Dene communities, including the Yellowknife Dene, and the importance of traditional foods (Receveur *et al.* 1996, Receveur *et al.* 1998). While there are a number of First Nation communities in the region (including Yellowknife Dene, Lutsel K'e, Deninu K'ue, K'atlodeeche, North Slave Metis, Hay River Metis and Fort Resolution Metis), given that these communities have similar characteristics and are influenced by comparable ecological surroundings, the intakes for the Yellowknife Dene were assumed for all First Nation receptors potentially affected by the Thor Lake Project.

Traditional food intakes were obtained from a study of Yellowknife Dene (Receveur *et al.* 1998). This report presents a secondary data analysis of dietary interviews completed in the communities of Dettah and Ndilo between 1993 to 1995 by Mackenzie Regional Health Services. To augment the data available for the Yellowknife Dene, serving sizes and yearly frequencies were estimated from the larger Dene/Metis survey (Receveur *et al.* 1996).

TABLE 3.2 AVERAGE ANNUAL INTAKE RATES AND CHARACTERISTICS OF HUMAN RECEPTORS

Characteristic	Unit	Site cook (adult)[a]	Member of local First Nations communities (toddler/adult)	Rationale
Body weight	kg	70.7	16.5 / 70.7	Health Canada PQRA guidance (Health Canada 2004, 2009)
Fraction of time at site	-	0.5[a]	0.023 / 0.023[b]	Based on proposed worker shift schedules, and 200 hours per year for Fist Nations peoples
Soil ingestion rate	kg/d	$2.0x10^{-5}$	$8.0x10^{-5}$ / $2.0x10^{-5}$	Health Canada PQRA guidance (Health Canada 2004, 2009)
Air inhalation rate	m^3/d	16.6	8.94 / 16.6	Health Canada PQRA guidance (Health Canada 2009)
Water ingestion rate	L/d	1.5	0.6 / 1.5	Health Canada PQRA guidance (Health Canada 2004, 2009)
Exposure duration	y	23[c]	3.5 / 60[d]	Avalon, 2010
Local meat				
Caribou	g/d	e	183 / 352	Based on Receveur *et al.* 1996, 1998
Moose	g/d		5.2 / 10	Based on Receveur *et al.* 1996, 1998
Hare	g/d		0.95 / 1.82	Based on Receveur *et al.* 1996, 1998
Waterfowl	g/d		2 / 4	Based on Receveur *et al.* 1996, 1998
Fish	g/d		44 / 84	Based on Receveur *et al.* 1996, 1998
Fraction of food from site	-		0.5	Conservative assumption
Other				
Berries	g/d	e	6.4 / 8.7	Akaitcho 2000

Note:

a - Time at site for Thor Lake area, based on proposed worker shifts schedule consisting of 3 weeks on-site followed by 3 weeks off-site.

b - Time at site for First Nations members assuming 200 hours at site per year.

c - Construction period of 2 years, mining operations expected to continue for approximately 18 years, followed by a decommissioning period of 3 years.

d - First Nations receptors expected to continue accessing adjacent areas after decommissioning.

e - Workers assumed to ingest no meat, fish, or vegetation from the project area

4.0 ASSESSMENT METHODOLOGY

For the current work program the environmental modelling and pathways analysis were performed at a screening level and, as such, simplifying assumptions were made. Modelling was conducted of the water and air emission to determine the expected dispersion. Environmental modelling was used based on these inputs to estimate the steady state (long-term) concentrations of the COPC in the environmental media of interest (e.g. fish, hare). Pathways modelling combined the receptor characteristics (i.e., inhalation rate, body weight, time at site, etc.) with the estimated environmental media concentrations of COPC to estimate exposure of each receptor. Exposure estimates were then compared to toxicological data (see Section 5.0) in the risk assessment to identify any areas of concern.

Exposure estimates were conducted for baseline conditions, as well as the operation of the Nechalacho Mine and Flotation Plant. Baseline concentrations of COPC in environmental media were determined during baseline studies (Stantec 2010).

4.1 PREDICTED ENVIRONMENTAL MEDIA CONCENTRATIONS

Changes to environmental media concentrations attributable to the Thor Lake Project were estimated using atmospheric dispersion modelling (CALPUFF), hydraulic modelling (H3D), and pathways modelling (INTAKE). These radiological source terms determine the potential impacts from the Thor Lake Project.

The production and distribution of airborne particulate at the Nechalacho Mine and Flotation Plant was determined by Rowan Williams Davies and Irwin Incorporated (RWDI), contracted by Avalon to assess impacts to air quality from the Thor Lake Project. Dust particles carried by air currents may provide an incremental radiation dose to receptors through direct inhalation and by ingestion of local vegetation. Concentrations of Total Suspended Particulate (TSP) due to the Thor Lake project were determined by RWDI using the US EPA CALPUFF model. CALPUFF is a multi-layer, multi-species, non-steady-state puff dispersion model, capable of simulating the effects of time and space, varying meteorological conditions on pollutant transport, transformation, and deposition. CALPUFF modelling estimated a maximum off-site TSP concentration of 4 $\mu g/m^3$ over the annual averaging period (RWDI 2011). All airborne particulate was conservatively assumed to be ore, the raw mine material most enriched in radionuclides (processed ore concentrate will be wet, and/or restricted from becoming airborne). Using radionuclide concentrations determined from previous ore characterization studies (shown in Table 2.4), incremental concentrations of airborne uranium and thorium are estimated at 9.6×10^{-5} $\mu g/m^3$ and 5.2×10^{-4} $\mu g/m^3$ respectively. Using the assumption of secular equilibrium (parent and progeny radionuclide activities are approximately constant through time), concentrations of uranium and thorium series radionuclides were determined (Table 4.1). These concentrations were applied to the INTAKE pathways model for the inhalation pathway and for determination of soil and vegetation concentrations.

Concentrations of radon from the Nechalacho Mine and Flotation Plant were also determined based on the radionuclide concentrations in ore. It is assumed that the ore contains an equilibrium amount of radon (0.0125 Bq/g per ppm), and that approximately 20% of this radon is released when the ore is processed. The rate of release of radon from the mine for the 2000 t/d operation is therefore approximately $1.4x10^3$ Bq/s of radon. RWDI (2011) did not model radon, therefore the results for SO_2 releases were used to estimate the radon concentration. Based on a release of 0.73 g/s of SO_2, primarily from the mine, a maximum annual concentration of 2 $\mu g/m^3$ was determined (RWDI 2011). Therefore, a radon release of $1.4x10^3$ Bq/s is expected to result in a concentration of 0.004 Bq/m^3.

EBA Engineering Limited (EBA) conducted water modelling using the proprietary H3D hydrodynamic model to project concentrations of uranium, thorium and radium-226 in the Nechalacho Tailings Facility, and other water bodies within the Thor Lake system. H3D is a three-dimensional time-stepping model that computes the velocity on a rectangular grid in three dimensions, as well as scalar fields such as temperature and contaminant concentrations. Contaminant loadings from the tailings to the water column were calculated within the Nechalacho Tailings Facility, and modelled within Thor Lake. Maximum incremental uranium, thorium and radium-226 for Thor Lake were estimated to be $7.3x10^{-6}$ mg/L, $5.8x10^{-7}$ mg/L, and $8.3x10^{-6}$ Bq/L respectively (EBA 2011). Estimates of the concentrations of key radionuclides in the uranium and thorium series were determined from the available information (Table 4.1). These values were used in the INTAKE pathways model to determine incremental concentrations in sediment, aquatic vegetation, and subsequently, in applicable receptors.

Direct radiation from waste rock, ore, and tailings at the Nechalacho Mine is not projected to increase to a measureable extent. Uranium concentrations in the mine materials are equivalent to low grade uranium mines (Table 2.4); however, the mass of waste rock/ore/tailings is far reduced from quantities typically observed at an economically viable low grade uranium deposit. Uranium and thorium concentrations are linearly related to the REE, and as such will be lesser in waste rock, and concentrated in the ore. Mining and milling will further enrich the ore concentrate with uranium and thorium, leaving the tailings depleted of radioactive elements. As a result, the ore and ore concentrate represent the only mine materials to provide an appreciable source of incremental direct radiation. Extraction, handling, and processing of the ore and ore concentrate will only be conducted by workers employed in mine activities, which is beyond the scope of this assessment. An assessment of radiation exposure to mine workers and a radiation protection program for the Thor Lake project has been provided under separate cover (SENES 2011).

TABLE 4.1 INCREMENTAL SOURCE TERM CONCENTRATIONS

COPC	Air *	Water
	Bq/m^3	Bq/L
Uranium-238	$1.2x10^{-6}$	$9.0x10^{-5}$
Thorium-230	$1.2x10^{-6}$	$9.0x10^{-5}$ (b)
Radium-226	$1.2x10^{-6}$	$8.3x10^{-6}$
Lead-210	$1.2x10^{-6}$	$9.0x10^{-5}$ (c)
Polonium-210	$1.2x10^{-6}$	$9.0x10^{-5}$ (d)
Thorium-232	$2.1x10^{-6}$	$2.4x10^{-6}$
Radium-228	$2.1x10^{-6}$	$2.5x10^{-4}$ (e)
Thorium-228	$2.1x10^{-6}$	$2.4x10^{-6}$ (f)
Radon	$4.0x10^{-3}$ (a)	N/A

Note:
Air and water concentrations based on assessments conducted by RWDI (2011) and EBA (2011), see text for discussion.

* Estimated from predicted dust concentrations assuming all dust generated is equivalent to ore, which provides a very conservative estimate of the concentrations
a - Estimated maximum annual concentration from radon released from the mine based on the results of the air dispersion modelling for SO_2
b - Due to the low solubility of thorium the assumption of secular equilibrium is expected to be conservative
c - As levels of Pb-210 in tailings water (SGS 2010a) was similar to U-238 it was assumed Pb-210 would be the same as U-238 in all waterbodies
d - No information available on Po-210 in tailings water, assumed to be the same as Pb-210
e - Ra-228 measured at approximately 100 times Th-232 levels in tailings water (SGS 2010a), water concentration estimated based on this ratio.
f - No information available on Th-228 in tailings water, assumed to be the same as Th-232.

4.2 EXPOSURE ANALYSIS

For this screening level assessment, a spreadsheet pathways built on the INTAKE pathways model was used to calculate the total exposure of radiological COPC to ecological and human receptors.

INTAKE was developed by SENES for use in simulating environmental transfer, uptake and risk due to exposure to radionuclides, stable metals and inorganic species released to the environment (e.g., air, water, groundwater, soil). The model has an extensive history of development and quality assurance. It can be run in a deterministic mode or in a probabilistic framework to facilitate uncertainty and sensitivity analyses.

4.2.1 Input Parameters

Input parameters used in the pathways model are as follows:

- Dietary characteristics (Sections 3.1 and 3.2 for ecological and human characteristics, respectively);
- Existing Conditions (Baseline Concentrations) (Section 4.2.1.1);
- Project Conditions (Source Terms) (Section 4.1);
- Transfer factors (Section 4.2.1.2); and,
- Dose coefficients (Section 4.2.1.3).

4.2.1.1 Existing Conditions (Baseline)

Prior to the referral of the Thor Lake Project to Environmental Assessment, Avalon initiated baseline studies of environmental media and ecological systems at the proposed Nechalacho Mine and Flotation Plant site. Conducted over several years by Stantec Incorporated (Stantec), final reports were issued in January 2010 and categorized into the following six volumes:

- Volume 1: Climate and Hydrology (Stantec 2010a);
- Volume 2: Hydrogeology (Stantec 2010b);
- Volume 3: Aquatics and Fisheries (Stantec 2010c);
- Volume 4: Terrain, Soils and Permafrost (Stantec 2010d);
- Volume 5: Vegetation Resources (Stantec 2010 e); and
- Volume 6: Wildlife Resources (Stantec 2010f).

The studies provided baseline levels of uranium, thorium, and assorted daughter radionuclides in surface water and sediment. Data gaps were filled whenever possible using the assumption of secular equilibrium, permitting the approximate concentration determination of radionuclides within the same series from a known concentration. Before summarizing the data to select appropriate statistics for use as baseline concentrations, values reported as non-detects were set equal to half the method detection limit (½MDL). The 95% Upper Confidence Limit of the Mean (UCLM) was calculated, and selected as baseline values for use in this assessment (Table 4.2). Where less than ten data points were available, the maximum observed concentration was selected for use in the assessment.

Site-specific soil data were not available, and as a result values from alternate sources were selected to best represent typical soil quality in the area. For uranium and thorium, data were downloaded from the Geological Survey of Canada (GSC) Canadian Geochemical Survey catalogue which is found on the Geoscience Data Repository (GDR) at Natural Resources Canada (NRCan 2010). The catalogue contains searchable metadata for approximately 700 geochemical surveys carried out by the GSC and provincial geological agencies since the 1950s.

For radium-226, the baseline concentration was set equal to a value reported for northern Canada by Zikovsky and Blagoeva (1994). Soil data selected for inclusion in the pathways assessment is provided in Table 4.2.

Site specific measurements of radionuclides in air were not conducted during the Thor Lake Project Baseline Study. In addition, insufficient data sources were available to provide a reasonable estimate of regional concentrations of radionuclides within baseline ambient air. However, numerous studies have been conducted on radionuclide concentrations of lichen, with the majority of radionuclide input to the lichen provided by the surrounding air. Using verified formulas within the INTAKE spreadsheets, the radionuclide concentrations in air were estimated from known radionuclide concentrations in Great Slave Lake area *Cladina mitis* and *Cetraria nivalis* (Thomas *et al.* 1994), two species of lichen common to the Thor Lake Project Area.

Uranium-238 concentration was based on the chemical uranium concentrations using a specific activity of 12.35 Bq U-238/mg U. In the absence of measured data, the baseline activities for other uranium series radionuclides, lead-210, polonium-210 and thorium-230 in all media were considered to be equivalent to those of radium-226. Thorium-232 was based on the chemical thorium concentrations using a specific activity of 4.06 Bq Th-232/mg Th. In the absence of measured data, activities of other radionuclides in the thorium series were assumed equal to thorium-232 or radium-228. The baseline concentrations selected for this assessment are summarized in Table 4.2.

TABLE 4.2 SUMMARY OF BASELINE CONCENTRATIONS

COPC	Water (mg/L or Bq/L)	Soil (mg/kg dw or Bq/kg)	Sediment (mg/kg dw or Bq/kg dw)
Uranium	4.77E-04[a]	4.43E+00[b]	7.53E+00[d]
Lead-210	1.00E-02[a]	3.93E+01[f]	3.48E+02[a]
Polonium-210	1.00E-02[f]	3.93E+01[f]	9.30E+01[f]
Radium-226	1.00E-02[a]	3.93E+01[c]	9.30E+01[a]
Thorium-230	2.00E-02[a]	3.93E+01[f]	7.00E+01[a]
Uranium-238	5.89E-03[d]	5.46E+01[d]	9.30E+01[a]
Thorium	1.23E-03[e]	1.32E+01[b]	1.01E+01[e]
Radium-228	3.00E-02[a]	5.37E+01[h]	9.30E+01[a]
Thorium-228	3.00E-02[g]	5.37E+01[h]	9.30E+01[g]
Thorium-232	5.00E-03[a]	5.37E+01[e]	4.10E+01[a]

Note:

a - Values from 2009 baseline water/sediment study (Stantec, 2010c)
b - Values from Geological Survey of Canada (GSC) Canadian Geochemical Survey
c - Zikovsky and Blagoeva (1994)
d - Calculated to/from uranium using a conversion factor of 12.347 Bq U-238 /mg U-chem
e - Calculated to/from thorium using a conversion factor of 4.06 Bq Th-232 /mg Th-chem
f - Assumed activity equal to radium-226
g - Assumed activity equal to radium-228
h - Assumed activity equal to thorium-232

Baseline radionuclide concentrations were not available for many of the environmental media required for the pathways assessment. For instance, baseline studies did not examine concentrations of radionuclides in fish, terrestrial vegetation, and aquatic vegetation. To identify baseline (and incremental) radionuclide concentrations in these media, transfer factors were used from media of known concentrations.

4.2.1.2 Transfer Factors

Pathways modelling relies on transfer factors to estimate concentrations in environmental media. Transfer factors (TFs) are empirical values that provide a measure of the partitioning behaviour of a COPC between two environmental media. TFs can describe partitioning between many different media, including water-to-sediment, water-to-fish, water-to-benthic invertebrates, food-to-animal flesh and other media.

TFs from the abiotic environment (water, soil, sediment and air) to biota, are employed to relate the concentration in one medium to another. This permits prediction of incremental project effects, and establishment of baseline conditions for those biota for which measured concentrations were not available (i.e., benthic invertebrates, forage, browse, berries). The TFs include water-to-aquatic plants, water-to-benthos, water-to-fish, water-to-sediment and soil-to-terrestrial vegetation (browse, forage and berries). TFs have been acquired for all radionuclides that are carried through the pathways assessment. The values used in the assessment are summarized in Table 4.3 for transfer from the abiotic environment.

In general, the approach taken for estimating the exposure of radiological contaminants to non-human biota is to model the intake of a contaminant by the biota (in Bq/d) and then use a TF (d/kg) to obtain a body or flesh concentration where necessary.

Food-to-animal flesh transfer factors are generally only available in literature for agricultural animals such as beef and poultry. The values used in the assessment are summarized in Table 4.4 for mammals and Table 4.5 for birds. However, as these TFs are derived for beef, this can lead to a significant underestimate of the biota concentration, particularly for small animals. To obtain a more appropriate TF, allometric scaling can be applied to the TF with a relationship of -0.75. This approach is consistent with the allometric scaling for intake rates and inhalation by wildlife, as used in the ecological profiles (U.S. EPA 1993a), which has shown a similar relationship. Allometric scaling of TFs has been discussed by others (e.g. Nalezinski *et al.* 1996, Higley *et al.* 2003) as a useful method for deriving TFs for biota. It is acknowledged that not all radionuclides would scale to the same factor, as shown by the U.S. DOE (2002). However, the use of the -0.75 factor is a conservative approach. Other factors that can be found in the literature (e.g. 0.25 may be appropriate for actinides) would result in smaller predicted transfer factors for smaller biota than the reference animal. As most of the ecological receptors are smaller than cattle, the -0.75 is used as a conservative approach. The scaling can be applied as follows:

$$TF_w = TF_a \left(\frac{BW_w}{BW_a} \right)^{-0.75}$$

Where:

TF_w	Transfer factor for wildlife (d/kg)
TF_a	Transfer factor for animal available from literature (d/kg)
BW_w	Body weight of wildlife (kg)
BW_a	Body weight of animal (kg)

The scaled TFs used in this assessment are summarized in Table 4.6.

TABLE 4.3 SUMMARY OF TRANSFER FACTORS FROM THE ABIOTIC ENVIRONMENT USED IN THE ASSESSMENT

COPC	Water to Sediment		Water to Fish		Water to Benthic		Water to Aq. Veg		Soil to Berries		Soil to Browse		Soil to Forage	
	L/kg dw	**Reference**	**L/kg (fw)**	**Reference**	**L/kg (ww)**	**Reference**	**L/kg (ww)**	**Reference**	**kg/kg (ww)**	**Reference**	**kg/kg (ww)**	**Reference**	**kg/kg (ww)**	**Reference**
Uranium	50	Bechtel Jacobs 1998	0.86	IAEA 2009	170	IAEA 2009	230	Generic macrophytes from IAEA 2009	5.4E-03	IAEA 2009 (converted from dw value)	1.0E-03	IAEA 2009 (converted from dw value)	0.055	ICRP 2010
Thorium	1.8E+05	IAEA 2009 (Table 12)	100	N288.1-08 (CSA 2008)	2900	IAEA 2009	3000	PNNL 2003	5.1E-04	IAEA 2009 (converted from dw value)	1.0E-05	IAEA 2009 (converted from dw value)	3.0E-03	ICRP 2010
Radium	7400	IAEA 2009 (Table 12)	4	IAEA 2009	100	IAEA 2009	2000	Generic macrophytes from IAEA 2009	0.039	IAEA 2009 (converted from dw value)	6.0E-04	IAEA 2009 (converted from dw value)	0.65	ICRP 2010
Lead	270	Bechtel Jacobs 1998	25	IAEA 2009	22	IAEA 2009	1800	Generic macrophytes from IAEA 2009	0.117	IAEA 2009 (converted from dw value)	0.05	IAEA 2009 (converted from dw value)	0.525	ICRP 2010
Polonium	150	Bechtel Jacobs 1998	36	IAEA 2009	2.0E+04	PNNL 2003	2000	PNNL 2003	2.9E-05	IAEA 2009 (converted from dw value)	0.04	IAEA 2009 (converted from dw value)	4.8E-03	ICRP 2010

All isotopes use the transfer factors for the element (e.g. thorium TFs used for Th-230, Th-232 and Th-228).

TABLE 4.4 FEED-TO-MAMMAL TRANSFER FACTORS

COPC	Value (d/kg) [a]	Reference
Uranium	3.9×10^{-4}	IAEA 2009
Lead	9.3×10^{-4}	IAEA 2009
Polonium	1.0×10^{-2} – smaller mammals	Thomas 1997[b]
	1.3×10^{-3} – larger mammals	Thomas *et al.* 1994[c]
Radium	1.7×10^{-3}	IAEA 2009
Thorium	3.5×10^{-4}	IAEA 2009

Note:
a – Cited average feed-to-beef transfer factors for all COPC except polonium-210.
b – Based on food chain concentration ratios for vegetation and voles in Thomas 1997.
c – Calculated from lichen to caribou data in Thomas *et al.* 1994.

TABLE 4.5 FEED-TO-BIRD TRANSFER FACTORS

COPC	Value (d/kg ww) [a]	Reference
Uranium	0.75	IAEA 2009
Lead	0.47	No poultry data available; calculated as feed-to-mammal transfer factor multiplied by 500
Polonium	2.4	IAEA 2009
Radium	0.03	CSA 2008
Thorium	0.01	CSA 2008

Note:
a – Based on information for poultry.

TABLE 4.6 FEED-TO-WILDLIFE SCALED TRANSFER FACTORS

COPC[a]	Snowshoe Hare	Spruce Grouse	Moose	Barren Ground Caribou	Scaup
Uranium	3.96E-02	2.20E+00	4.20E-04	1.29E-03	9.45E-01
Thorium	3.30E-02	2.94E-02	3.50E-04	1.07E-03	1.95E-02
Radium	1.60E-01	8.82E-02	1.70E-03	5.20E-03	5.86E-02
Lead	8.76E-02	1.37E+00	9.30E-04	2.85E-03	9.08E-01
Polonium	1.30E-03	7.05E+00	1.00E-02	1.00E-02	4.68E+00
COPC[a]	**Mallard**	**Common Merganser**	**Black Bear**	**Wolf**	**Peregrine Falcon**
Uranium	1.19E+00	9.45E-01	1.13E-03	3.03E-03	1.37E+00
Thorium	1.59E-02	1.26E-02	9.43E-04	2.53E-03	1.82E-02
Radium	4.76E-02	3.78E-02	4.58E-03	1.23E-02	5.46E-02
Lead	7.38E-01	5.86E-01	2.51E-03	6.71E-03	8.46E-01
Polonium	3.81E+00	3.02E+00	1.00E-02	1.00E-02	4.37E+00

Note:
a – Values calculated from allometric scaling using a beef body weight of 600 kg and a poultry body weight of 2 kg (CSA 2008).

4.2.1.3 Dose Coefficients

Table 4.7 shows the selected Dose Coefficients (DCs) for the estimation of dose to ecological receptors. The DCs were obtained from Amiro (1997) and Blaylock *et al*. (1993). DCs for internal and external (water) exposure are provided.

TABLE 4.7 DOSE COEFFICIENTS USED FOR ECOLOGICAL RECEPTORS

COPC	DC (in mGy/d per Bq/g)*	
	Internal	External
U-238+	$1.42x10^{-1}$	$1.73x10^{-5}$
Th-230	$6.58x10^{-2}$	$1.96x10^{-5}$
Ra-226+	$1.59x10^{-1}$	$8.77x10^{-5}$
Pb-210+	$6.03x10^{-3}$	$6.05x10^{-5}$
Po-210	$7.40x10^{-2}$	$9.42x10^{-8}$
Th-232+	$5.64x10^{-2}$	$1.70x10^{-5}$
Ra-228+	$1.95x10^{-2}$	$1.30x10^{-2}$
Th-228	$7.64x10^{-2}$	$4.11x10^{-5}$

Reference:

* Dose (mGy/d) per Bq/g tissue concentration for internal dose and per Bq/g of environmental concentration for external dose

Note: the radionuclides included in each dose coefficients are as follows:

U-238+ Internal: U-238 + Th-234 + Pa-234m+ U-234 + 0.045 U-235
External: U-238 + Th-234 + Pa-234m+ U-234 + 0.045 U-235 (beta + gamma only)
Ra-226+ Internal: Ra-226 + 0.3* (Rn-222 + ...Po-214)
External: Ra-226 + 1.0* (Rn-222 + ...Po-214) (beta + gamma only)
Pb-210+ Internal: Pb-210 + Bi-210
Th-232+ Internal: Th-232 + ...Po-212/Tl-208 (Th-232 + Th-228 are inputs)
External: Th-232 + Po-212/Tl-208T
Ra-228+ Internal: Ra-228 + ...Po-212/Tl-208

For human receptors, the DCs used in the assessment are those recommended by the International Commission on Radiological Protection (ICRP). Ingestion DCs depend on the chemical form of the radionuclide and the consequent gut-to-blood transfer factor (f_1). The values selected reflect the ICRP Publication 72 (1996) recommended f_1 values and DCs for members of the public. Inhalation DCs depend on the chemical form of the radionuclide and the consequent rate of clearance from the lungs to body fluids - slow (S), moderate (M) or fast (F). The ICRP recommends type M for most unspecified conditions with the exception of Th-230 for which type S is recommended. To be conservative, the generally larger DCs (i.e. less soluble S type DCs) were used for all radionuclides in this assessment. DCs for inhalation and ingestion exposure are shown in Table 4.8 for humans.

TABLE 4.8 DOSE COEFFICIENTS USED FOR HUMAN RECEPTORS

	Toddler [a]		Adult	
COPC	**Inhalation**	**Ingestion**	**Inhalation**	**Ingestion**
U-238+	52.5	0.25	17.8	0.0995
Th-230	35	0.41	14	0.21
Ra-226+	29	0.96	9.5	0.28
Pb-210+	18.3	3.6	5.6	0.69
Po-210+	14	8.8	4.3	1.2
Ra-228+	48	5.7	16	0.69
Th-228+	130	0.37	40	0.072
Th-232+	50	0.42	25	0.23

Units: µSv/Bq
[a] Taken to be equivalent to a 1-year old. As the toddler age range includes children up to 4 years old this is a conservative value.
References: ICRP 72 (1996)

5.0 HAZARD ASSESSMENT

5.1 ECOLOGICAL RISK ASSESSMENT

Within the Ecological Risk Assessment (ERA) framework, assessment endpoints are based on potential effects at population or community levels. At these levels of biological organization, population and community characteristics can be defined over fairly extended temporal and spatial scales, making the potential for the direct measurement of effects challenging (Environment Canada 1997).

The assessment of effects from exposure to radioactive constituents was carried out for the Thor Lake Project at the Nechalacho Mine and Flotation Plant site. The assessment of radioactivity involves estimation of the combined dose which a receptor may receive from radionuclides taken into the body as well as from exposure to radiation fields in the external environment. In addition, it is standard practice to take into account differences in the effects of alpha, beta and gamma radiation. These factors are discussed below.

5.1.1 Relative Biological Effectiveness (RBE) Factors

Radiation effects on biota depend not only on the absorbed dose, but also on the type or "quality" of radiation. For example, alpha particles can produce observable damage at lower absorbed doses than beta or gamma radiation. Therefore, the absorbed dose (in Gy) is multiplied by an appropriate radiation weighting factor, alternatively called relative biological effectiveness (RBE). Strictly, the term RBE is reserved for experimentally observed values; however, for this assessment the terms "RBE" and "radiation weighting factor" are used interchangeably.

The concept of RBE is illustrated in the following equation and can be understood as the *"inverse ratio of absorbed doses of different quality radiations, delivered to the same locus of interest, that produce the same degree of a given biological effect in a given organism, organ or tissue"* all other factors being equal (NCRP 1967), namely:

$$RBE = \frac{\textit{Dose of reference radiation needed to produce a given effect}}{\textit{Dose of the given radiation needed to produce (the same magnitude of) the same biological effect}}$$

For the purposes of human radiological protection, each component of the absorbed dose to a tissue or organ is weighted according to the radiation quality. For example, an RBE of 20 is used for alpha radiation, while a RBE of 1 is used for gamma radiation. The appropriate alpha RBE value for non-human biota is the subject of ongoing scientific discussion, as indicated by the review completed by UNSCEAR (1996):

> *"In the case of wild organisms, however, it is likely to be deterministic effects that are of greatest significance, and for alpha radiation the experimental data for animals indicate that a lower weighting factor, perhaps 5, would be more appropriate; the weighting factors for beta and gamma radiation would remain unity." (para. 18)*

Over the past decade, there have been a number of evaluations of published data on RBE for non-human biota exposed to alpha radiation; however, in considering these studies it is important to note the experimental RBEs are specific to the endpoint studied as well as the biological, environmental and exposure conditions. As noted in a recent report by the European Community (FASSET 2003), it is a challenge to develop a generally valid radiation weighting factor to be used in an environmental risk assessment. Therefore, some studies have proposed a range of values for such general application.

A report of the (former) Advisory Committee on Radiological Protection suggested a nominal alpha RBE value of 10 with a range of about 5 to 20 for non-human biota (ACRP 2002); a recent report of the European Community (FASSET 2003) suggests using an alpha RBE of 10. In addition, the U.S. DOE (2000) reviewed this issue and recognized that the critical biological endpoint of concern in radiation exposures of biota appears to be deterministic, and that the radiation weighting factor for deterministic effects is substantially less than the corresponding average quality factor used in radiation protection of humans (i.e. 20). Based on this information, U.S. DOE concluded that the radiation weighting factor for deterministic effects appears to lie in the range of about 5 to 10. However, as interim guidance, they recommend the use of an RBE of 20 in the proposed standard (U.S. DOE 2000). Also, Environment Canada and Health Canada completed the PSL2 assessment (EC/HC 2003) which suggests an alpha RBE of 40.

Another study that reviewed literature of deterministic effects (Trivedi and Gentner 2000) concluded that:

> *"since the majority of studies report RBE values less than or equal to 10 for endpoints, and doses and dose rates that are more ecologically significant, a value of 10 might be appropriate for weighting doses to evaluate the impact of alpha emitters at the population level, if any".*

It should be noted that uncertainty remains concerning the most appropriate RBE values for assessing risks to non-human biota. The RBE values depend on the radiation quality, the biota under consideration, the endpoint being considered and the reference radiation. For example, gamma rays from Cs-137 or Co-60 and 250 kVp X-rays which are used as the "reference radiations" have different effectiveness. The Co-60 gamma rays are less effective than the 250 kVp X-rays in producing radiobiological effects, and for many purposes, the difference in the relative effectiveness between the two types of radiation can be taken as a factor of 2. Overall, the RBE values selected to develop protection criteria should correspond to the endpoint being protected (e.g. health of a population).

In addition to the specific studies mentioned above, there has been a wide range of RBE values for internally deposited alpha particles have been published. The most recent UNSCEAR report (2008 Annex E) recommends a nominal value of 10 for the biota radiation weighting factor. Therefore, for the purposes of the Thor Lake assessment, uncertainty associated with the choices of RBE and hence biota radiation weighting factor, is acknowledged and a range of biota radiation weighting BE values (i.e. 5, 10, 20 and 40) were used to illustrate the effects of this uncertainty.

5.1.2 Aquatic Radiation Benchmarks

For radiation exposures, the International Atomic Energy Agency (IAEA 1992) suggests a dose rate of 10 mGy/d as the reference dose level below which population effects to aquatic biota would not be expected. This value is also suggested in UNSCEAR (1996) and has been used in recent assessments.

The NCRP (National Council on Radiation Protection and Measurements) in Report 109 (U.S. NCRP 1991) recommends 0.4 mGy/h (9.6 mGy/d) for the protection of aquatic biota. The NCRP state that a chronic dose rate of no more than 0.4 mGy/h (9.6 mGy/d) to the maximally exposed individual in a population would ensure protection of the population. The NCRP report also includes recommendations that if modelling and/or dosimetric measurements indicate a dose level of 0.1 mGy/h (2.4 mGy/d), then a more detailed evaluation of the potential ecological consequences to the endemic population should be conducted. The 1992 review by the IAEA (Technical Report No. 332) also concluded that limiting the dose rate to individuals in an aquatic population to a maximum of 10 mGy/d would provide adequate protection for the population.

A number of reviews on the effects of radiation on aquatic organisms were published prior to the publication of NCRP 109 (Anderson and Harrison 1966; Polikarpov 1966; Templeton *et al*. 1971; Chipman 1972; IAEA 1976; Blaylock and Trabalka 1978; Egami 1980; NRCC 1983; Woodhead 1984). In those reviews, deleterious effects of chronic irradiation were not observed in natural populations at dose rates of 0.4 mGy/h (9.6 mGy/d) or less, over the entire history of exposure to ionizing radiation. Taking into consideration the combined results from laboratory and field studies, it appears that reproductive and early developmental systems of vertebrates are most sensitive to chronic irradiation in both aquatic and terrestrial environments. Invertebrates appear to be relatively radioresistant. Effects on aquatic organisms, not necessarily detrimental when evaluated in the context of population dynamics, were detected at dose rates in the range of 1 to 10 mGy/d.

The U.S. DOE (2000) concluded that applying the aquatic dose limits suggested by the U.S. NCRP (1991) and IAEA (1992) would ensure protection of aquatic populations. UNSCEAR (1996) suggests that chronic dose rates of up to 400 µGy/h (10 mGy/d) to individuals in aquatic populations are unlikely to have a detrimental effect at the population level.

The Canadian Nuclear Safety Commission (CNSC) has recently recommended that a dose limit value of 0.6 mGy/d be used for fish, a value of 3 mGy/d be used for aquatic plants (algae and macrophytes) and a value of 6 mGy/d be applied for benthic invertebrates (Bird *et al*. 2002; EC/HC 2003). The dose limit value for fish was based on a reproductive effects study in carp in the Chernobyl cooling pond (Makeyeva *et al*. 1995). A value of 0.6 mGy/d was found to be in the range where both effects and no effects were observed. The aquatic plant benchmark was based on information related to terrestrial plants (conifers), which are considered to be sensitive to the effects of radiation. Reproductive effects in polychaete worms were used to derive the dose limit for benthic invertebrates.

As indicated by the brief reviews of the literature cited above, the selection of reference dose levels for aquatic biota is a topic of ongoing discussion in the scientific literature. In light of this, it is proposed that the following reference dose levels be used in the risk assessment:

- fish – 0.6 mGy/d and 10 mGy/d;
- aquatic plants (algae and macrophytes) – 3 mGy/d and 10 mGy/d; and,
- benthic invertebrates – 6 mGy/d and 10 mGy/d.

5.1.3 Terrestrial Wildlife Radiation Benchmarks

A level of 1 mGy/d is generally used as an acceptable level for terrestrial biota. In 1992, the IAEA (1992) published the results of an assessment of the effects of acute and chronic radiation on terrestrial populations and communities. They reached several general conclusions regarding chronic radiation: reproduction is likely to be the most limiting endpoint in terms of population maintenance, and irradiation at chronic dose rates of 1 mGy/d or less does not appear likely to cause observable changes in terrestrial animal populations. Also, they concluded that irradiation at chronic dose rates of 10 mGy/d or less does not appear likely to cause observable changes in terrestrial plant populations. However, reproductive effects in long-lived species with low reproductive capacity may require further consideration. The U.S. DOE (2000) has suggested that applying the terrestrial dose limits suggested by IAEA (1992) would be protective of terrestrial species populations. UNSCEAR (1996) suggests that chronic dose rates below 400 µG/h (10 mGy/d) would not likely produce any significant effects in natural plant communities; that for terrestrial mammals, dose rates below 400 µG/h (10 mGy/d) to the most exposed animal are unlikely to affect mortality in the population and that dose rates below 40 µGy/h (1 mGy/d) are unlikely to cause a loss of reproductive capacity.

The CNSC has recently provided a dose rate guideline of 3 mGy/d as an appropriate limit for small mammals and terrestrial plants (Bird *et al*. 2002; EC/HC 2003). This limit is based on reproductive endpoints for small mammals. In the absence of data for avian species, the CNSC suggest that the dose limit for small mammals should also apply to aquatic and terrestrial birds.

From the above discussion, it is recognized that the selection of reference dose levels is a topic of ongoing debate; therefore, dose limits for:

- Terrestrial biota of 1 mGy/d and 3 mGy/d were selected for this assessment.
- It is worth noting for context that the most recent review of UNSCEAR(2008 Annex E) concluded that chronic dose rates of 100 µGy/h (2.4 mGy/day) to the most highly, exposed biota are unlikely to have an effect on populations of non human biota, consistent with values used in this assessment.

5.1.4 Sediment Toxicity Evaluations

The possible ecological effects of increased uranium, thorium and associated radionuclides in sediment, as a result of long-term tailings storage in Ring and Buck Lakes, were addressed through the examination of potential effects on benthic invertebrates, waterfowl, predator fish species, forage fish species, and humans consuming waterfowl and fish.

Comparison with Canadian Council of Ministers of the Environment (CCME) guidelines was not conducted due to the absence of guidelines for any of the COPC. Similarly, the toxicity benchmarks commonly used from Thompson *et al.* (2005) do not exist for thorium-230, uranium-238, radium-228, thorium-228, or thorium-232. Due to the limited information available for sediment quality benchmarks this comparison was not conducted and the assessment of benthic invertebrates is through the dose calculations which depend on water and sediment concentrations.

5.2 HUMAN HEALTH RISK ASSESSMENT

Assessment of radiation exposures to members of the public is based on estimation of the incremental effects of the project or site. Such assessments consider the radiation dose received from direct exposure to gamma radiation (not a concern at the Nechalacho Mine and Flotation Plant) as well as the dose received from the inhalation and ingestion of radionuclides. The human receptor model converts radionuclide intake by the human receptors from the various pathways into a radiation dose.

The incremental doses were then compared to the dose constraint of 0.3 millisieverts per year (300 µSv/y) recommended by Health Canada in the Canadian NORM Guidelines (Health Canada 2000). Doses below this level are considered as “unrestricted” and no further action is needed to control doses or materials.

6.0 RESULTS

Results for exposures to radionuclides for ecological (aquatic and terrestrial) and human (worker, adult and toddler) receptors are presented herein. The results indicate there is not expected to be a statistically relevant increase in radiation or radioactive COPC to the environment from the Thor Lake Project.

6.1 PREDICTED ENVIRONMENTAL MEDIA CONCENTRATIONS

Predicted radionuclide concentrations in environmental media are provided in Table 6.1 through to Table 6.10. Uranium and thorium concentrations are provided as these form the basis for the estimates of the other radionuclides.

TABLE 6.1 PREDICTED TOTAL SOIL CONCENTRATIONS

COPC	Units	Concentrations		
		Baseline	Project	Baseline + Project
Uranium [a]	mg/kg	4.43E+00	1.91E-01	4.62E+00
Lead-210 [b]	Bq/kg	3.93E+01	2.36E+00	4.16E+01
Polonium-210 [b]	Bq/kg	3.93E+01	2.36E+00	4.16E+01
Radium-226 [b]	Bq/kg	3.93E+01	2.36E+00	4.16E+01
Thorium-230 [b]	Bq/kg	3.93E+01	2.36E+00	4.16E+01
Uranium-238 [c]	Bq/kg	5.46E+01	2.36E+00	5.70E+01
Thorium [a]	mg/kg	1.32E+01	1.09E+00	1.43E+01
Radium-228 [d]	Bq/kg	5.37E+01	4.43E+00	5.82E+01
Thorium-228 [d]	Bq/kg	5.37E+01	4.43E+00	5.82E+01
Thorium-232 [e]	Bq/kg	5.37E+01	4.43E+00	5.82E+01

Note:
a - Maximum TSP in air modelling (RWDI 2011) used as source, and ore as concentration (SGS 2010a)
b - Incremental concentrations assumed equal to uranium-228
c - Incremental concentrations calculated from uranium using a conversion factor of 12.347 Bq U-238 /mg U-chem
d - Incremental concentrations assumed equal to thorium-232
e - Incremental concentrations calculated from thorium using a conversion factor of 4.06 Bq Th-232 /mg Th-chem

TABLE 6.2 PREDICTED TOTAL BERRIES CONCENTRATION

COPC[a]	Units	Concentrations		
		Baseline	Project	Baseline + Project
Uranium	mg/kg	2.39E-02	1.03E-03	2.49E-02
Lead-210	Bq/kg	4.59E+00	2.76E-01	4.87E+00
Polonium-210	Bq/kg	1.12E-03	6.72E-05	1.19E-03
Radium-226	Bq/kg	1.53E+00	9.20E-02	1.62E+00
Thorium-230	Bq/kg	2.00E-02	1.20E-03	2.12E-02
Uranium-238	Bq/kg	2.95E-01	1.27E-02	3.08E-01
Thorium	mg/kg	6.75E-03	5.56E-04	7.31E-03
Radium-228	Bq/kg	2.10E+00	1.73E-01	2.27E+00
Thorium-228	Bq/kg	2.74E-02	2.26E-03	2.97E-02
Thorium-232	Bq/kg	2.74E-02	2.26E-03	2.97E-02

Note:
a - TFs from soil to berries used to determine baseline and project concentrations

TABLE 6.3 PREDICTED TOTAL BROWSE CONCENTRATIONS

COPC[a]	Units	Concentrations		
		Baseline	Project	Baseline + Project
Uranium	mg/kg	4.43E-03	1.91E-04	4.62E-03
Lead-210	Bq/kg	1.96E+00	1.18E-01	2.08E+00
Polonium-210	Bq/kg	1.57E+00	9.43E-02	1.66E+00
Radium-226	Bq/kg	2.36E-02	1.41E-03	2.50E-02
Thorium-230	Bq/kg	3.93E-04	2.36E-05	4.16E-04
Uranium-238	Bq/kg	5.46E-02	2.36E-03	5.70E-02
Thorium	mg/kg	1.32E-04	1.09E-05	1.43E-04
Radium-228	Bq/kg	3.22E-02	2.66E-03	3.49E-02
Thorium-228	Bq/kg	5.37E-04	4.43E-05	5.82E-04
Thorium-232	Bq/kg	5.37E-04	4.43E-05	5.82E-04

Note:

a - TFs from soil to browse used to determine baseline and project concentrations

TABLE 6.4 PREDICTED TOTAL FORAGE CONCENTRATIONS

COPC[a]	Units	Concentrations		
		Baseline	Project	Baseline + Project
Uranium	mg/L	2.43E-01	1.05E-02	2.54E-01
Lead-210	Bq/L	2.06E+01	1.24E+00	2.19E+01
Polonium-210	Bq/L	1.86E-01	1.12E-02	1.98E-01
Radium-226	Bq/L	2.55E+01	1.53E+00	2.71E+01
Thorium-230	Bq/L	1.16E-01	6.96E-03	1.23E-01
Uranium-238	Bq/L	3.01E+00	1.30E-01	3.13E+00
Thorium	mg/L	3.91E-02	3.22E-03	4.23E-02
Radium-228	Bq/L	3.49E+01	2.88E+00	3.78E+01
Thorium-228	Bq/L	1.59E-01	1.31E-02	1.72E-01
Thorium-232	Bq/L	1.59E-01	1.31E-02	1.72E-01

Note:

a - TFs from soil to forage used to determine baseline and project concentrations

TABLE 6.5 PREDICTED TOTAL LICHEN CONCENTRATIONS

COPC	Units	Concentrations		
		Baseline[a]	Project[b]	Baseline + Project
Uranium	mg/kg	3.46E+01	1.24E+00	3.59E+01
Lead-210	Bq/kg	4.28E+02	1.54E+01	4.43E+02
Polonium-210	Bq/kg	4.28E+02	1.54E+01	4.43E+02
Radium-226	Bq/kg	4.28E+02	1.54E+01	4.43E+02
Thorium-230	Bq/kg	4.28E+02	1.54E+01	4.43E+02
Uranium-238	Bq/kg	4.28E+02	1.54E+01	4.43E+02
Thorium	mg/kg	1.15E+02	6.74E+00	1.22E+02
Radium-228	Bq/kg	4.67E+02	2.74E+01	4.94E+02
Thorium-228	Bq/kg	4.67E+02	2.74E+01	4.94E+02
Thorium-232	Bq/kg	4.67E+02	2.74E+01	4.94E+02

Note:

a - Baseline lichen concentrations calculated with INTAKE, and air concentrations calibrated such that concentrations are consistent with previous studies (Thomas *et al*. 1994)

b - COPC concentrations in lichen determined from suspended particulate in air, assumed to be exclusively ore

TABLE 6.6 PREDICTED TOTAL WATER CONCENTRATIONS

COPC	Units	Option		
		Baseline	Project [b]	Baseline + Project
Uranium [a]	mg/L	4.77E-04	7.30E-06	4.84E-04
Lead-210	Bq/L	1.00E-02	8.98E-05	1.01E-02
Polonium-210	Bq/L	1.00E-02	8.98E-05	1.01E-02
Radium-226 [a]	Bq/L	1.00E-02	8.30E-06	1.00E-02
Thorium-230	Bq/L	2.00E-02	8.98E-05	2.01E-02
Uranium-238 [c]	Bq/L	5.89E-03	8.98E-05	5.98E-03
Thorium [a]	mg/L	1.23E-03	5.80E-07	1.23E-03
Radium-228	Bq/L	3.00E-02	2.51E-04	3.03E-02
Thorium-228	Bq/L	3.00E-02	2.35E-06	3.00E-02
Thorium-232 [d]	Bq/L	5.00E-03	2.35E-06	5.00E-03

a - Incremental concentrations from water modelling (EBA 2011)
b - See Table 4.1 for source term assumptions for water
c - Incremental concentrations calculated from uranium using a conversion factor of 12.347 Bq U-238 /mg U-chem
d - Incremental concentrations calculated from thorium using a conversion factor of 4.06 Bq Th-232 /mg Th-chem

TABLE 6.7 PREDICTED TOTAL SEDIMENT CONCENTRATIONS

COPC[a]	Units*	Concentrations		
		Baseline	Project	Baseline + Project
Uranium	mg/kg	7.53E+00	3.65E-04	7.53E+00
Lead-210	Bq/kg	3.48E+02	2.42E-02	3.48E+02
Polonium-210	Bq/kg	9.30E+01	1.35E-02	9.30E+01
Radium-226	Bq/kg	9.30E+01	6.14E-02	9.31E+01
Thorium-230	Bq/kg	7.00E+01	1.62E+01	8.62E+01
Uranium-238	Bq/kg	9.30E+01	4.49E-03	9.30E+01
Thorium	mg/kg	1.01E+01	1.04E-01	1.02E+01
Radium-228	Bq/kg	9.30E+01	1.86E+00	9.49E+01
Thorium-228	Bq/kg	9.30E+01	4.24E-01	9.34E+01
Thorium-232	Bq/kg	4.10E+01	4.24E-01	4.14E+01

Note:
* - Dry weight basis
a - Estimated using water to sediment transfer factors (Kd values in Table 4.3)

TABLE 6.8 PREDICTED TOTAL FISH CONCENTRATIONS

COPC[a]	Units*	Concentration		
		Baseline	Project	Baseline + Project
Uranium	mg/kg	4.10E-04	6.28E-06	4.16E-04
Lead-210	Bq/kg	2.50E-01	2.24E-03	2.52E-01
Polonium-210	Bq/kg	3.60E-01	3.23E-03	3.63E-01
Radium-226	Bq/kg	4.00E-02	3.32E-05	4.00E-02
Thorium-230	Bq/kg	2.00E+00	8.98E-03	2.01E+00
Uranium-238	Bq/kg	5.06E-03	7.72E-05	5.14E-03
Thorium	mg/kg	1.23E-01	5.80E-05	1.23E-01
Radium-228	Bq/kg	1.20E-01	1.00E-03	1.21E-01
Thorium-228	Bq/kg	3.00E+00	2.35E-04	3.00E+00
Thorium	Bq/kg	5.00E-01	2.35E-04	5.00E-01

Note:
* - Wet weight basis
a - Estimated using water to fish transfer factors (Table 4.3)

TABLE 6.9 PREDICTED TOTAL AQUATIC VEGETATION CONCENTRATIONS

COPC[a]	Units*	Concentration		
		Baseline	Project	Baseline + Project
Uranium	mg/kg	1.10E-01	1.68E-03	1.11E-01
Lead-210	Bq/kg	1.80E+01	1.62E-01	1.82E+01
Polonium-210	Bq/kg	2.00E+01	1.80E-01	2.02E+01
Radium-226	Bq/kg	2.00E+01	1.66E-02	2.00E+01
Thorium-230	Bq/kg	6.00E+01	2.69E-01	6.03E+01
Uranium-238	Bq/kg	1.35E+00	2.07E-02	1.38E+00
Thorium	mg/kg	3.69E+00	1.74E-03	3.70E+00
Radium-228	Bq/kg	6.00E+01	5.01E-01	6.05E+01
Thorium-228	Bq/kg	9.00E+01	7.06E-03	9.00E+01
Thorium-232	Bq/kg	1.50E+01	7.06E-03	1.50E+01

Note:
* - Wet weight basis
a - Estimated using water to aquatic vegetation transfer factors (Table 4.3)

TABLE 6.10 PREDICTED TOTAL BENTHOS CONCENTRATIONS

COPC[a]	Units*	Concentration		
		Baseline	Project	Baseline + Project
Uranium	µg/g	8.11E-02	1.24E-03	8.23E-02
Lead-210	Bq/g	2.20E-04	1.98E-06	2.22E-04
Polonium-210	Bq/g	2.00E-01	1.80E-03	2.02E-01
Radium-226	Bq/g	1.00E-03	8.30E-07	1.00E-03
Thorium-230	Bq/g	5.80E-02	2.60E-04	5.83E-02
Uranium-238	Bq/g	1.00E-03	1.53E-05	1.02E-03
Thorium	µg/g	3.57E+00	1.68E-03	3.57E+00
Radium-228	Bq/g	3.00E-03	2.51E-05	3.03E-03
Thorium-228	Bq/g	8.70E-02	6.83E-06	8.70E-02
Thorium-232	Bq/g	1.45E-02	6.83E-06	1.45E-02

Note:
* - Wet weight basis
a - Estimated using water to benthos transfer factors (Table 4.3)

6.2 ECOLOGICAL ASSESSMENT

Screening index values provide an integrated description of the potential hazard, the exposure (or dose) -response relationship, and the exposure evaluation. In this study, ecological impacts from COPC were characterized by the value of a simple screening index. This index was calculated by dividing the expected exposure or dose concentration by the reference dose (in the case of radionuclides), for each ecological receptor, as shown in equation (6-1).

$$Screening\ Index = \frac{Equivalent\ Dose}{Reference\ Dose} \tag{6-1}$$

The screening index values reported in this section are not estimates of the probability of ecological impact. Rather, the index values are positively correlated with the potential of an effect, i.e., higher index values imply greater potential of an effect. In this study, an index value of 1.0 was used to examine the impacts of COPC for the receptors.

6.2.1 Aquatic Biota

There are no federal or territorial water quality guidelines to compare the estimated radionuclide levels in water based on ecological considerations. Equivalent doses were determined for aquatic receptors based on the estimated water and sediment concentrations, from which screening index values were calculated. The doses are estimated for total exposure and include baseline plus the effect of the project. As all screening index values are lesser than 1 (Table 6.11), there are no adverse effects expected.

TABLE 6.11 SUMMARY OF SCREENING INDEX VALUES FOR AQUATIC BIOTA EXPOSED TO RADIONUCLIDES

VEC	Reference Dose (mGy/d)	Screening Index			
		RBE=5	RBE=10	RBE=20	RBE=40
Aquatic Plants	3	0.03	0.06	0.12	0.24
	10	0.01	0.02	0.04	0.07
Benthic Invertebrates	6	0.02	0.04	0.09	0.18
	10	0.01	0.03	0.05	0.11
Predator Fish	0.6	0.004	0.007	0.014	0.03
	10	<0.001	<0.001	<0.001	0.002
Forage Fish	0.6	0.004	0.007	0.014	0.03
	10	<0.001	<0.001	<0.001	0.002

Note: Values in **bold** exceed the benchmark screening index value of 1

6.2.2 Terrestrial Biota

The terrestrial biota incorporated in the assessment include:

- Barren Ground Caribou;
- Moose;
- Wolf;
- Peregrine Falcon;
- Black Bear;
- Spruce Grouse;
- Snowshoe Hare;
- Mallard;
- Common Merganser; and
- Scaup.

Table 6.12 provides the results of the screening index calculations of radionuclide exposure for terrestrial biota. The doses are estimated for total exposure and include baseline plus the effect of the project. From the table, it can be seen that all SI values are below 1 and thus no adverse effects are expected. The increase associated with the project is also very low.

TABLE 6.12 SUMMARY OF SCREENING INDEX VALUES FOR TERRESTRIAL BIOTA EXPOSED TO RADIONUCLIDES

RBE	Screening Index									
	Snowshoe Hare	**Spruce Grouse**	**Mallard**	**Barren ground caribou**	**Moose**	**Black bear**	**Wolf**	**Peregrine Falcon**	**Scaup**	**Common Merganser**
Reference Dose = 1 mGy/d										
5	5.4E-04	8.4E-04	2.8E-02	2.3E-03	1.5E-04	2.4E-04	1.0E-05	8.8E-04	4.2E-02	2.2E-04
10	1.1E-03	1.7E-03	5.7E-02	4.6E-03	2.9E-04	4.7E-04	2.0E-05	1.8E-03	8.3E-02	4.3E-04
20	2.2E-03	3.4E-03	1.1E-01	9.2E-03	5.8E-04	9.4E-04	4.0E-05	3.5E-03	1.7E-01	8.6E-04
40	4.3E-03	6.7E-03	2.3E-01	1.8E-02	1.2E-03	1.9E-03	8.0E-05	7.0E-03	3.3E-01	1.7E-03
Reference Dose = 3 mGy/d										
5	1.8E-04	2.8E-04	9.4E-03	7.6E-04	4.9E-05	7.9E-05	3.3E-06	2.9E-04	1.4E-02	7.2E-05
10	3.6E-04	5.6E-04	1.9E-02	1.5E-03	9.7E-05	1.6E-04	6.6E-06	5.8E-04	2.8E-02	1.4E-04
20	7.2E-04	1.1E-03	3.8E-02	3.1E-03	1.9E-04	3.1E-04	1.3E-05	1.2E-03	5.5E-02	2.9E-04
40	1.4E-03	2.2E-03	7.6E-02	6.1E-03	3.9E-04	6.3E-04	2.7E-05	2.3E-03	1.1E-01	5.7E-04

Note: Values in **bold** exceed the benchmark screening index value of 1

6.3 HUMAN HEALTH ASSESSMENT

A human health risk assessment (HHRA) evaluates whether there is likely to be an adverse health effect caused by the potential exposure to contaminants in the environment. In an HHRA, receptor characteristics (e.g., portion of time spent in the study area, source of drinking water, composition of diet) and exposure pathways (e.g., ingestion of fish) are taken into consideration to quantify the risk of adverse health effects. Unlike an ecological risk assessment (ERA), which is concerned with population effects, the HHRA focuses on effects on individuals.

This assessment considers the potential exposure to radiation to a worker not involved in the mining operations (e.g. camp cook, security guard), and First Nations that may use lands adjacent to the Nechalacho Mine and Flotation Plant.

Table 6.13 provides the results of the human health radiological dose calculation for human receptors that may access the site. Since the appropriate comparison benchmark is an incremental dose, the values shown in Table 6.13 exclude background.

Using conservative assumptions of pathways, the predicted total incremental dose to camp workers is 0.9 µSv/y, primarily due to inhalation. First Nations persons using the site were calculated to have a total incremental dose of 12 µSv/y for an adult and 45 µSv/y for a toddler. These doses are primarily from the assumptions related to the intake of caribou from the area.

All of the estimated doses are well below the 300 µSv/y dose limit recommended by Health Canada, and no adverse effects are expected. -

It should be noted that the estimated doses to people are primarily due to the air emissions from the site (inhalation for the camp worker and caribou intake for the First Nations individuals). Very conservative assumptions were incorporated in the estimated air concentrations from the site; particularly that all dust generated at the site would have the same radionuclide content as ore. Therefore, the dose estimates provided are very conservative.

TABLE 6.13 SUMMARY OF DOSE ESTIMATES FOR HUMAN RECEPTORS EXPOSED TO RADIONUCLIDES

RECEPTOR	Total Ingestion Dose (μSv/y)								Total Inhalation Dose (μSv/y)	Total Radon Dose (μSv/y)	Total Incremental Dose (μSv/y)
	Water	Soil	Barren Ground Caribou	Moose	Snowshoe Hare	Fish	Mallard	Berries			
Worker*	0.1	0.04	--	--	--	--	--	--	0.7	0.08	0.9
Adult	0.005	0.002	11	0.02	0.02	0.1	0.6	0. 6	0.03	<0.001	12
Toddler	0.013	0.04	40	0.07	0.01	0.4	2	2	0.05	<0.001	45

Note: Doses are compared to a benchmark value of 300 μSv/y; values in **bold** exceed this benchmark
-- This is not a potential pathway of exposure for this receptor
* Worker not involved in mining activities (e.g. camp cook, security guard)

7.0 SUMMARY AND CONCLUSIONS

Avalon is proposing to develop the Thor Lake Project rare earth mineral mine on the shores of Great Slave Lake, Northwest Territories. The project will be located at two locations, the Nechalacho Mine and Flotation Plant in the East Arm region, and the Hydrometallurgical Plant on the southern shore of Great Slave Lake. Three years is estimated for the construction phase, 18 years of active mining operations, followed by two years of decommissioning.

SENES has been contracted by Avalon to conduct a Radioactivity Pathways Assessment of the Thor Lake Project, as elevated radioactivity is often associated with rare earth mineral deposits. The screening level pathways assessment examined the potential exposure of human and ecological receptors to radioactivity from the Thor Lake Project. Exposure pathways analysis was conducted to evaluate contaminant sources, assesses the environmental fate of released radioactive species, and to estimate doses to workers, people who hunt, fish or live in the area, and to non-human biota (aquatic and terrestrial systems).

For the current work program, the environmental modelling and pathways analyses were performed at a screening level and, as such, simplifying assumptions were made. Air and water dispersion modelling was conducted to provide an estimate of radionuclides in these media. Environmental modelling estimated the steady-state (long-term) concentrations of the COPC in the environmental media of interest (e.g. vegetation, fish). Pathways modelling combined the receptor characteristics (ingestion rate, body weight, time at site, etc.) with the estimated environmental media concentrations of Constituents of Potential Concern (COPC) to estimate exposure of each receptor. For this screening level assessment, a spreadsheet pathways model was used. This spreadsheet model was built on the INTAKE pathways model, which calculates exposures and doses to ecological and human receptors. The INTAKE model has been applied to several uranium mining projects in northern Saskatchewan to simulate radiological and non-radiological constituent fate and transport in the environment and the subsequent evaluation of exposures to ecological species and humans. The dose estimates are then compared to dose limits in the risk assessment to identify any areas of concern.

Radionuclides of potential concern include the thorium series radionuclides (including thorium-232, radium-228 and thorium-228) and the uranium series radionuclides (including uranium-238, thorium-230, radium-226, lead-210 and polonium-210). Thor Lake has uranium levels that are higher than an average granite but far below those of even very low grade uranium deposits. The thorium levels in the Nechalacho deposit are anomalous, although thorium has about one quarter the radioactive effect of uranium at the same concentration level.

At the Nechalacho Mine and Flotation Plant, the pathways assessment was conducted for both aquatic and terrestrial receptors within and surrounding Thor Lake. Thor Lake was selected as it is the first fish bearing waterbody downstream of the Nechalacho Tailings Facility (within Ring and Buck Lakes), and the proximity to both the mine and flotation plant through which radiological COPC may be introduced to water, and subsequently to the sediment. Ore extraction, transfer, and processing may introduce radiological COPC to the air as suspended particulate, which may be respired by receptors, or fall as dust to enter the soil profiles and be taken up by vegetation. Radon emitted from the Nechalacho Mine was also considered to be a COPC and was included in the assessment.

At the Hydrometallurgical Plant site, there were no pathways identified that could lead to a significant incremental increase in radioactivity exposure for receptors. Results of air quality modelling at the site indicated there is will be no significant increase to suspended particulate or dustfall due to the Hydrometallurgical Plant (RWDI 2011), with no subsequent loadings to the air, soil, or vegetation. The tailings slurry will be discharged to the L-37 pit (former pit within the brownfield site), and excess water to the N-42 pit, with the pits isolated from the surface hydrological regime and tailings water will discharge to the groundwater system, requiring many decades of groundwater flow before discharge to Great Slave Lake. There are consequently no pathways of incremental radioactivity due to the Hydrometallurgical Plant site, and the site was removed from the assessment.

Ecological Assessment

Ecological receptors were selected to capture exposure from drinking water, consumption of aquatic plants, fish, invertebrates and sediments. Ecological receptor characteristics were assumed to represent a reasonable maximum exposure scenario, in that cautious assumptions were made regarding the receptor's behaviour and home range. While in the regional area, ecological receptors were assumed to spend all of their time near the areas of proposed mine infrastructure (i.e. Thor Lake), when in reality terrestrial mammals would largely be deterred by the noise and large number of people present in the active mine site.

All trophic levels were included in the pathways assessment of the Thor Lake aquatic environment at the Nechalacho Mine and Flotation Plant site. Receptors assessed include:

- Aquatic plants;
- Phytoplankton (e.g. *Chlorophyta*);
- Zooplankton (e.g. *Cladocerans*);
- Benthic invertebrates (e.g. *Chironomidae*);
- Primary consumers (e.g. whitefish); and
- Tertiary consumers (e.g. lake trout).

The ecological receptors included in the assessment of terrestrial ecological species include a range of biota, to identify potential impacts to receptors and throughout the food web. Terrestrial receptors included in the pathways assessment include:

- Barren-ground caribou;
- Moose;

- Black bear;
- Wolf;
- Snowshoe hare;
- Peregrine falcon;
- Spruce grouse;
- Merganser;
- Mallard; and,
- Scaup.

Screening Index (SI) values were calculated using baseline + project values, with all SI values below 1 and thus no adverse effects are expected.

Human Health Assessment

The humans selected as receptors for the Thor Lake Project area are workers not directly involved in the mine operations (e.g. site cook) and First Nations members using land surrounding the Nechalacho Mine and Flotation Plant. It is assumed that the site cook receptor will not consume food from the area but may be exposed to impacted media (soil, water and air). As a conservative assumption, the First Nations receptor was modeled at Thor Lake, receiving maximum concentrations of radiation exposure in water, air, and soil pathways. In reality, the First Nations receptor is not expected to be present on site during mining and ore processing operations, but may obtain food and water resources from the downstream environment.

Traditional food intakes were obtained from a study of Yellowknife Dene (Receveur *et al.* 1998). To augment the data available for the Yellowknife Dene, serving sizes and yearly frequencies were estimated from the larger Dene/Metis survey (Receveur *et al.* 1996).

The pathways that were considered in the human health assessment include inhalation, water ingestion and the intake of hare, moose, caribou, duck, fish, and berries.

Using conservative assumptions of pathways, the predicted total incremental dose to camp workers is 0.9 µSv/y. First Nations persons using the site were calculated to have a total incremental dose of 12 µSv/y for an adult and 45 µSv/y for a toddler. The estimated doses are primarily affected but the assumed air emissions from the site. A very conservative approach was taken where all of the dust generated at the site was assumed to have the same radionuclide content as the ore. Even considering this very conservative approach, the doses are well below Health Canada’s 300 µSv/y dose constraint, and no adverse effects are expected.

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APPENDIX A:

ECOLOGICAL PROFILES

Black Bear

Black bears (*Ursus americanus*), are members of the family Ursidae, which has representatives throughout most of the northern hemisphere and in northern South America. The black bear prefers heavily wooded areas and dense bushland. Maximum numbers probably occur in areas of mixed coniferous deciduous forests. Colours can range from black to cinnamon brown, silver-blue and, occasionally, even white. Black bears spend the winter months in a state of hibernation and may hibernate up to 7 months a year in the northern parts of their range (CWS 1992, ADF&G 1994).

Size

Adult males weigh about 135 kg; females average 70 kg (CWS 1992).
Weight: 200 kg (NatureServe 2008)
An average adult male in spring weighs about 81.8 to 90.9 kg (ADF&G 1994).
Males weigh between 47 and 409 kg, females weigh between 39 and 236 kg (Dewey and Kronk 2007)

Based on the above information a typical black bear is expected to weigh 160 kg (CWS 1992, NatureServe 2008, Dewey and Kronk 2007).

Home Range:

Black bears are capable of traveling great distances (CWS 1992).
Home ranges of males averaged 505 to 5,200 hectares in Washington, 1,060 to 2,240 hectares in California and 1,660 to 13,030 hectares in Idaho (NatureServe 2008).
Home range for a female bear can range between 2.6 km^2 to 40 km^2; the home range for a male bear can range from 21 km^2 to 155 km^2 (ABA 2003).

Feeding Habits:

Black bear's food comprises mainly vegetation, especially in the late summer and autumn when berries and nuts are available. They also feed on fish, small mammals, and occasionally birds. Only a small portion of the diet of bears consists of animal matter, and then primarily in the form of colonial insects and beetles. Most vertebrates are consumed in the form of carrion. Black bears are not active predators and feed on vertebrates only if the opportunity exists. (CWS 1992, NatureServe 2008, Dewey and Kronk 2007, ABA 2003).

Based on the available information the black bear is assumed to consume berries and other vegetation, fish and juveniles of moose and caribou. In the model this is expressed as 40% berries, 35% summer forage, 15% fish, 10% moose and caribou.

Food Consumption Rate:

Allometric equation for mammals (U.S. EPA 1993): FI (g dw/day) = 0.235 $Wt^{0.822}$ (g)

Based on a body weight of 160000 g the FI is 4455 g dw/d or 14850 g ww/d (moisture content of 70%)

Soil Ingestion:

The estimated % soil in diet (dry weight) is assumed 5% (Average of mammals based on Beyer *et al*. 1994). Based on a dry weight consumption rate of 4455 g/d this corresponds to approximately 223 g/d.

Water Intake Rate:
Allometric equation for mammals (U.S. EPA 1993): WI (L/day) = 0.099 $Wt^{0.9}$ (kg)
Based on a body weight of 160 kg the WI is 9.5 L/d

Inhalation Rate:
Allometric equation for mammals (U.S. EPA 1993): IR (m^3/day) = 0.5458 $Wt^{0.8}$ (kg)
Based on a body weight of 160 kg the IR is 31.6 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	160	CWS 1992, NatureServe 2008, Dewey and Kronk 2007
Food Intake Rate (g ww/d)	14850	U.S. EPA 1993 (allometric scaling)
Soil Ingestion Rate: (g/d) Fraction of ww diet:	 223 0.015	Beyer *et al*. 1994
Water Intake Rate (L/d)	9.5	U.S. EPA 1993 (allometric scaling)
Inhalation rate (m^3/d)	31.6	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	1	Assumed
Fractional Composition of Diet		
Berries	0.4	CWS 1992, NatureServe 2008, Dewey and Kronk 2007, ABA 2003
Summer forage	0.35	
Fish	0.15	
Large Game	0.1	

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Caribou

The caribou (*Rangifer tarandus*) is a medium-sized member of the deer family. In Europe, caribou are called reindeer, but in Alaska and Canada only the domestic forms are called reindeer. Both female and male caribou carry antlers. Four subspecies of caribou occur in Canada: woodland, Peary, barren-ground west of the Mackenzie River (also known as Grant's caribou), and barren-ground east of the Mackenzie River. About half of the 2.4 million caribou in Canada are barren-ground caribou. They spend much or all of the year on the tundra from Alaska to Baffin Island. (CWS 2005, Shefferly and Joly 2000)

Size:

- Barren-ground caribou are somewhat smaller than woodland caribou. (CWS 2005).
- Mass 55 to 318 kg, subspecies inhabiting the more southerly latitudes are larger than their northern cousins (Shefferly and Joly 2000).
- Weight 270000 grams (NatureServe 2007).
- Weights of adult bulls average 159-182 kg. Mature females average 80-120 kg. (ADF&G 1999).

  Based on the above information a typical barren-ground caribou is expected to weigh 135 kg (ADF&G 1999).

Home Range:

Caribou are known to travel distances greater than any other terrestrial mammal. They can traverse more than 5,000 kilometres in a year, with extensive migrations in spring and fall (Shefferly and Joly 2000).

Tundra caribou may travel extensively in summer in attempt to avoid bothersome insects (NatureServe 2007).

It was assumed that the caribou spends 100% of its time in the study area; although most herds are migratory, there have been observances of non-migratory herds in the area.

Feeding Habits:

Ground and tree lichens are the primary winter food of caribou, providing a highly digestible and energy-rich food source. Although lichens are a good source of energy, they are not a good source of protein (nitrogen). As soon as spring snow melts, caribou are eager to switch to fresh green vegetation (e.g. leaves of willows and birches, mushrooms, cotton grass, sedges), which is rich in nitrogen. (CWS 2005, NatureServe 2007, Shefferly and Joly 2000)

Based on the available information caribou is assumed to consume terrestrial vegetation. This is likely to comprise primarily lichen in the winter and primarily forage and browse in the summer (75% lichen, 11% summer forage, 11% browse and 3% soil (as discussed below)).

Food Consumption Rate:

Allometric equation for mammals (U.S. EPA 1993): $FI\ (g\ dw/day) = 0.235\ Wt^{0.822}\ (g)$

Based on a body weight of 1.35×10^5 g the FI is 3874 g dw/d, or 6457 g ww/d (moisture content of 40%, based on diet composed mainly of lichen as discussed below).

Soil Ingestion:

No specific information is available; therefore the general value for all mammals of 5% based on the information provided by Beyer *et al.* (1994) was used.

Based on a dry weight consumption rate of 3874 g/d this corresponds to approximately 194 g/d, or 3% of the wet weight FI of 6457 g ww/d.

Water Intake Rate:

Allometric equation for mammals (U.S. EPA 1993): $WI\ (L/day) = 0.099\ Wt^{0.9}\ (kg)$

Based on a body weight of 135 kg the WI is 8.2 L/d.

Summary Table:

Exposure Characteristics		
Body Weight (kg)	135	ADF&G 1999
Food Intake Rate (g ww/d)	6457	U.S. EPA 1993 (allometric scaling)
Soil Ingestion Rate (g dw/d)	194	Beyer *et al.* 1994
Water Intake Rate (L/d)	8.2	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	1	Assumed
Fractional Composition of Diet		
Soil	0.03	Fraction of wet weight diet (Beyer *et al.* 1994)
Summer Forage	0.11	Based on CWS 2005, NatureServe 2007, Shefferly and Joly 2000
Browse	0.11	
Lichen	0.75	

References:

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United States Environmental Protection Agency (U.S. EPA) 1993. *Wildlife Exposure Factors Handbook.* EPA/600/R-93/187.

Mallard

One of the most familiar of ducks, the Mallard (*Anas platyrhynchos)* is found throughout North America. The Mallard is a surface-feeding duck, known as a dabbling duck. It is generally found near shallow waters such as ponds and wetlands. Nests are established on the ground and may be located away from the waterbody. The mallard is the most extensively hunted duck in Canada, representing over 50 percent of all ducks killed. (CWS 1996, Cornell 2003, Rogers 2001, NatureServe 2008)

Size

Average adults weighs 1.24 kg (CWS 1996)
Average mallard 1082 g (Rogers 2001)
Weight 1082 grams (NatureServe 2007)
Weight: 1000-1300 g (Cornell 2003)
Adult weight ranges from 1043 g to 1246g with an average of 1166 g (U.S. EPA 1993)
Adult body weight 1.082 kg (CCME 1998)

Based on the above information a typical mallard is expected to weigh approximately 1.082 kg (NatureServe 2007, CCME 1998).

Home Range:

Mallards have a breeding range of 111 ha with a total home range of approximately 524 ha (U.S. EPA 1993).
In Manitoba, nesting home range size averaged 283 hectares. Average breeding home ranges of radio-tagged birds in Minnesota were 210 hectares and 240 hectares; range 66 hectares to 760 hectares (NatureServe 2008).

Feeding Habits:

The mallard feeds mostly on aquatic plants, seeds, and aquatic invertebrates. In winter, mallards feed primarily on seeds but also on invertebrates. In spring, there is a shift from a largely herbivorous diet to a diet of mainly invertebrates (U.S. EPA 1993, NatureServe 2008, Rogers 2001, Cornell 2003).

The diet of the mallard is variable throughout the year, thus in characterizing the diet of the mallard consideration was given to the point that they are generally in the area during the summer period. Considering the information above and diet breakdown for summer months (U.S. EPA 1993) it was determined that mallards consume 75% benthic invertebrates and 25% aquatic vegetation.

Food Consumption Rate:

Daily food consumption rate is 0.25 kg (ww)/d (CCME 1998 – calculated using allometric equation). The dry weight value can be taken as 50 g(dw)/d using a moisture content of 80%).
Allometric equation for birds (U.S. EPA 1993): FI (g (dw)/day) = 0.648 $Wt^{0.651}$ (g)

> Based on a body weight (Wt) of 1082 g the FI is 61 g (dw)/d or 306 g (ww)/d (moisture content of 80%)

Based on the above information the food consumption rate was taken to be 250 g (ww)/d.

Sediment Ingestion:

Beyer *et al.* (1994) provides a value of 3.3% for mallard. It is further noted that samples from most mallards contained little or no sediment but 10% of the mallards consumed an estimated 26% sediment in their diet. Using the value of 3.3%, based on a dry weight consumption rate of 50 g/d this corresponds to approximately 1.7 g/d.

Water Intake Rate:
Allometric equation for birds (U.S. EPA 1993): WI (L/day) = 0.059 $Wt^{0.67}$ (kg)
Based on a body weight (Wt) of 1.082 kg the WI is 0.06 L/d

Inhalation Rate:
Allometric equation for birds (U.S. EPA 1993): IR (m^3/day) = 0.4089 $Wt^{0.77}$ (kg)
Based on a body weight (Wt) of 1.082 kg the IR is 0.43 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	1.082	NatureServe 2007, CCME 1998
Food Intake Rate (g (ww)/d)	250	CCME 1998
Sediment Ingestion Rate: (g/d) Fraction of ww diet:	 1.7 0.006	Beyer *et al.* 1994
Water Intake Rate (L/d)	0.06	U.S. EPA 1993 (allometric scaling)
Inhalation rate (m^3/d)	0.43	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	0.5	Assumed (migratory)
Fractional Composition of Diet		
Benthic invertebrates Aquatic plants	0.75 0.25	Based on information from U.S. EPA 1993, NatureServe 2007 and Cornell 2003

References:

Beyer, W. N., E. Connor, and S. Gerould. 1994. *Survey of Soil Ingestion by Wildlife.* Journal of Wildlife Management 58:375-382.

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Merganser

The Common Merganser (*Mergus merganser)* is the largest of the mergansers and the largest North American inland ducks. Common mergansers prefer to live in wooded areas along streams and rivers or near small, inland lakes. Nests are typically in a crevice of a deciduous tree along the shore. Common mergansers are diving predators who locate their prey by sight, and therefore tend to feed in clear waters, less than 4 m deep. The long bill has toothy projections along its edges that help the duck hold onto its fish prey. (Cornell 2003, Becker and Fraser 2006)

Size

Common mergansers are 1050 to 2054 g (Becker and Fraser 2006)
Weight 1709 grams (NatureServe 2008)
Weight: 900-2160 g (Cornell 2003)
Adult body weight male 1.709 kg, female1.232 kg (CCME 1998) Average: 1.47 kg

Based on the above information a typical merganser is expected to weigh approximately 1.47 kg (CCME 1996, Cornell 2003, Becker and Fraser 2006).

Home Range:

Nesting sites are usually separated from one another, but common mergansers have also been known to nest in close proximity in some cases. Territorial behavior is minimal. Individuals feed over a large range, seeking medium to large bodies of clear water. (Becker and Fraser 2006).

Feeding Habits:

Common mergansers are skilled diving predators, eating mainly fish. Clear water is preferred for feeding because the birds hunt primarily by sight. When fish are scarce, mergansers will substitute other small aquatic prey such as insects, mollusks, crustaceans, frogs, and other invertebrates. (Becker and Fraser 2006, NatureServe 2008, Cornell 2003).

Based on the available information the merganser, the principal source of food is fish (this is assumed to comprise equally pelagic and benthic fish).

Food Consumption Rate:

Daily food consumption rate ranges between 0.33 and 0.41 kg (ww)/d (CCME 1998 – calculated using allometric equation). The average is 0.37 kg (ww)/d.
Allometric equation for birds (U.S. EPA 1993): FI (g (dw)/day) = 0.648 $Wt^{0.651}$ (g)

> Based on a body weight (Wt) of 1470 g the FI is 75 g (dw)/d or 374 g (ww)/d (moisture content of 80%)

Based on the above information the food consumption rate was taken to be 370 g (ww)/d.

Sediment Ingestion:

Data on sediment ingestion by merganser were not found in the open literature. However, Beyer *et al.* (1994) provides a value of 2% for ring-necked duck and blue winged teal. Since the merganser is piscivorous and would not ingest significant amounts of sediment this value was used. Based on a dry weight consumption rate of 75 g/d this corresponds to approximately 1.5 g/d.

Water Intake Rate:
Allometric equation for birds (U.S. EPA 1993): WI (L/day) = 0.059 $Wt^{0.67}$ (kg)
Based on a body weight (Wt) of 1.47 kg the WI is 0.08 L/d

Inhalation Rate:
Allometric equation for birds (U.S. EPA 1993): IR (m^3/day) = 0.4089 $Wt^{0.77}$ (kg)
Based on a body weight (Wt) of 1.47 kg the IR is 0.55 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	1.47	CCME 1998, Cornell 2003, Becker and Fraser 2006
Food Intake Rate (g (ww)/d)	370	CCME 1998
Sediment Ingestion Rate: (g/d) Fraction of ww diet:	 1.5 0.004	Beyer *et al.* 1994
Water Intake Rate (L/d)	0.08	U.S. EPA 1993 (allometric scaling)
Inhalation rate (m^3/d)	0.55	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	0.5	Assumed (migratory)
Fractional Composition of Diet		
Fish - pelagic - benthic	0.5 0.5	Based on information from Becker and Fraser 2006, NatureServe 2008, Cornell 2003

References:

Becker, R. and A. Fraser. 2006. "Mergus merganser" (On-line), Animal Diversity Web. Accessed January 11, 2008 at http://animaldiversity.ummz.umich.edu/site/accounts/information/Mergus_merganser.html.

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Moose

Moose (*Alces alces*) are found on the rocky, wooded hillsides of the western mountain ranges; along the margins of lakes, muskegs, and streams of the boreal forest; and even on the northern tundra and in the aspen parkland of the prairies. Moose are quite at home in the water. They sometimes dive 5.5 m or more for plants growing on a lake or pond bottom. Moose are good swimmers, able to sustain a speed of 6 miles an hour. They move swiftly on land; adults can run as fast as 56 km/h (CWS 1997, Dewey *et al.* 2000).

Size
Big bulls weigh up to 600 kg in most of Canada (CWS 1997).
Moose weigh between 270 and 600 kg (Dewey *et al.* 2000).
Weight 630000 grams (630 kg) (NatureServe 2007).

Based on the above information a typical moose is expected to weigh 600 kg (CWS 1997).

Home Range:
Moose home ranges average 5 to 10 square kilometers (Dewey *et al.* 2000).
Based on radio-collared individuals in Copper River Delta in south-central Alaska, a mean value of 59 km^2 was calculated (MacCracken *et al.* 1997).
In Idaho, the home range for female moose has been observed to range from 15.5 to 25.9 km^2, and for male moose from 31 to 51.8 km^2 (Pierce and Peck 1984).

Feeding Habits:
Moose eat twigs, bark, roots and the shoots of woody plants, especially willows and aspens. In summer the moose's diet includes leaves, some upland plants, and water plants. They dip their heads under the surface of the water to feed on the lilies and other water plants. During the winter months, moose live almost solely on twigs and shrubs such as balsam fir, poplar, red osier dogwood, birch, willow, and red and striped maples (CWS 1997, Dewey *et al.* 2000). Browsing on leaves from deciduous trees and shrubs are the principal summer moose diet, while aquatic plants make up the remainder of the diet (LeResche and Davis 1973).

Based on the available information the moose is assumed to consume terrestrial vegetation (browse) and aquatic vegetation. This is likely to comprise primarily browse in the winter and primarily browse and aquatic plants in the summer. In general, this corresponds to 80% terrestrial vegetation (browse) and 20% aquatic plants on an annual basis.

Food Consumption Rate:
A large adult moose eats from 15 to 20 kg, green weight, of twigs each day in winter, and in summer eats from 25 to 30 kg of forage—twigs, leaves, shrubs, upland plants, and water plants (CWS 1997).

They require 20 kg of food per day (Dewey *et al.* 2000).
Allometric equation for mammals (U.S. EPA 1993): FI (g (dw)/day) = 0.235 $Wt^{0.822}$ (g)

Based on a body weight of 6E5 g the FI is 13000 g (dw)/d or 44000 g (ww)/d (moisture content of 70%).

Based on the above information the food consumption rate was taken to be 23 kg (ww)/d (CWS 1997) or 6.9 kg (dw)/d (moisture content of 70%). This value agrees well with that provided by Dewey *et al.* (2000).

Sediment Ingestion:
Beyer *et al.* (1994) provides a value of 2% for moose. Based on a dry weight consumption rate of 6900 g/d this corresponds to approximately 140 g/d. Due to the behaviour of consuming aquatic plants by pulling up the plant it is assumed that this ingestion is primarily sediment. There would be minimal soil ingested from the consumption of browse (twigs, leaves).

Water Intake Rate:
Allometric equation for mammals (U.S. EPA 1993): WI (L/day) = 0.099 $Wt^{0.9}$ (kg)
Based on a body weight of 600 kg the WI is 31 L/d

Inhalation Rate:
Allometric equation for mammals (U.S. EPA 1993): IR (m^3/day) = 0.5458 $Wt^{0.8}$ (kg)
Based on a body weight of 600 kg the IR is 91 m^3/d.

Summary Table:

Exposure Characteristics		
Body Weight (kg)	600	CWS 1997
Food Intake Rate (g (ww)/d)	23000	CWS 1997
Sediment Ingestion Rate: (g (dw)/d) Fraction of ww diet:	 140 0.006	Beyer *et al.* 1994
Water Intake Rate (L/d)	31	U.S. EPA 1993 (allometric scaling)
Inhalation Rate (m^3/d)	91	U.S. EPA 1993 (allometric scaling)
Fraction of Time in Area	1	Conservative assumption
Fractional Composition of Diet		
Terrestrial Plants	0.8	Assumed based on CWS 1997, Dewey *et al.* 2000, LeResche and Davis 1973
Aquatic Plants	0.2	

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Peregrine Falcon

General Description

The Peregrine Falcon (*Falco peregrinus*) is found in Nunavut.. It is a sturdy crow-sized falcon and has a small head, firm compact plumage, and long pointed wings; adaptations that allow it to fly at great speed. Powerful and fast-flying, the Peregrine Falcon hunts medium-sized birds, dropping down on them from high above in a spectacular stoop. They nest on cliff faces and crevices. (CWS 1990, Cornell 2003)

Size

Adult females weigh about 910 g, compared with the males' weight of about 570 g (CWS 1990).
Weight: 530-1600 g (Cornell 2003).
Weight: 1500 grams (NatureServe 2008)
Mass: 907 g (average) (Dewey and Potter 2002)

Based on the above information, typical Peregrine Falcon is expected to weigh 900 g (CWS 1990, Cornell 2003, Dewey and Potter 2002).

Home Range:

Home ranges have been estimated from 177 to 1508 square kilometers (White 2002).
Home ranges in Great Britain varied from 44-65 km^2, and averaged 52 km^2; In Utah, home range radii varied from 0.3 to 29.8 kilometers, average 12.2 km (NatureServe 2008)

Feeding Habits:

At Rankin Inlet, on the west shore of Hudson Bay, Peregrines eat mostly lemmings and shorebirds (CWS 1990).

Feeds primarily on birds (medium-size passerines up to small waterfowl); rarely or locally, small mammals (e.g., bats, lemmings), lizards, fishes, and insects (by young birds) may be taken (NatureServe 2008).

Peregrine falcons prey almost exclusively on birds, which make up 77 to 99% of prey items. The most important set of prey, by biomass, is Columbidae (doves, pigeons) as well as shorebirds, waterfowl, ptarmigan, grouse, and relatives, and smaller songbirds. They will also eat small reptiles and mammals. Most frequent mammal prey are bats, rodents, squirrels, and rats. (Dewey and Potter 2002)

Based on the available information the Peregrine Falcon is assumed to consume shorebirds (80%) and small mammals (20%).

Food Consumption Rate:

Allometric equation for birds (U.S. EPA 1993): FI (g dw/day) = $0.648\ Wt^{0.651}$ (g)

Based on a body weight of 900 g the FI is 54 g dw/d or 181 g ww/d (moisture content of 70%)

Based on the above information the food consumption rate was taken to be 180 g (ww)/d.

Soil Ingestion:
There is no specific information available on falcons. The estimated % soil/sediment in diet (dry weight) for birds (other than shorebirds) is 5% (Beyer *et al.* 1994). This value was used in lieu of species specific data. Based on a dry weight consumption rate of 54 g/d this corresponds to approximately 2.7 g/d.

Water Intake Rate:
Allometric equation for birds (U.S. EPA 1993): WI (L/day) = 0.059 $Wt^{0.67}$ (kg)
Based on a body weight of 900 g the WI is 0.055 L/d

Inhalation Rate:
Allometric equation for birds (U.S. EPA 1993): IR (m^3/day) = 0.4089 $Wt^{0.77}$ (kg)
Based on a body weight of 900 g the IR is 0.38 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	0.9	CWS 1990, Cornell 2003, Dewey and Potter 2002
Food Intake Rate (g ww/d)	180	U.S. EPA 1993 (allometric scaling)
Soil Ingestion Rate: (g/d) Fraction of ww diet:	 2.7 0.015	Beyer *et al.* 1994
Water Intake Rate (L/d)	0.055	U.S. EPA 1993 (allometric scaling)
Inhalation rate (m^3/d)	0.38	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	1	Assumed
Fractional Composition of Diet		
Small mammals Shorebirds	0.2 0.8	CWS 1990, Dewey and Potter 2002 and NatureServe 2008

References:

Beyer, W. N., E. Connor, and S. Gerould. 1994. *Survey of Soil Ingestion by Wildlife.* Journal of Wildlife Management 58:375-382.

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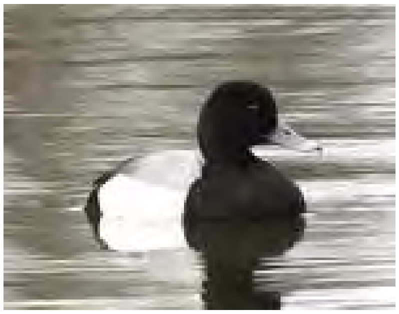
Scaup



The Greater Scaup (*Aythya marila)* is a medium-sized diving duck. It nests in bowl-shaped depressions in ground placed in tall grass. These birds typically breed near shores of ponds and lakes, in marshes, or on islands. The breeding area is primarily in forested tundra and northern borders of the taiga. Greater and lesser scaup are often found together and these species are very similar, although the greater scaup is slightly larger than the lesser scaup. (Cornell 2003, NatureServe 2008)

Size
Weight 957 grams (NatureServe 2008)
Weight: 726-1360 g (Cornell 2003)

Based on the above information a typical greater scaup is expected to weigh approximately 1.0 kg (Cornell 2003, NatureServe 2008).

Home Range:
No information available on the Greater Scaup. It is noted that Lesser Scaup have relatively small nesting territories and large highly overlapping foraging ranges (approximately 89 ± 6.5 ha). (U.S. EPA 1993).

Feeding Habits:
Greater scaup are omnivorous, eating 50 to 99 percent animal matter and the remainder plant foods during the winter (U.S. EPA 1993). Animal matter would include clams, snails, crustaceans and aquatic insects. (NatureServe 2008, Cornell 2003).

Based on the available information for the greater scaup, the food sources are taken to be benthic invertebrates (90%) and aquatic plants (10%).

Food Consumption Rate:
Allometric equation for birds (U.S. EPA 1993): FI (g (dw)/day) = 0.648 $Wt^{0.651}$ (g)

Based on a body weight (Wt) of 1000 g the FI is 58 g (dw)/d or 291 g (ww)/d (moisture content of 80%)

Based on the above information the food consumption rate was taken to be 291 g (ww)/d.

Sediment Ingestion:
Data on sediment ingestion by scaup were not found in the open literature. However, Beyer *et al.* (1994) provides a value of 11% for all bird species (including those with significant exposure to soil and sediment) which was used in this assessment. Based on a dry weight consumption rate of 58 g/d this corresponds to approximately 6.4 g/d.

Water Intake Rate:
Allometric equation for birds (U.S. EPA 1993): WI (L/day) = 0.059 $Wt^{0.67}$ (kg)

Based on a body weight (Wt) of 1.0 kg the WI is 0.06 L/d

Inhalation Rate:
Allometric equation for birds (U.S. EPA 1993): IR (m^3/day) = 0.4089 $Wt^{0.77}$ (kg)
Based on a body weight (Wt) of 1 kg the IR is 0.41 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	1.4	Cornell 2003, NatureServe 2008
Food Intake Rate (g (ww)/d)	291	U.S. EPA 1993 (allometric scaling)
Sediment Ingestion Rate: (g/d) Fraction of ww diet:	 6.4 0.022	Beyer *et al.* 1994
Water Intake Rate (L/d)	0.06	U.S. EPA 1993 (allometric scaling)
Inhalation rate (m^3/d)	0.41	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	0.5	Assumed (migratory)
Fractional Composition of Diet		
Benthic invertebrates Aquatic plants	0.9 0.1	Based on information from U.S. EPA 1993, NatureServe 2008, Cornell 2003

References:

Beyer, W. N., E. Connor, and S. Gerould. 1994. *Survey of Soil Ingestion by Wildlife.* Journal of Wildlife Management 58:375-382.

Cornell 2003. *All About Birds. Bird Guide.* Cornell Lab of Ornithology. Accessed January 11, 2008 http://www.birds.cornell.edu/AllAboutBirds/BirdGuide/

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United States Environmental Protection Agency (U.S. EPA) 1993. *Wildlife Exposure Factors Handbook.* EPA/600/R-93/187.

Snowshoe Hare

The snowshoe hare (*Lepus americanus*) lives in the boreal forest and is one of the most common forest mammals. Snowshoe hares are very active between sundown and dawn, and they remain active all winter. Generally they prefer areas with a dense understory as the cover helps to protect them from predators and provide them with food. Snowshoe hares consume a variety of herbaceous plants as well as small twigs, buds, and bark in the winter (CWS 2005).

***Size*:**

- Adult snowshoe hares range in weight from 1.2 to 1.6 kg (CWS 2005)
- Snowshoe hares usually weigh between 1.43 and 1.55 kg (Shefferly 2007).

Based on the above information a typical snowshoe hare is expected to weigh 1.4 kg.

Home Range:

The home range of a snowshoe hare is small and ranges from 6 to 10 ha (CWS 2005). A typical home range is from 0.03 to 0.07 square kilometres (Shefferly 2007).

Feeding Habits:

Snowshoe hares consume a variety of herbaceous plants during the summer, including forage plants such as vetch, strawberry, fireweed, lupine, bluebell, brome, asters, jewelweed, pussy-toes, dandelions, clovers, daisies and grasses. The new growth of trembling aspen, birches and willows is also eaten. They also eat many leaves from shrubs. Their winter diet consists of browse such as small twigs, buds, and bark from many coniferous and deciduous species. (CWS 2005, Shefferly 2007) Their geographic range where snowshoe hares exist is so large that they may have completely different diets, depending entirely on the local forest type.

Based on the available information the snowshoe hare is assumed to consume terrestrial vegetation, comprising browse (60%), forage (38%) and soil (2%, as discussed below).

Food Consumption Rate:

Allometric equation for mammals (U.S. EPA 1993): $FI\ (g\ dw/day) = 0.235\ Wt^{0.822}\ (g)$

Based on a body weight of 1400 g the FI is 91 g dw/d, or 302 g ww/d (moisture content of 70% based on a diet comprising mainly terrestrial vegetation as discussed above). This value is similar to a value of 300 g ww/d provided by Pease *et al.* (1979).

Soil Ingestion:

The estimated % soil in diet (dry weight) for a jackrabbit is 6.3% (U.S. EPA 1993, Table 4-5).

Based on a dry weight consumption rate of 91 g/d this corresponds to approximately 5.7 g/d, which represents approximately 2% of the wet weight FI of 302 g/d.

Water Intake Rate:

Allometric equation for mammals (U.S. EPA 1993): $WI\ (L/day) = 0.099\ Wt^{0.9}\ (kg)$

Based on a body weight of 1.4 kg the WI is 0.13 L/d.

Summary Table:

Exposure Characteristics		
Body Weight (kg)	1.4	CWS 2005, Shefferly 2007
Food Intake Rate (g (ww)/d)	302	U.S. EPA 1993 (allometric scaling); Pease *et al.* 1979
Soil Ingestion Rate (g dw/d)	5.7	Beyer *et al.* 1994
Water Intake Rate (L/d)	0.13	U.S. EPA 1993 (allometric scaling)
Fraction of time in area	1	Assumed (small home range)
Fractional Composition of Diet		
Soil	0.02	Fraction of wet weight diet (U.S. EPA 1993)
Forage	0.38	Based on information from CWS 2005, Shefferly 2007
Browse	0.6	

References:

Canadian Wildlife Service (CWS) 2005. *Hinterland Who's Who. Mammal Fact Sheet: Snowshoe Hare*. Available at: http://www.ffdp.ca/hww2.asp?id=103

Pease, J. L., R. H. Vowles, and L. B. Keith. 1979. *Interaction of snowshoe hares and woody vegetation*. Journal of Wildlife Management 43:43-60.

Shefferly, N. 2007. "*Lepus americanus" (On-line)*, Animal Diversity Web. Accessed August 21, 2007 at http://animaldiversity.ummz.umich.edu/site/accounts/information/Lepus_americanus.html.

United States Environmental Protection Agency (U.S. EPA) 1993. *Wildlife Exposure Factors Handbook*. EPA/600/R-93/187.

Spruce Grouse

General Description

The Spruce Grouse (*Falcipennis canadensis)*, also known as spruce hens, spruce chicken or Fool Hen, are found in coniferous forests, generally those dominated by dense stands of spruce, pine, or fir. They are generally year-round residents throughout their range. It feeds largely on the needles of spruces and other conifers and forages in trees and on the ground. They nest in a depression in the ground, lined with conifer needles and feathers. The nesting site always has overhead cover, often at the base of a tree. (Beaudoin, 2002, NatureServe 2008, Cornell 2003).

Size

Weight 492 grams (NatureServe 2008).
Weight: 400-650 g (Cornell 2003).

Based on the above information a typical spruce grouse is expected to weigh approximately 500 g (0.5 kg) (NatureServe 2008, Cornell 2003).

Home Range:
Territories range in size from 10 to 15 acres (Beaudoin. 2002).
In Alaska, home range sizes were highly variable among individuals, ranging from 6 to 21 ha for preincubating females, 6 to 155 ha for brood-rearing females, 3 to 20 ha for molting males, 6 to 160 ha for either sex in fall, and 3 to 113 ha in winter. In Michigan, highly variable range size were noted for females with broods, but 12 to 16 ha would be adequate. In Maine, home ranges for broods were 13-26 ha. (NatureServe 2008).

Feeding Habits:
The Spruce Grouse feeds almost exclusively on pine and spruce needles in winter. In the summer, they may consume berries, insects and ground vegetation. Fruits and leaves of huckleberry, snowberry, white mandarin, blueberry, cranberry, and crowberry may also be important to the grouses' diet differing slightly with season and climate. Blueberries are often noted as a favored food in summer. (Beaudoin. 2002, NatureServe 2008, Cornell 2003).

Based on the available information the grouse is assumed to consume terrestrial vegetation. Terrestrial vegetation is assumed to be represented by 60% browse, 20% forage and 20% berries.

Food Consumption Rate:
Allometric equation for birds (U.S. EPA 1993): FI (g (dw)/day) = 0.648 $Wt^{0.651}$ (g)
Based on a body weight of 500 g the FI is 37 g (dw)/d or 125 g (ww)/d (moisture content of 70%)

Based on the above information the food consumption rate was taken to be 125 g (ww)/d.

Soil Ingestion:
Beyer *et al.* (1994) provides a value of 10.4% for a woodcock and 9.3% for wild turkey, the average of these values (9.9%) was used in lieu of species specific data. Based on a dry weight consumption rate of 37 g/d this corresponds to approximately 3.6 g/d.

Water Intake Rate:
Allometric equation for birds (U.S. EPA 1993): WI (L/day) = 0.059 $Wt^{0.67}$ (kg)
Based on a body weight of 0.5 kg the WI is 0.04 L/d

Inhalation Rate:
Allometric equation for birds (U.S. EPA 1993): IR (m^3/day) = 0.4089 $Wt^{0.77}$ (kg)
Based on a body weight of 0.5 kg the IR is 0.24 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	0.5	NatureServe 2008, Cornell 2003
Food Intake Rate (g (ww)/d)	125	U.S. EPA 1993 (allometric scaling)
Soil Ingestion Rate: (g (dw)/d) Fraction of ww diet:	 3.6 0.03	Beyer *et al.* 1994
Water Intake Rate (L/d)	0.04	U.S. EPA 1993 (allometric scaling)
Inhalation Rate (m^3/d)	0.24	U.S. EPA 1993 (allometric scaling)
Fraction of Time in Area	1	Assumed
Fractional Composition of Diet		
Browse	0.6	Based on information from Beaudoin 2002, NatureServe 2008 and Cornell 2003
Forage	0.2	
Berries	0.2	

References:

Beaudoin, E. 2002. "Canachites canadensis" (On-line), Animal Diversity Web. Accessed May 22, 2008 at: http://animaldiversity.ummz.umich.edu/site/accounts/information/Canachites_canadensis.html

Beyer, W. N., E. Connor, and S. Gerould. 1994. *Survey of Soil Ingestion by Wildlife.* Journal of Wildlife Management 58:375-382.

Cornell 2003. *All About Birds. Bird Guide.* Cornell Lab of Ornithology. Accessed September 18, 2007 http://www.birds.cornell.edu/AllAboutBirds/BirdGuide/

NatureServe. 2008. NatureServe Explorer: An online encyclopedia of life. Version 7.0. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. 1 February (Accessed: May 22, 2008).

United States Environmental Protection Agency (U.S. EPA) 1993. *Wildlife Exposure Factors Handbook.* EPA/600/R-93/187.

Wolf

The gray wolf (*Canis lupus*) is a social animal and has a highly organized social structure centering on a dominant male and a dominant female. Gray wolves are one of the most wide ranging land animals. They occupy a wide variety of habitats, from arctic tundra to forest, prairie, and arid landscapes. The original range of the wolf consisted of the majority of the Northern hemisphere, however, gray wolf populations are now found only in a few areas of the contiguous United States, Alaska, Canada, Mexico (a small population), and Eurasia. They are mainly nocturnal (CWS 1993, Dewey and Smith 2002).

Size
Weigh between 20 and 75 kg (Dewey and Smith 2002).
Weight 40000 grams (40 kg) (NatureServe 2007).
43 kg (Schmidt and Gilbert 1978).

Based on the above information a typical wolf is expected to weigh 43 kg (Schmidt and Gilbert 1978).

Home Range:
Wolves are territorial. Each pack occupies an area that it will defend against intruders. Sizes of territories vary greatly and are dependent on the kind and abundance of prey available (CWS 1993). The territory of a pack ranges from 130 to 13,000 square kilometers (Dewey and Smith 2002).

Feeding Habits:
Gray wolves are carnivores. Wolves' chief prey are large mammals such as deer, moose, caribou, elk, bison, and muskox. Wolves also eat a variety of smaller mammals and birds, but these rarely make up more than a small part of their diet (CWS 1993, NatureServe 2007, Dewey and Smith 2002).

Based on the available information the wolf is assumed to consume moose and deer in equal proportion.

Food Consumption Rate:
Gray wolf in northeastern Alberta eat 5.5 kg/d (Fuller and Keith 1980).
Allometric equation for mammals (U.S. EPA 1993): FI (g (dw)/day) = 0.235 $Wt^{0.822}$ (g)

> Based on a body weight of 43000 g the FI is 1500 g (dw)/d or 5000 g (ww)/d (moisture content of 70%)

Based on the above information the food consumption rate was taken to be 5.5 kg (ww)/d (Fuller and Keith 1980), this value agrees well with the allometric estimate.

Soil Ingestion:
Beyer *et al.* (1994) provides values of 2.8% for red fox which was used for the wolf in lieu of a species specific value. This should be a conservative assumption as the wolves hunt larger prey. Based on a dry weight consumption rate of 1650 g/d this corresponds to approximately 46 g/d.

Water Intake Rate:
Allometric equation for mammals (U.S. EPA 1993): WI (L/day) = 0.099 $Wt^{0.9}$ (kg)

> Based on a body weight of 43 kg the WI is 2.9 L/d

Inhalation Rate:
Allometric equation for mammals (U.S. EPA 1993): IR (m^3/day) = 0.5458 $Wt^{0.8}$ (kg)
Based on a body weight of 43 kg the IR is 11 m^3/d

Summary Table:

Exposure Characteristics		
Body Weight (kg)	43	Schmidt and Gilbert 1978
Food Intake Rate (g (ww)/d)	5500	Fuller and Keith 1980
Soil Ingestion Rate: (g (dw)/d) Fraction of ww diet:	 46 0.008	Beyer *et al.* 1994
Water Intake Rate (L/d)	2.9	U.S. EPA 1993 (allometric scaling)
Inhalation Rate (m^3/d)	11	U.S. EPA 1993 (allometric scaling)
Fraction of Time in Area	0.25	Assumed based on large home range
Fractional Composition of Diet		
Moose	0.5	Based on information from CWS 1993, NatureServe 2007, Dewey and Smith 2002
Deer	0.5	

References:

Beyer, W. N., E. Connor, and S. Gerould. 1994. *Survey of Soil Ingestion by Wildlife.* Journal of Wildlife Management 58:375-382.

Canadian Wildlife Service (CWS) 1993. *Hinterland Who's Who. Mammal Fact Sheet: Wolf.* Available at: http://www.ffdp.ca/hww2.asp?id=107.

Dewey, T. and J. Smith. 2002. "Canis lupus" (On-line), Animal Diversity Web. Accessed September 18, 2007 at http://animaldiversity.ummz.umich.edu/site/accounts/information/Canis_lupus.html.

Fuller, T.K. and L.B. Keith. 1980. *Wolf Population Dynamics and Prey Relationships in Northeastern Alberta*. J. Wildl. Manage. 44:583-602.

NatureServe. 2007. NatureServe Explorer: An online encyclopedia of life. Version 6.2. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. 8 June (Accessed: September 17, 2007).

Schmidt, J.L. and D.L. Gilbert 1978. *Big Game of North America, Ecology and Management.* Stackpole Books, Harrisburg, PA 17105.

United States Environmental Protection Agency (U.S. EPA) 1993. *Wildlife Exposure Factors Handbook.* EPA/600/R-93/187.

APPENDIX B

DEPOSITION MODEL

B.1 DEPOSITION MODEL

The soil concentration at time Tc (Sc_{Tc}) is calculated as follows:

$$Sc_{Tc} = \frac{Ds \times \left(1 - e^{(-ks \times Tc)}\right)}{ks} \qquad \text{(B-1)}$$

Where:

Ds	=	Deposition term (mg/(kg y)) [calculated (B-2)]
ks	=	Soil loss constant (1/y) [calculated (B-3)]
Tc	=	Time period over which deposition occurs (y) [assumed to be 20]

The deposition term (Ds) is calculated as follows:

$$Ds = \frac{100}{z \times BD} \times \frac{V_{settle} \times C_a}{10000} \qquad \text{(B-2)}$$

Where:

100	=	Safety factor
z	=	Soil mixing depth (cm) [assumed to be 2]
BD	=	Soil bulk density (g/cm^3) [assumed to be 1.5]
10000	=	Conversion factor (m^2 to cm^2)
V_{settle}	=	Settling velocity (m/y) [assumed to be 3153.6 m/yr, equivalent to 0.01 cm/s, using particle density of 4.0 g/cm^3, particle diameter 1 µm, and stable atmosphere with roughness height 0.1 cm]
C_a	=	Concentration of chemical in air (µg/m^3)

The soil mixing depth (z) changes depending on the type of exposure being calculated. For this application of deposition in an area with undisturbed soil (compared to an agricultural area where soil would be tilled) the soil concentration calculated with z for forage was used.

The soil loss constant (ks) accounts for the loss of chemical from soil by several mechanisms and is calculated as follows:

$$ks = ksl + kse + ksr + ksg + ksv \qquad \text{(B-3)}$$

Where:

ksl	=	Loss constant due to leaching (1/y) [calculated (B-4)]
kse	=	Loss constant due to soil erosion (1/y) [use recommended value of 0 (U.S. EPA (2005)]
ksr	=	Loss constant due to surface runoff (1/y) [calculated (B-5)]

ksg	=	Loss constant due to degradation (1/y) [assumed to be 0]
ksv	=	Loss constant due to volatilization (1/y) [calculated (B-6)]

Since none of the COPC are volatile, ksv is set to 0.

The loss constant due to leaching (ksl) is calculated as follows:

$$ksl = \frac{q}{\Theta_s \times z \times \left[1 + \left(\frac{BD \times Kd_s}{\Theta_s}\right)\right]} \qquad \text{(B-4)}$$

Where:

q	=	Average annual recharge (cm/y) [assumed to be 5]
Θ_s	=	Soil volumetric water content (mL/cm^3) [assumed to be 0.2]
Kd_s	=	Soil-water partition coefficient (cm^3/g) [chemical-specific (Table B-1)]

The chemical loss constant due to runoff from soil (ksr) is calculated as follows:

$$ksr = \frac{R}{\Theta_s \times z} \times \left(\frac{1}{1 + \left(\frac{BD \times Kd_s}{\Theta_s}\right)} \right) \qquad \text{(B-5)}$$

Where:

R	=	Average annual runoff (cm/y) [assumed to be 2.5]

Table B.1 Chemical-Specific Parameters used in the Calculations

COPC	Kds, soil-water partition coefficient (cm^3/g)	
Thorium	1500000	RAIS
Uranium	450	RAIS

Notes:
NA Not Applicable for non-volatile COPC
Data obtained from RAIS (U.S. DOE 2011)

B.2 REFERENCES

United States Department of Energy (U.S. DOE) 2011. *Risk Assessment Information System (RAIS): On-line database*. http://rais.ornl.gov/.

United States Environmental Protection Agency (U.S. EPA) 2005. *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities*. EPA Region 6, Office of Solid Waste, September.

APPENDIX C

DETAILED SAMPLE CALCULATIONS

C.1 EXAMPLE CALCULATION: RADIATION AQUATIC BIOTA – Baseline+Project; Fish

		U-238+	Th-230	Ra-226+	Pb-210+	Po-210	Th-232	Ra-228	Th-228	Subtotals
Water										
Predicted	Bq/m3	5.98	20.09	10.01	10.09	10.09	5.00	30.25	30.00	
Sediment										
Predicted Concentration	Bq/g(dry)	0.093	0.086	0.093	0.348	0.093	0.0415	0.095	0.093	
water fraction of sed	-	0.9								
Concentration	Bq/g(wet)	9.31E-03	8.6E-03	9.3E-03	3.5E-02	9.3E-03	4.2E-03	9.5E-03	9.4E-03	
Fish										
Predicted Conc	Bq/g wet	5.14E-06	2.01E-03	4.00E-05	2.52E-04	3.63E-04	5.00E-04	1.21E-04	3.00E-03	
Absorbed Doses - Fish										
Internal Dose Factor	mGy/d per Bq/g	1.42E-01	6.58E-02	1.59E-01	6.03E-03	7.40E-02	5.64E-02	2.0E-02	7.6E-02	
Internal dose	mGy/d	7.30E-07	1.32E-04	6.37E-06	1.52E-06	2.69E-05	2.82E-05	2.36E-06	2.29E-04	4.3E-04
Ext. dose factor	mGy/d per Bq/g	1.73E-05	1.96E-05	8.77E-05	6.05E-05	9.42E-08	1.70E-05	1.30E-02	4.11E-05	
Ext. dose pelagic	mGy/d	1.04E-10	3.94E-10	8.77E-10	6.11E-10	9.51E-13	8.52E-11	3.92E-07	1.23E-09	4.0E-07
Ext. dose benthic	mGy/d	8.06E-08	8.48E-08	4.09E-07	1.05E-06	4.39E-10	3.54E-08	6.18E-05	1.93E-07	6.4E-05
Total dose - pelagic	mGy/d	7.30E-07	1.32E-04	6.37E-06	1.52E-06	2.69E-05	2.82E-05	2.75E-06	2.29E-04	4.3E-04
Total dose - benthic	mGy/d	8.11E-07	1.32E-04	6.77E-06	2.58E-06	2.69E-05	2.83E-05	6.42E-05	2.30E-04	4.9E-04
Equivalent Doses - Fish										
RBE		10								
Total dose - pelagic	mGy/d	7.30E-06	1.32E-03	6.37E-05	1.52E-06	2.69E-04	2.82E-04	2.40E-05	2.29E-03	4.3E-03
Total dose - benthic	mGy/d	7.38E-06	1.32E-03	6.41E-05	1.52E-06	2.69E-04	2.82E-04	8.54E-05	2.29E-03	4.3E-03

SI = 4.3E-03/0.6 = 7.1E-03

Or

SI = 4.3E-03/10 =4.3E-04

C.2 EXAMPLE CALCULATION: RADIATION TERRESTRIAL BIOTA – Snowshoe Hare, Baseline+Project; RBE 10

		U-238+	Th-230	Ra-226+	Pb-210+	Po-210+	Ra-228	Th-228	Th-232	Subtotals
Absorbed Doses - Snowshoe Hare										
Concentration	Bq/g	2.8E-05	8.4E-06	5.4E-04	2.7E-04	7.3E-07	7.5E-04	1.2E-05	1.2E-05	
Internal Dose Factor	mGy/d per Bq/g	1.4E-01	6.6E-02	1.6E-01	6.0E-03	7.5E-02	2.0E-02	7.6E-02	5.64E-02	
Internal dose rate	mGy/d	3.9E-06	5.5E-07	8.5E-05	1.6E-06	5.5E-08	1.5E-05	9.0E-07	6.6E-07	1.1E-04
External Gamma rate	uGy/h									
Fraction of time on site	-	1								
External dose rate	mGy/d									
Internal plus external	mGy/d	1.1E-04								
Equivalent Doses - Snowshoe Hare										
RBE for alpha		10								
Dose rate	mGy/d	3.9E-05	5.5E-06	8.5E-04	1.6E-06	5.5E-07	1.5E-04	9.0E-06	6.6E-06	1.1E-03
Total dose rate	mSv/d	1.1E-03								

SI = 1.1E-03 / 1 = 1.1E-03

Or

SI = 1.1E-03 / 3 =3.6E-04

C.3 EXAMPLE CALCULATION: HUMAN RADIOLOGICAL EXPOSURE DOSE – First Nations Adult; Inhalation and Ingestion of Water Pathways

Adult			**U-238+**	**Th-230**	**Ra-226+**	**Pb-210+**	**Po-210+**	**Ra-228+**	**Th-228+**	**Th-232+**	**TOTALS**
Inhalation	Air										
	Air conc-baseline	Bq/m3	3.30E-05	3.30E-05	3.30E-05	3.30E-05	3.30E-05	3.60E-05	3.60E-05	3.60E-05	
	Air conc-baseline+project	Bq/m3	3.42E-05	3.42E-05	3.42E-05	3.42E-05	3.42E-05	3.81E-05	3.81E-05	3.81E-05	
	Air conc-project	Bq/m3	1.19E-06	1.19E-06	1.19E-06	1.19E-06	1.19E-06	2.11E-06	2.11E-06	2.11E-06	
	DCF for inhalation	µSv/Bq	17.8	14	9.5	5.6	4.3	16	40	25	
	Dose from inhalation	µSv/yr	2.92E-03	2.30E-03	1.56E-03	9.18E-04	7.05E-04	4.67E-03	1.17E-02	7.30E-03	0.032
	DCF for ingestion	µSv/Bq	0.0995	0.21	0.28	0.69	1.2	0.69	0.072	0.23	
Ingestion	**Water**										
	Water conc-baseline	Bq/L	5.89E-03	2.00E-02	1.00E-02	1.00E-02	1.00E-02	3.00E-02	3.00E-02	5.00E-03	
	Water conc-baseline+project	Bq/L	5.98E-03	2.01E-02	1.00E-02	1.01E-02	1.01E-02	3.03E-02	3.00E-02	5.00E-03	
	Water conc-project	Bq/L	8.98E-05	8.98E-05	8.30E-06	8.98E-05	8.98E-05	2.51E-04	2.35E-06	2.35E-06	
	Dose from ingestion	µSv/yr	1.12E-04	2.36E-04	2.90E-05	7.74E-04	1.35E-03	2.16E-03	2.12E-06	6.77E-06	4.7E-03
Radon			INSIDE	OUTSIDE				CONSTANTS			
	Incremental radon conc in air	Bq/m^3	0.004	0.004				Bq/m3 per WL		3.70E+03	
	Radon/progeny equil fraction	ICRP 65 1993	3.00E-01	5.00E-01				M per h		5.90E-03	
	Fraction of time		5.00E-01	5.00E-01				µSv/WLM		4.00E+03	
	Incremental radon dose	µSv/yr	4.70E-05	1.18E-04				h per yr		8.76E+03	
	Incremental total radon dose	µSv/yr	1.65E-04					F_Loc		0.023	

APPENDIX D

SUMMARY OF RESULTS

D.1 SUMMARY OF COPC CONCENTRATIONS USED IN ASSESSMENT

BASELINE

COPC	Water (mg/L or Bq/L)	Soil (mg/kg dw or Bq/kg)	Sediment (mg/kg dw or Bq/kg dw)	Fish Flesh (mg/kg ww or Bq/kg ww)	Whole Fish (mg/kg or Bq/kg ww)	Berries (mg/kg or Bq/kg ww)	Lichen (mg/kg or Bq/kg ww)	Browse (mg/kg or Bq/kg ww)	Forage (mg/kg or Bq/kg ww)	Aquatic Vegetation (mg/kg or Bq/kg ww)
Uranium	4.77E-04	4.43E+00	7.53E+00	4.10E-04	4.10E-04	2.39E-02	3.46E+01	4.43E-03	2.43E-01	1.10E-01
Lead-210	1.00E-02	3.93E+01	3.48E+02	2.50E-01	2.50E-01	4.59E+00	4.28E+02	1.96E+00	2.06E+01	1.80E+01
Polonium-210	1.00E-02	3.93E+01	9.30E+01	3.60E-01	3.60E-01	1.12E-03	4.28E+02	1.57E+00	1.86E-01	2.00E+01
Radium-226	1.00E-02	3.93E+01	9.30E+01	4.00E-02	4.00E-02	1.53E+00	4.28E+02	2.36E-02	2.55E+01	2.00E+01
Thorium-230	2.00E-02	3.93E+01	7.00E+01	2.00E+00	2.00E+00	2.00E-02	4.28E+02	3.93E-04	1.16E-01	6.00E+01
Uranium-238	5.89E-03	5.46E+01	9.30E+01	5.06E-03	5.06E-03	2.95E-01	4.28E+02	5.46E-02	3.01E+00	1.35E+00
Thorium	1.23E-03	1.32E+01	1.01E+01	1.23E-01	1.23E-01	6.75E-03	1.15E+02	1.32E-04	3.91E-02	3.69E+00
Radium-228	3.00E-02	5.37E+01	9.30E+01	1.20E-01	1.20E-01	2.10E+00	4.67E+02	3.22E-02	3.49E+01	6.00E+01
Thorium-228	3.00E-02	5.37E+01	9.30E+01	3.00E+00	3.00E+00	2.74E-02	4.67E+02	5.37E-04	1.59E-01	9.00E+01
Thorium-232	5.00E-03	5.37E+01	4.10E+01	5.00E-01	5.00E-01	2.74E-02	4.67E+02	5.37E-04	1.59E-01	1.50E+01

BASELINE + PROJECT

COPC	Water (mg/L or Bq/L)	Soil (mg/kg dw or Bq/kg)	Sediment (mg/kg dw or Bq/kg dw)	Fish Flesh (mg/kg ww or Bq/kg ww)	Whole Fish (mg/kg or Bq/kg ww)	Berries (mg/kg or Bq/kg ww)	Lichen (mg/kg or Bq/kg ww)	Browse (mg/kg or Bq/kg ww)	Forage (mg/kg or Bq/kg ww)	Aquatic Vegetation (mg/kg or Bq/kg ww)
Uranium	4.84E-04	4.62E+00	7.53E+00	4.16E-04	4.16E-04	2.49E-02	3.59E+01	4.62E-03	2.54E-01	1.11E-01
Lead-210	1.01E-02	4.16E+01	3.48E+02	2.52E-01	2.52E-01	4.87E+00	4.43E+02	2.08E+00	2.19E+01	1.82E+01
Polonium-210	1.01E-02	4.16E+01	9.30E+01	3.63E-01	3.63E-01	1.19E-03	4.43E+02	1.66E+00	1.98E-01	2.02E+01
Radium-226	1.00E-02	4.16E+01	9.31E+01	4.00E-02	4.00E-02	1.62E+00	4.43E+02	2.50E-02	2.71E+01	2.00E+01
Thorium-230	2.01E-02	4.16E+01	8.62E+01	2.01E+00	2.01E+00	2.12E-02	4.43E+02	4.16E-04	1.23E-01	6.03E+01
Uranium-238	5.98E-03	5.70E+01	9.30E+01	5.14E-03	5.14E-03	3.08E-01	4.43E+02	5.70E-02	3.13E+00	1.38E+00
Thorium	1.23E-03	1.43E+01	1.02E+01	1.23E-01	1.23E-01	7.31E-03	1.22E+02	1.43E-04	4.23E-02	3.70E+00
Radium-228	3.03E-02	5.82E+01	9.49E+01	1.21E-01	1.21E-01	2.27E+00	4.94E+02	3.49E-02	3.78E+01	6.05E+01
Thorium-228	3.00E-02	5.82E+01	9.34E+01	3.00E+00	3.00E+00	2.97E-02	4.94E+02	5.82E-04	1.72E-01	9.00E+01
Thorium-232	5.00E-03	5.82E+01	4.14E+01	5.00E-01	5.00E-01	2.97E-02	4.94E+02	5.82E-04	1.72E-01	1.50E+01

D.2 TOTAL INTAKE FOR TERRESTRIAL RECEPTORS OF COPC

BASELINE

COPC	Snowshoe Hare	Spruce Grouse	Moose	Barren Ground Caribou	Scaup	Mallard	Common Merganser	Black Bear	Wolf	Peregrine Falcon
Bq/kg-d	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**
Lead-210	2.10E+00	7.33E-01	6.31E-02	1.55E+00	1.47E+00	8.14E-01	2.09E-01	2.71E-01	5.13E-03	2.23E-01
Polonium-210	3.79E-01	4.78E-01	4.35E-02	1.54E+00	2.83E+01	1.80E+01	9.28E-02	2.32E-02	5.62E-03	4.21E-01
Radium-226	2.26E+00	2.12E-01	2.75E-02	1.55E+00	7.36E-01	7.39E-01	5.27E-02	2.84E-01	5.72E-03	1.43E-01
Thorium-230	1.71E-01	1.51E-01	6.72E-02	1.54E+00	9.11E+00	6.83E+00	2.87E-01	2.68E-02	4.56E-03	1.33E-01
Uranium-238	4.76E-01	2.30E-01	8.48E-03	1.54E+00	4.75E-01	1.99E-01	4.82E-02	5.59E-02	5.99E-03	2.27E-01
Radium-228	3.09E+00	2.91E-01	6.93E-02	1.70E+00	1.57E+00	2.07E+00	6.33E-02	3.89E-01	1.88E-02	1.97E-01
Thorium-228	2.35E-01	2.07E-01	1.00E-01	1.68E+00	1.36E+01	1.02E+01	4.24E-01	3.78E-02	1.17E-02	1.82E-01
Thorium-232	2.32E-01	2.05E-01	1.84E-02	1.68E+00	2.36E+00	1.73E+00	8.37E-02	2.68E-02	7.00E-03	1.80E-01

BASELINE + PROJECT

COPC	Snowshoe Hare	Spruce Grouse	Moose	Barren Ground Caribou	Scaup	Mallard	Common Merganser	Black bear	Wolf	Peregrine Falcon
Bq/kg-d	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**
Lead-210	2.23E+00	7.77E-01	6.45E-02	1.61E+00	1.47E+00	8.19E-01	2.09E-01	2.86E-01	5.42E-03	2.36E-01
Polonium-210	4.02E-01	5.07E-01	4.47E-02	1.60E+00	2.85E+01	1.82E+01	9.32E-02	2.14E-02	5.91E-03	4.47E-01
Radium-226	2.39E+00	2.25E-01	2.76E-02	1.61E+00	7.37E-01	7.40E-01	5.28E-02	3.00E-01	6.05E-03	1.52E-01
Thorium-230	1.81E-01	1.60E-01	6.86E-02	1.60E+00	9.20E+00	6.87E+00	2.96E-01	2.76E-02	4.70E-03	1.40E-01
Uranium-238	4.97E-01	2.40E-01	8.52E-03	1.60E+00	4.78E-01	2.01E-01	4.83E-02	5.79E-02	6.25E-03	2.36E-01
Radium-228	3.34E+00	3.15E-01	7.00E-02	1.80E+00	1.59E+00	2.09E+00	6.43E-02	4.19E-01	8.74E-03	2.13E-01
Thorium-228	2.54E-01	2.24E-01	1.00E-01	1.78E+00	1.36E+01	1.02E+01	4.25E-01	3.94E-02	6.59E-03	1.96E-01
Thorium-232	2.51E-01	2.22E-01	1.85E-02	1.78E+00	2.36E+00	1.73E+00	8.40E-02	2.85E-02	6.33E-03	1.95E-01

D.3 CONCENTRATIONS OF COPC WITHIN TERRESTRIAL ECOLOGICAL RECEPTORS

BASELINE

COPC	Snowshoe Hare	Spruce Grouse	Moose	Barren Ground Caribou	Mallard	Black Bear	Wolf	Peregrine Falcon	Scaup	Common Merganser
Bq/kg ww	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**	**ThorLake-Baseline**
Lead-210	2.58E-01	4.76E-01	3.52E-02	5.96E-01	6.49E-01	1.08E-01	1.48E-03	1.70E-01	1.09E+00	1.80E-01
Polonium-210	6.90E-04	1.60E+00	2.61E-01	2.08E+00	7.41E+01	3.71E-02	2.42E-03	1.66E+00	1.09E+02	4.13E-01
Radium-226	5.06E-01	8.88E-03	2.81E-02	1.09E+00	3.80E-02	2.08E-01	3.02E-03	7.04E-03	3.53E-02	2.93E-03
Thorium-230	7.90E-03	2.11E-03	1.41E-02	2.23E-01	1.17E-01	4.05E-03	4.95E-04	2.17E-03	1.46E-01	5.31E-03
Uranium-238	2.64E-02	2.41E-01	2.14E-03	2.68E-01	2.56E-01	1.01E-02	7.81E-04	2.78E-01	5.70E-01	6.70E-02
Radium-228	6.93E-01	1.22E-02	7.07E-02	1.19E+00	1.06E-01	2.85E-01	9.90E-03	9.68E-03	7.55E-02	3.51E-03
Thorium-228	1.08E-02	2.89E-03	2.10E-02	2.43E-01	1.75E-01	5.70E-03	1.27E-03	2.97E-03	2.18E-01	7.86E-03
Thorium-232	1.07E-02	2.86E-03	3.87E-03	2.43E-01	2.96E-02	4.05E-03	7.60E-04	2.95E-03	3.77E-02	1.55E-03

BASELINE + PROJECT CONCENTRATIONS

COPC	Snowshoe Hare	Spruce Grouse	Moose	Barren ground caribou	Mallard	Black bear	Wolf	Peregrine Falcon	Scaup	Common Merganse r
Bq/kg ww	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake -Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake -Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake-Baseline+ Project**	**ThorLake Baseline+ Project**
Lead-210	2.74E-01	5.04E-01	3.60E-02	6.18E-01	6.53E-01	1.15E-01	2.46E-03	1.80E-01	1.10E+00	1.80E-01
Polonium-210	7.32E-04	1.70E+00	2.68E-01	2.16E+00	7.48E+01	3.88E-02	7.25E-03	1.76E+00	1.10E+02	4.14E-01
Radium-226	5.36E-01	9.41E-03	2.81E-02	1.13E+00	3.80E-02	2.21E-01	6.21E-03	7.46E-03	3.54E-02	2.93E-03
Thorium-230	8.37E-03	2.24E-03	1.44E-02	2.31E-01	1.18E-01	4.16E-03	6.24E-04	2.30E-03	1.47E-01	5.49E-03
Uranium-238	2.75E-02	2.51E-01	2.15E-03	2.78E-01	2.59E-01	1.05E-02	9.94E-04	2.90E-01	5.73E-01	6.70E-02
Radium-228	7.50E-01	1.32E-02	7.14E-02	1.26E+00	1.07E-01	3.08E-01	7.92E-03	1.05E-02	7.63E-02	3.57E-03
Thorium-228	1.17E-02	3.13E-03	2.10E-02	2.58E-01	1.75E-01	5.92E-03	8.37E-04	3.22E-03	2.18E-01	7.86E-03
Thorium-232	1.16E-02	3.10E-03	3.88E-03	2.57E-01	2.96E-02	4.34E-03	8.28E-04	3.19E-03	3.78E-02	1.55E-03

D.4 SUMMARY OF CALCULATED DOSES TO TERRESTRIAL ECOLOGICAL RECEPTORS

BASELINE

RBE	Total Dose (mGy/d)									
	Snowshoe Hare	Spruce Grouse	Moose	Barren Ground Caribou	Mallard	Black Bear	Wolf	Peregrine Falcon	Scaup	Common Merganser
5	5.0E-04	7.8E-04	1.4E-04	2.2E-03	2.8E-02	2.1E-03	1.7E-03	2.2E-04	5.7E-06	8.3E-04
10	1.0E-03	1.6E-03	2.8E-04	4.4E-03	5.6E-02	4.3E-03	3.3E-03	4.4E-04	1.1E-05	1.7E-03
20	2.0E-03	3.1E-03	5.7E-04	8.8E-03	1.1E-01	8.5E-03	6.7E-03	8.8E-04	2.3E-05	3.3E-03
40	4.0E-03	6.3E-03	1.1E-03	1.7E-02	2.2E-01	1.7E-02	1.3E-02	1.8E-03	4.6E-05	6.6E-03

BASELINE + PROJECT CONCENTRATIONS

RBE	Total Dose (mGy/d)									
	Snowshoe Hare	Spruce Grouse	Moose	Barren ground caribou	Mallard	Black bear	Wolf	Peregrine Falcon	Scaup	Common Merganser
5	5.3E-04	8.3E-04	2.8E-02	2.3E-03	1.5E-04	2.1E-03	1.8E-03	2.3E-04	5.2E-06	8.7E-04
10	1.1E-03	1.7E-03	5.7E-02	4.5E-03	2.9E-04	4.3E-03	3.5E-03	4.6E-04	1.0E-05	1.7E-03
20	2.1E-03	3.3E-03	1.1E-01	9.1E-03	5.8E-04	8.5E-03	7.1E-03	9.2E-04	2.1E-05	3.5E-03
40	4.2E-03	6.6E-03	2.3E-01	1.8E-02	1.2E-03	1.7E-02	1.4E-02	1.8E-03	4.1E-05	7.0E-03

D.6 SUMMARY OF CALCULATED DOSES TO AQUATIC ECOLOGICAL RECEPTORS

BASELINE

RBE	Total Dose (mGy/d)				
	Fish		Aquatic Vegetation		Benthic
	Pelagic	Benthic	Leaf	Root	Invertebrates
5	0.002	0.002	0.09	0.09	0.13
10	0.004	0.004	0.18	0.18	0.26
20	0.009	0.009	0.35	0.35	0.53
40	0.017	0.017	0.71	0.71	1.06

BASELINE + PROJECT CONCENTRATIONS

RBE	Total Dose (mGy/d)				
	Fish		Aquatic Vegetation		Benthic
	Pelagic	Benthic	Leaf	Root	Invertebrates
5	0.002	0.002	0.09	0.09	0.13
10	0.004	0.004	0.18	0.18	0.27
20	0.009	0.009	0.35	0.36	0.53
40	0.017	0.017	0.71	0.71	1.06