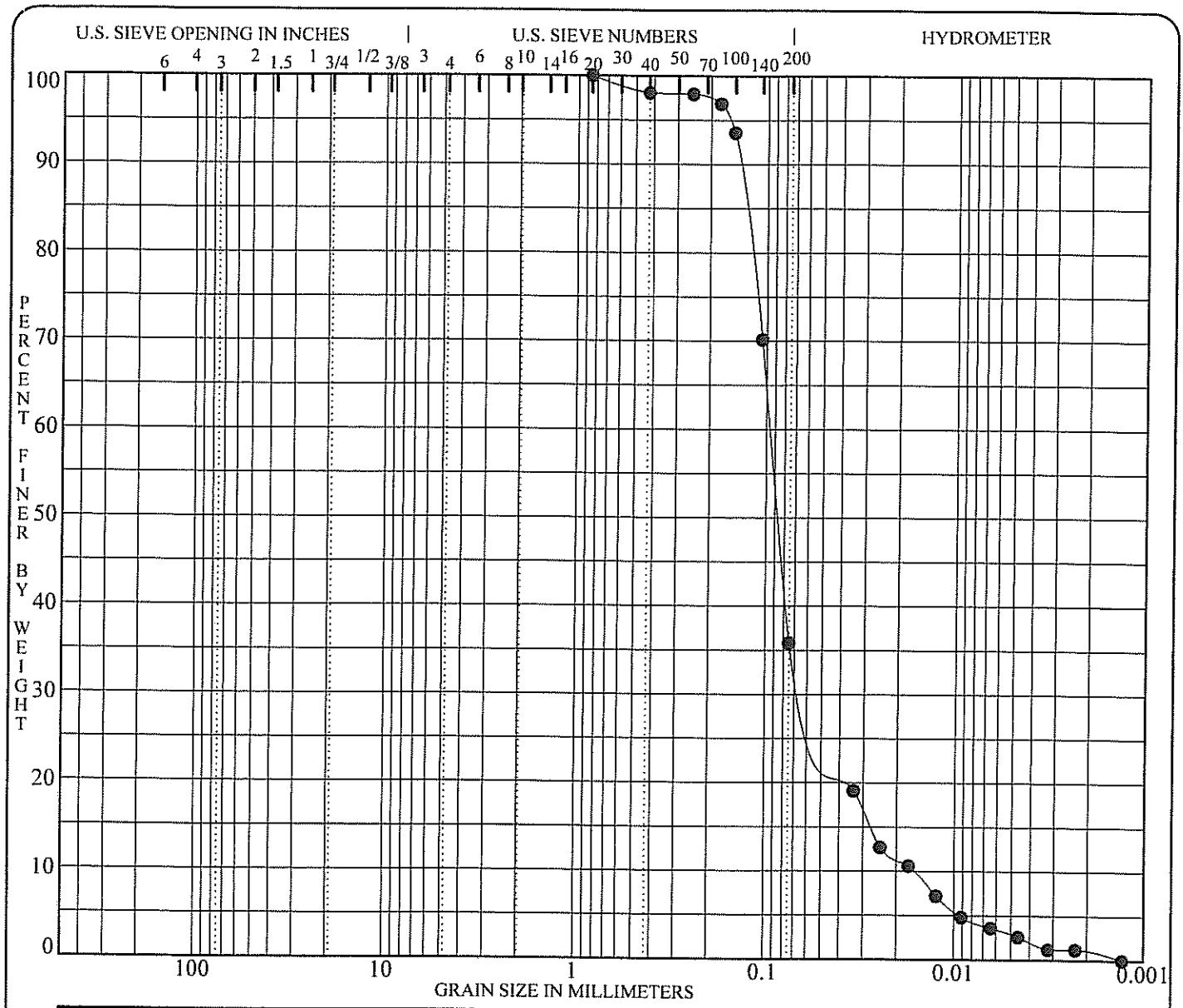
Appendix A

Gradation and Specific Gravity Measurements for Representative Tailings



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
●	**Semi-Massive**	**SILTY SAND (SM)**					**2.06**	**5.9**
⊠	LAB ID: **SH2533**	**Specific Gravity = 2.78**						
▲								
★								
⊙								

	Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**Semi-Massive**	**0.85**	**0.10**	**0.057**	**0.0163**	**0.0**	**64.2**	**33.0**	**2.9**
⊠									
▲									
★									
⊙									

CLIENT : **Foth & Van Dyke**
PROJECT: **2007 Lab Testing**

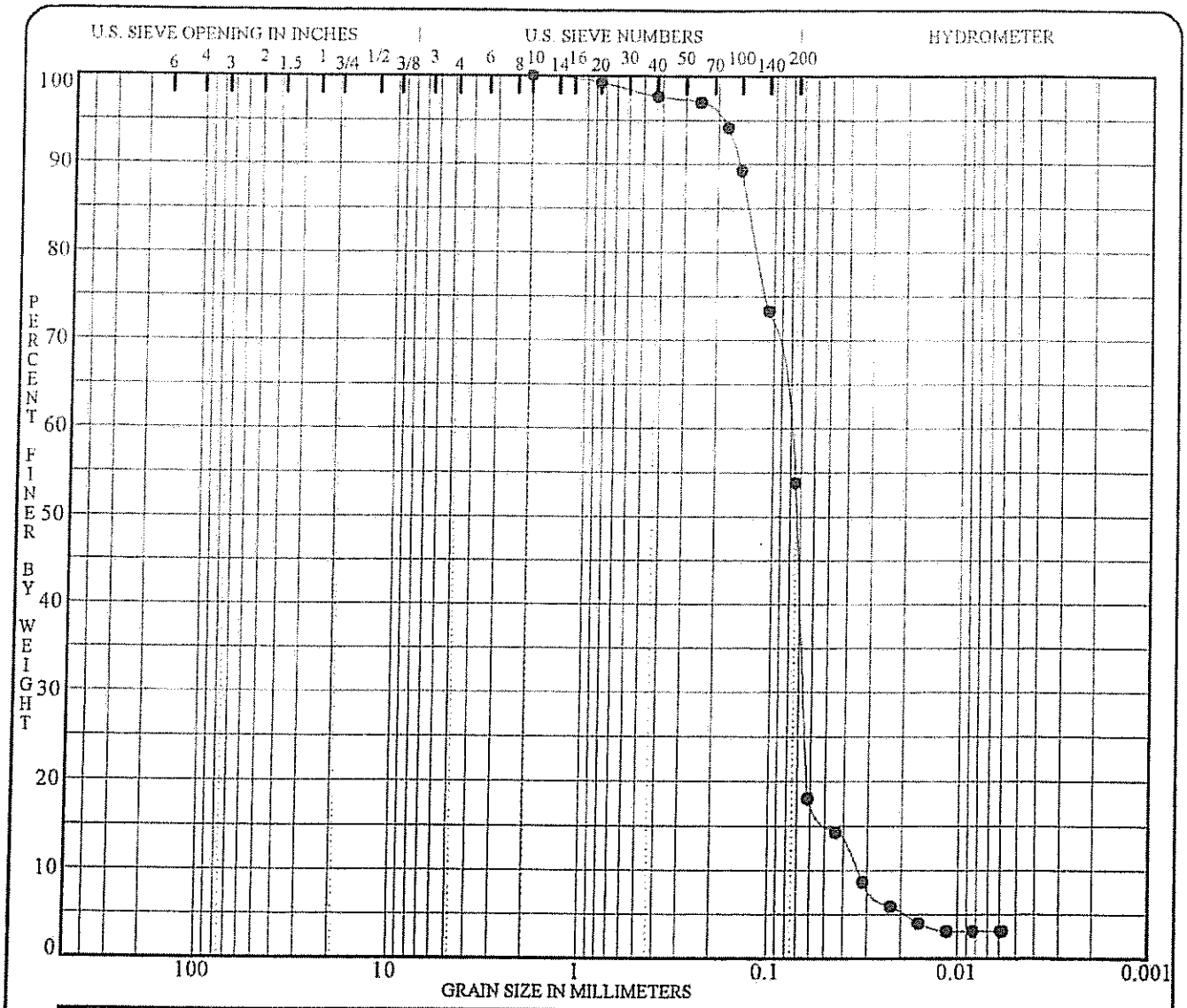
JOB NO.: **07-1-17422**
TEST DATE: **7/2/07**

MILLER
ENGINEERS
SCIENTISTS

GRAIN SIZE ANALYSIS
ASTM D422

SOURCE: **KEMC**
SAMPLED BY: **F&VD**
TESTED BY: **SCJ**
REVIEWED BY: **RGM**

GRAFSIEV GINT 2007.GPJ MLLR_ENG.GDT 7/2/07 11:03



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
●	11237-001	Non-Plastic SILT with fine sand, 5Y2.5/1					1.51	2.4
⧗	LAB ID: SH2497	Specific Gravity = 3.27						
▲								
★								
⊙								

	Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	11237-001	2.00	0.08	0.066	0.0342	0.0	46.2		
⧗									
▲									
★									
⊙									

CLIENT : Foth & Van Dyke
PROJECT: 2007 Lab Testing

JOB NO.: 07-1-17422
TEST DATE: 2/1/07
SOURCE: KEMC/Humboldt
SAMPLED BY: F&VD
TESTED BY: SLH
REVIEWED BY: RGM

MILLER
ENGINEERS
SCIENTISTS

GRAIN SIZE ANALYSIS
ASTM D422

GRAFSIEV GINT 2007.GPJ MILLR ENG.GDT 2/1/07 14:36

Appendix B

Cyanamid Report

CYANAMID

Cyanamid Canada Inc.
2255 Sheppard Avenue East
Willowdale, Ontario M2J 4Y5
Telephone: (416) 498-9405
Telex: 06-966602

March 3, 1986

Callahan Mining Corporation
Ropes Unit
Rte. #1, Box 300
Champion, Michigan
U.S.A. 49814

Attention: Mr. Nelson King, Mill Supt.

Dear Nelson:

Enclosed is our report on the microscopical work done on your flotation concentrates.

Examination of the transparent gangue minerals on both concentrates received, identified tale and dolomite as the major gangue minerals present. Both were present in each concentrate sample. The amount of dilution caused by the different proportions of the transparent gangue in the two concentrates, is shown to be greater for the November 17th concentrate vs. the December 8th concentrate. Otherwise, no difference in mineralogy could be seen between the two concentrates.

Metallic gold and metallic silver was found "free", locked with pyrite, and present as a gold/silver alloy. Also identified were two nickel minerals bravoite and millerite. Copper and lead values were present as chalcopyrite and galena respectively with trace amounts of metallic copper also identified.

The report is fairly self-explanatory but I will be in touch with you next week to discuss it.

Yours very truly,

CYANAMID CANADA INC.

for: Pauline Gross

J. O. Burton
National Accounts Manager
Mining Products

Enc.

CM6/2019c

TECHNICAL SERVICE REPORT

Microscopical Examination of Concentrate Samples from Callahan Mining Corporation

PROJECT NO. 2551

FEBRUARY 1986

CYANAMID

American Cyanamid Company
Cyanamid International Divisions
Mining Chemicals
Wayne, NJ 07470

CYANAMID

American Cyanamid Company

TECHNICAL SERVICE REPORT

Microscopical Examination of Concentrate Samples from Callahan Mining Corporation

PROJECT NO. 2551

INTRODUCTION-

In a letter dated December 17, 1985, Mr. Nelson D. King, Callahan Mining Corporation, requested a microscopical examination be conducted on two concentrate samples labeled November 17 and December 8.. Callahan Mining experienced poor recovery due to what they believed to be excessive amounts of talc present in the ore being processed during the period from which the November 17 composite sample was taken. A microscopical examination was conducted in Cyanamid's Stamford Research Laboratory to identify what minerals are present and determine the difference in mineral content of the two composite samples submitted.

IMPORTANT NOTICE: The information and statements herein are believed to be reliable but are not to be construed as a warranty or representation for which we assume legal responsibility. Users should undertake sufficient verification and testing to determine the suitability for their own particular purpose of any information or products referred to herein. NO WARRANTY OF FITNESS FOR A PARTICULAR PURPOSE IS MADE.

Nothing herein is to be taken as permission, inducement or recommendation to practice any patented invention without a license.

SUMMARY AND CONCLUSIONS

Microscopical examination of the November 17 Concentrate and December 8 Concentrate Samples identified talc and dolomite as the principal transparent gangue minerals in both samples. Traces of quartz, chlorite, and pyrite (mostly locked with talc) were also identified in the November 17 Concentrate. In the December 8 Concentrate, trace amounts of phlogopite, quartz and pyrite (mostly locked with talc) were also identified. With talc and dolomite the abundant transparent gangue minerals in both samples, the only difference evident is the proportion of these gangue minerals in each sample shown by the specific gravity test results.

Microscopical examination identified the heavy opaque minerals in each sample to be pyrite, chalcopyrite, galena, millerite, bravoite, metallic gold, metallic silver, and trace amounts of metallic copper. Both metallic gold and metallic silver were found as "free" particles, and locked with pyrite. Electron microprobe work showed the metallic silver to be gold bearing and the metallic gold to be silver bearing. Gold and silver occurring as an alloy was also identified. The only major difference seen in the November 17 and December 8 samples was the actual proportion of transparent gangue. Confirmation of this difference may be seen through examination of the feed and tail samples from these two time periods.

Characterization and Description of Pyrite and Iron Concentrates from the Ropes Mill Site

The Ropes Mill was operated by Callahan Mining Corp. between 1985 and 1990 to process gold ore from the Ropes Mine. Prior to Callahan's occupation of the site, the Humbolt Mining Company processed iron ore in the mill facility.

Description of Pyrite Flotation Concentrates

Gold ore processing by Callahan involved on site crushing and grinding of crude ore to -80 mesh, and the subsequent flotation and selective removal of pyrite, other sulfides, and gold and silver in a flotation concentrate. The crude ore consisted of 5 to 10% sulfides and associated precious metals in a gangue of quartz, chlorite and sericite, with varying amounts of carbonate (calcite and ferroan dolomite), talc, and other silicates. This gangue material was separated from the sulfide fraction during flotation, and the non sulfide fraction (tailings) were pumped into the Humbolt Pit for disposal.

The flotation concentrate was then re-ground to 80% -325 mesh and leached of its precious metals in a dilute cyanide solution. Petrographic examination of the flotation concentrate shows it to be composed of approximately 50% sulfides and 50% of the above gangue impurities. The sulfide fraction is composed of approximately 90% pyrite with the other 10% composed of chalcopyrite, pyrrhotite, galena, millerite, bravoite, metallic silver, metallic gold, metallic copper, and rare sphalerite, tetrahedrite, and the oxides hematite and magnetite. A list of these minerals and their composition as well as the petrographic reports characterizing them are presented in Appendix 1.

Cyanide leaching of this flotation concentrate selectively removed the gold and silver from the concentrate, leaving the remainder as a leach residue-essentially the same material with 80 to 90% of the gold and silver removed. This leach residue was washed, filtered and stockpiled on the stockpile area south of the mill buildings. According to Callahan records, approximately 75,000 tons of this material was stockpiled on the site between October 1985 and March 1990 (Callahan Draft Report 1995). The attached photographs illustrate the piles of leach residue, or flotation concentrate in this area.

Trace element analyses and iron and sulfur analyses of this concentrate or residue are presented in Appendix 1 (samples 3098A and 3098B). Iron and sulfur values represent the pyrite content of the material, which amounts to 47% and 41% pyrite for the two samples. Trace element analyses reflect the presence of the above sulfide suite.

Large volumes of the leach residue material were eventually refloated to upgrade the pyrite content to levels which enabled it to be sold to the White Pine smelter as an additive for their smelting process. This upgraded material was also stockpiled on the stockpile area prior to shipment to White Pine. According to Callahan, some 30,000 tons of this material were stockpiled on the site before shipment to White Pine. Appendix 1 shows the composition of this pyrite product (Sample 3098C). Five to ten tons of this

refloated material remain on the site as a tarped pile on the west landing area, and as spillage in the loadout tower area.

A substantial tonnage of the leach residue was not refloated and sold to White Pine. This material was eventually buried along side of the access road on the west landing area in a trench excavated to provide fill to cover the residual pyrite concentrates on the stockpile area. The extent of this buried pyrite was defined by auger drilling as a part of this BEA. The results of this drilling program and the extent of buried pyrite are shown in Appendix 2. Calculations based upon these data provide an estimate of 12,000 to 14,000 tons of leach residue pyrite buried here. This estimate is consistent with the size of trench excavation, and verbal recollection of Callahan employees engaged in the burial operation. The bulk density used to compute the buried tonnage (3.6 g/cm.^{3}) was obtained from Callahan mill records.

Additional tonnage's of both leach residue concentrate and refloated pyrite concentrate remain on the original stockpile area where these materials were originally stored, and subsequently covered with fill from the previously mentioned trench area. To quantify this material, 35 pits were excavated in the stockpile area, and the thickness of the pyrite layer measured. Calculations made from these measurements suggest approximately 28,200 ft.^{3}, or 3200 tons of pyrite concentrates remain in this area. This tonnage is covered with approximately 1to 2 ft. of fill in the western portion of the stockpile area, but is exposed on the surface in the eastern part of the area.

Effects of Pyrite Concentrates on Ground and Surface Waters

Studies of surface water in contact with, or derived from these pyrite concentrates (this report), suggest that these materials are capable of producing low pH waters with elevated concentrations of iron, manganese, chrome, nickel, cadmium, copper and zinc. Although present exposure of surface waters to these concentrates is limited mainly to the eastern portion of the stockpile area, elevated metal concentrations due to this exposure have been documented (this report). It is likely that past exposure to much larger volumes of concentrates stored on the stockpile area between 1985 and 1990, may have produced substantially larger impact to surface and ground water.

While elevated metal levels in surface water are related to proximity to the stockpile area, elevated metal concentrations in ground water at the site are limited to a few shallow wells north of the stockpile area (this report). The ground water in these wells appears to be a perched condition with little or no communication with deeper aquifers. Monitor well MW-105 located down gradient of the buried pyrite also shows no significant metal concentrations, indicating little or no metal dispersion from this source.

Description of the Iron Ore Concentrate

Humbolt Mining Company's processing involved flotation of finely ground iron ore, and the production of an iron rich concentrate, which was pelletized in the adjacent pellet plant.
Iron ore flotation concentrate produced by Humbolt Mining consisted of mainly hematite and lessor magnetite, and gangue silicates. Similar to the pyrite concentrates produced by Callahan, substantial quantities of this material were also stored on the stockpile area later used by Callahan. Pellets of iron ore concentrate with lime and a clay binder were also stockpiled on the east end of the stockpile area prior to shipment off the site. Remnants of both the concentrate and the pellets are evident on the stockpile area and were exposed in pits excavated to characterize the stockpile area. A review of the pit logs shows substantial amounts of concentrate remaining in the western portion of the stockpile area.

Additionally, large piles of concentrate and iron rich slag from the pelletizing operations are present to the west and south of the stockpile area, on adjacent CCI property. Appendix 3 shows a chemical analyses of iron ore concentrate (Sample # 3120) from a pit in the stockpile area, and the chemical composition of the main constituents of this material. In addition to iron, manganese, sulfur, copper, chromium, and zinc are present in amounts > .002%.

Effects of Iron Ore Concentrates on Surface and Ground Water

Iron and manganese concentrations are high in ground and surface water on and around the mill site (this report). These high background concentrations are likely due to large volumes of iron rich bedrock associated with the iron ore deposits in the area, as well as to the large scale processing of iron ore, and the creation of the products mentioned above, as well as large piles of iron rich waste rock, and large areas of iron rich tailings impoundment.

The highest concentrations of iron and manganese in surface and ground water appear to be related to other high metal values derived from pyrite concentrates in the stockpile area. However, the source of the iron and manganese is probably iron ore concentrates and other iron rich surface materials which have come in contact with acidic water generated from the pyrite, and not the pyrite itself. Similar to the other metals mentioned above, the highest iron and manganese values in surface water appear to be related to proximity to the stockpile area, and in ground water appear to be confined mainly to the shallow aquifer mentioned above.

Appendix I

Py Conc Analyses — Trace Metals
Fe & S

Iron ore Conc. — Fe + S
+ Trace (reported in %)

Petrographic Reports (2)

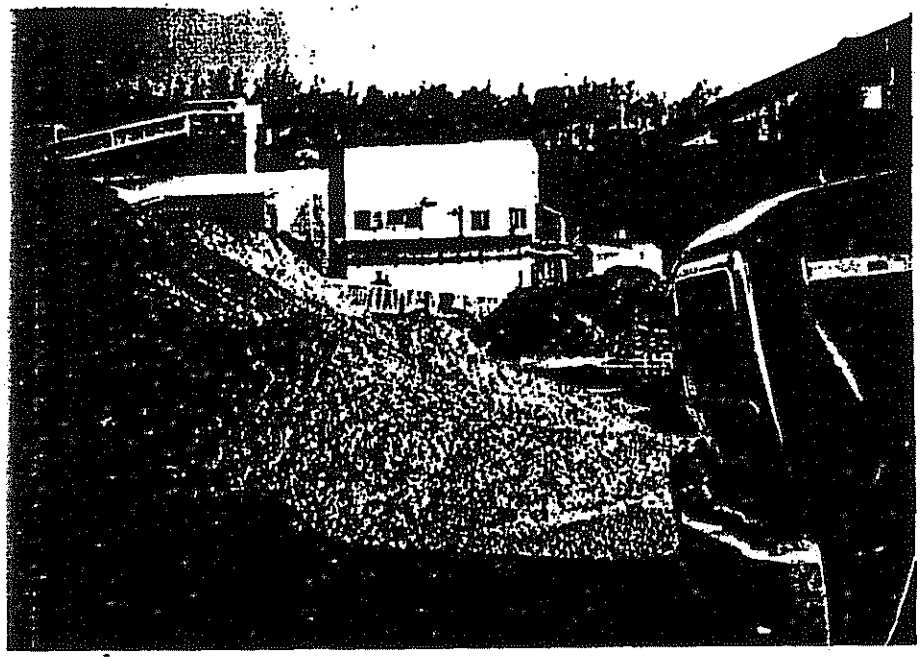
A list of minerals and compositions from gangue and flotation concentrates.

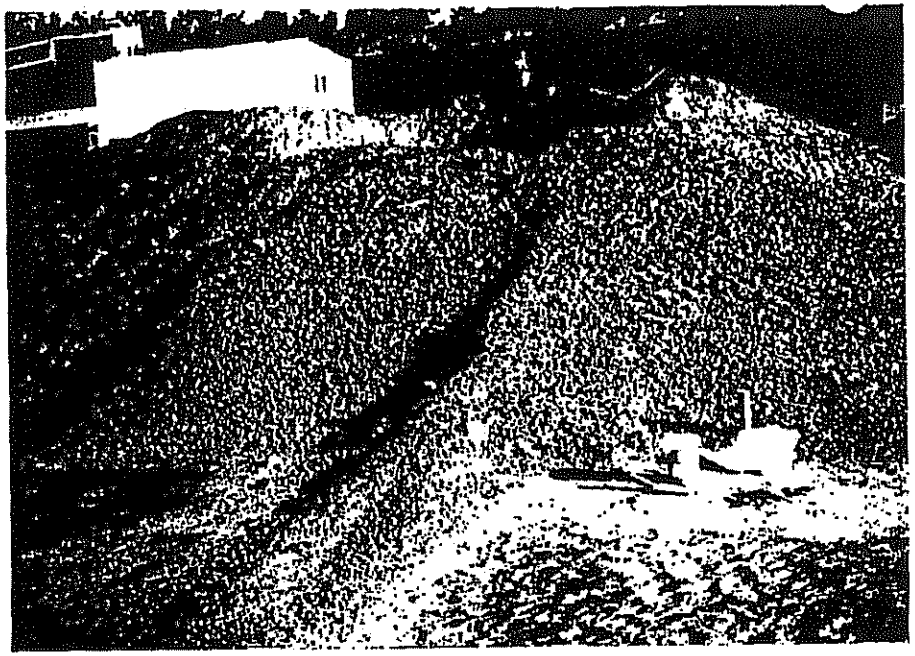
Major Gangue Constituents

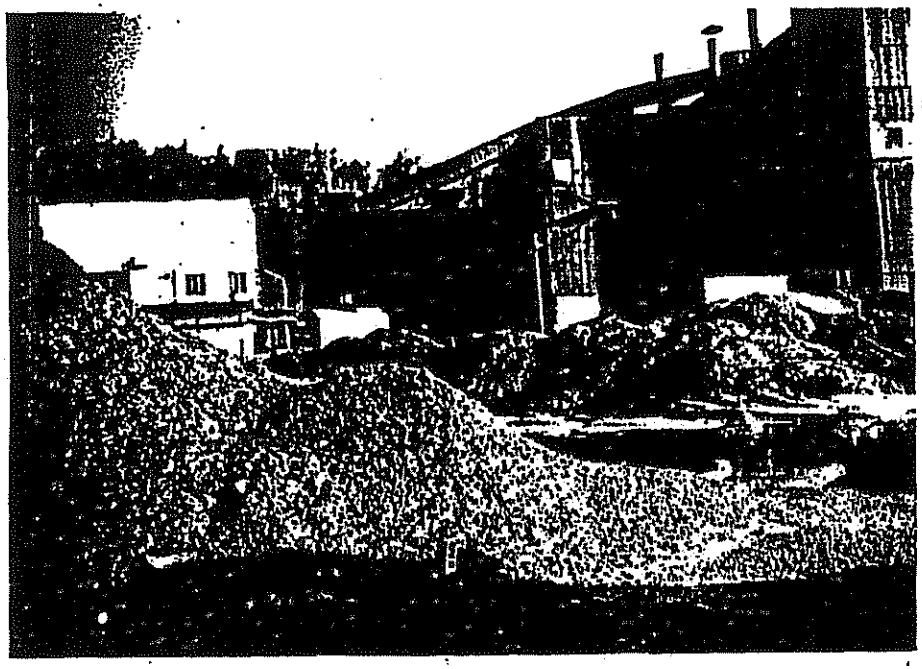
Quartz	SiO_2
Muscovite (sericite)	$KAl_2(AlSi_3O_{10})(OH)_6$
Carbonates	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Talc	$Mg_3Si_4O_{10}(OH)_2$

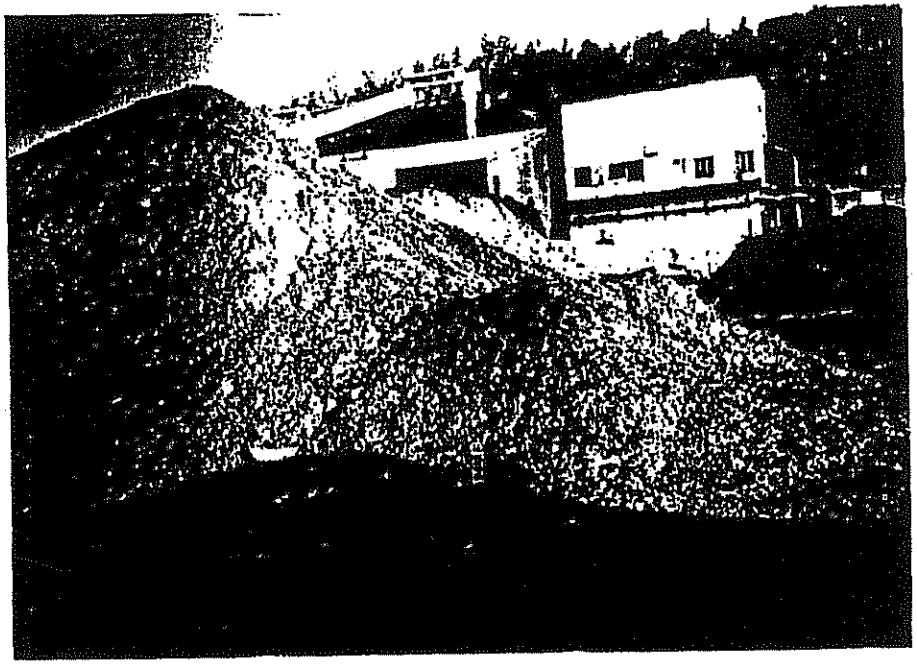
Major Flotation Concentrate Constituents

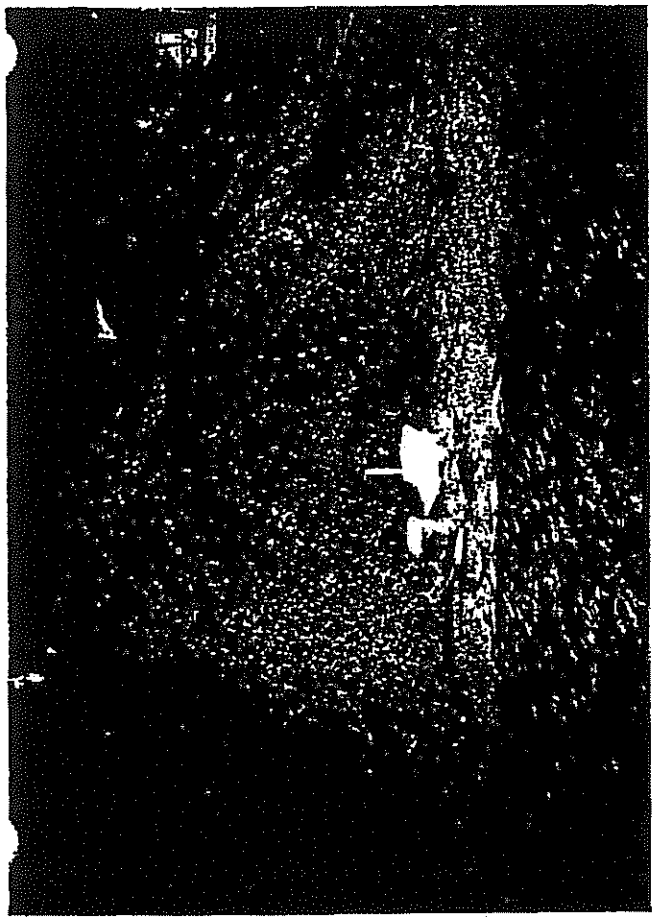
Pyrite	FeS_2
Chalcopyrite	$CuFeS_2$
Pyrrhotite	FeS
Galena	PbS
Millerite	NiS
Bravoite	$(Ni,Fe)S_2$
Sphalerite	ZnS
Metallic Silver	Ag
Metallic Gold	Au
Metallic Copper	Cu
Tetrahedrite	$Cu_{12}Sb_4S_{13}$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4

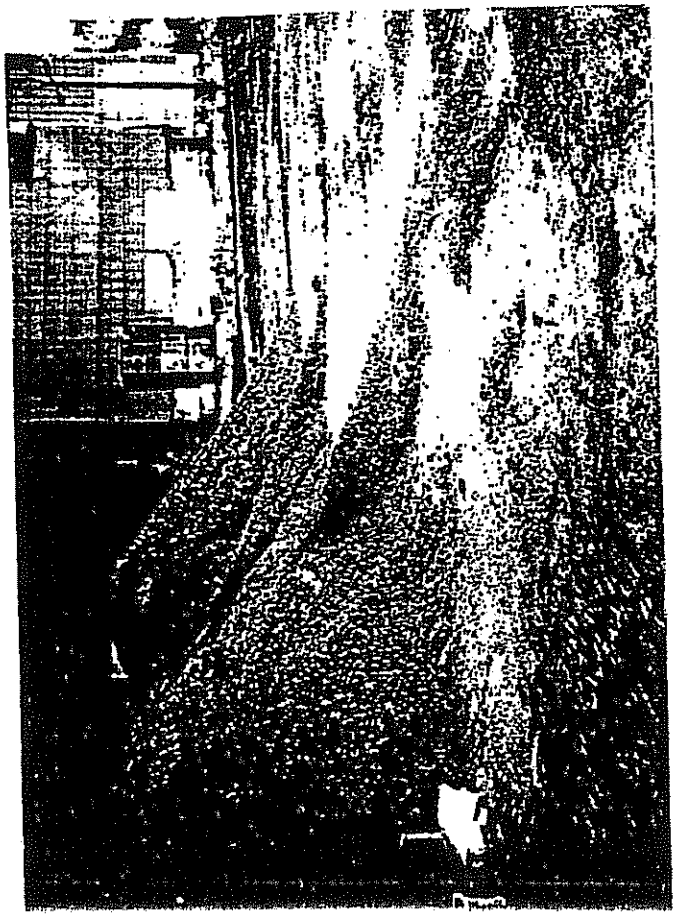












ACTLAB, Inc.
11485 I-70 Frontage Road North
Wheat Ridge, CO 80033
(303) 456-2981

CERTIFICATE OF ANALYSIS

Results and Invoice to:
BPI, INC.
612 SO. TRENTON AVENUE
PITTSBURGH PA 15221

CERTIFICATE	BPI2126
DATE	December 14, 1995
P.O. /REFERENCE #	3098

Sample ID:	AU	AG	AS	BA	BR	CA	CO	CR	CS	FE	HF	HG
Units	PPB	PPM	PPM	PPM	PPM	%	PPM	PPM	PPM	%	PPM	PPM
3098A	4780	26	520	100	<0.5	<1	280	1100	<1	27	3	<1
3098B	4500	29	430	<50	<0.5	<1	280	1100	<1	26.7	4	<1
3098C	6620	58	340	<50	<0.5	<1	450	490	<1	34.6	<1	<1
2504	18	<5	12	<50	<0.5	<1	140	360	<1	34.8	<1	<1

Sample ID:	IR	MO	NA	NI	RB	SB	SC	SE	SN	SR	TA	TH
Units	PPB	PPM	%	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM
3098A	<5	260	0.07	1000	<15	230	3.9	6	<100	<500	<0.5	6.2
3098B	<5	230	0.03	1500	<15	230	4.2	<3	<100	<500	<0.5	5.9
3098C	<5	180	0.02	1700	<15	290	1.3	4	<100	<500	<0.5	3.3
2504	<5	8	<0.01	<27	<15	2.4	1.5	47	<100	<500	<0.5	0.8

Sample ID:	U	W	ZN	LA	CE	ND	SM	EU	TB	YB	LU	Mass
Units	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	g
3098A	<0.5	16	130	18	46	<5	2.2	0.6	<0.5	1	0.2	8.787
3098B	2.7	15	200	17	36	8	2.1	0.6	<0.5	1.3	0.17	9.305
3098C	<0.5	12	160	12	24	<5	1.4	0.4	<0.5	0.7	0.09	10.86
2504	<0.5	<1	510	1.7	<3	<5	0.2	<0.2	<0.5	<0.2	<0.05	19

Sample ID:	MO	CU	PB	ZN	AG	NI	MN	SR	CD	BI	V	CA
Units	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	PPM	%
3098A	243	632	596	72	28.5	871	160	13	0.5	8	25	0.15
3098B	205	878	537	169	31.4	1022	330	16	1.1	8	24	0.78
3098C	170	1488	575	132	66.6	1182	40	4	2.6	<5	8	0.16
2504	6	485	58	528	0.6	87	26	2	0.9	<5	8	0.01

Sample ID:	P	MG	TI	AL	K	Y	BE
Units	%	%	%	%	%	PPM	PPM
3098A	0.028	3.99	0.04	1.56	0.52	5	<2
3098B	0.022	4.07	0.04	1.55	0.47	6	<2
3098C	0.005	1.94	0.02	0.41	0.16	4	<2
2504	0.002	0.25	0.01	0.08	0.01	2	<2

Allan Carlson
Technical Director

GOULD ENERGY DIVISION
P.O. BOX 214
CRESSON, PA 16630
STANDARD LABORATORIES, INC.

DATE: 11-30-95
SAMPLE NO. 340615

BY-PRODUCTS INDUSTRIES, INC.
612 SOUTH TRENTON AVENUE
PITTSBURGH, PA 15221

SAMPLE ID: 3098-A PYRITE

'PERATING CO.:
AMPLED BY: CUSTOMER PROVIDED
INE:
.OCATION:

ATE SAMPLED:
EATHER:
ROSS WEIGHT:

DATE RECEIVED: 11/8/95

'THER ID:

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	.20%	XXX
SULFUR	D3177 METHOD A	26.81%	26.86%
ORMS OF SULFUR	D2492		
PYRITIC SULFUR		25.29%	25.35%
.FATE SULFUR		.62%	.62%
;ANIC SULFUR		.89%	.90%

PARTIAL
ASH MINERAL COMPOSITION
D2795 D3682

FERRIC OXIDE 45.39 %

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BLACK SEAL ANALYSIS

GOULD ENERGY DIVISION
P. O. BOX 214
CRESSON, PA 16630
STANDARD LABORATORIES, INC.

DATE: 11-21-95
SAMPLE NO. 340616

BY-PRODUCTS INDUSTRIES, INC.
612 SOUTH TRENTON AVENUE
PITTSBURGH, PA 15221

SAMPLE ID: 3098-B PYRITE

PERATING CO.:
AMPLED BY: CUSTOMER PROVIDED
INE:
OCATION:

ATE SAMPLED:
EATHER:
ROSS WEIGHT:

THER ID:

DATE RECEIVED: 11/8/95

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	.42%	XXX
SULFUR	D3177 METHOD A	22.61%	22.70%
ORMS OF SULFUR	D2492		
PYRITIC SULFUR		21.62%	21.71%
SULFATE SULFUR		.95%	.95%
ANIC SULFUR		.04%	.04%

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PAGE 1 OF 1
42

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GOULD ENERGY DIVISION
P.O. BOX 214
CRESSON, PA 16630
STANDARD LABORATORIES, INC.

DATE: 12-12-95
SAMPLE NO. 340617

BY-PRODUCTS INDUSTRIES, INC.
612 SOUTH TRENTON AVENUE
PITTSBURGH, PA 15221

SAMPLE ID: 3098-C PYRITE

OPERATING CO.:
SAMPLED BY: CUSTOMER PROVIDED
MINE:
LOCATION:

DATE SAMPLED:
WEATHER:
GROSS WEIGHT:

DATE RECEIVED: 11/8/95

OTHER ID:

CERTIFICATE OF ANALYSIS

	ASTM METHOD	AS RECEIVED	DRY BASIS
MOISTURE	D2961 D3302 D3173	.13%	XXX
SULFUR	D3177 METHOD A	41.77%	41.82%
FORMS OF SULFUR	D2492		
PYRITIC SULFUR		41.80%	41.85%
SULFATE SULFUR		.55%	.55%
ORGANIC SULFUR		-.58%	-.58%

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BLACK SEAL ANALYSIS

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UEC
USX Engineers & Consultants, Inc.
Analytical Chemistry Laboratory
4000 Tech Center Drive
Monroeville, PA 15146
(412) 825-2400

FOR: Ms. Erin Larkin
DIVISION: BPI, Inc.
SAMPLE NO: AL96-0005
P.O. NO:
DATE: January 10, 1996

3120 Iron Francium	
Element	%
Fe	61.64
S	.069
Cu	0.011
Ni	<.002
Cr	0.004
Mn	0.037
As	<0.002
Ba	<0.002
Zn	0.014
Pb	0.025
Cd	<0.002

Approved By: K. Ouchgoski *Date:* 1/10/96

① Nelson
② Dale
③ Mineralogy File:

RUSSELL M. HONEA
Consulting Geologist

AC 303 466-9779

Office
1105 BELLAIRE
BROOMFIELD, COLORADO 80020

Mailing Address
P.O. BOX 323
BROOMFIELD, COLORADO 80020

March 5, 1986

Nelson D. King
Callahan Mining Corporation
Route No. 1, Box 300
Champion, Michigan 49814

Re: Mineralogy of 2/5/86
Mill Samples

Dear Nelson:

Enclosed are results of polished section examination and X-ray powder diffraction analysis of samples forwarded under your cover letter of February 17, 1986. Photomicrographs are included of polished sections to illustrate some of the pertinent mineralogic and textural characteristics. Sorry for the delay in getting the report in the mail - had to make a short out-of-town trip.

It appears to me that liberation of the sulfide minerals is quite good. Gold is extremely fine grained (average maximum diameter of particles is 8 microns), is rather well liberated considering grain size, but was seen in a few small grains locked in the dominant pyrite or in gangue quartz. Next to pyrite, chalcopyrite is the second most common sulfide - but still makes up less than one percent of the total flot concentrate. Chalcopyrite at times contains intergrown tetrahedrite (silver-bearing), and is at times enclosed by sphalerite. Galena is also present in small amount - and is silver-bearing. Pyrrhotite occurs in trace amount as microscopic inclusions in the abundant pyrite. Other opaque minerals included the oxides hematite, magnetite, and rutile. Rare trash iron particles have been added by the grinding process.

The non-metallic portion of the flot concentrate makes up slightly over 50% of the sample, and consists of talc and minor quartz. Bulk components of the host rock include major quartz and chlorite along with lesser amounts of talc, muscovite (sericite), hornblende, and dolomite.

Please let me know if there are questions regarding the data. Was a pleasure doing the work for you.

Sincerely,

Russell M. Honea

Encl.

X-RAY POWDER DIFFRACTION ANALYSIS OF

SELECTED ROPES MILL SAMPLES

Sample 2/5/86 Mill Feed *

Major - Quartz
Chlorite
Minor - Talc
Muscovite (Sericite)
Hornblende
Dolomite
Pyrite

Sample 2/5/86 Flot Con

Major - Talc
Pyrite
Minor - Quartz

*Note: Includes only those mineral phases present in the content level range of above three percent by volume.

A list of minerals and compositions from gangue and flotation concentrates.

Major Gangue Constituents	
Quartz	SiO_2
Muscovite (sericite)	$KAl_2(AlSi_3O_{10})(OH)_6$
Carbonates	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Talc	$Mg_3Si_4O_{10}(OH)_2$

Major Flotation Concentrate Constituents	
Pyrite	FeS_2
Chalcopyrite	$CuFeS_2$
Pyrrhotite	FeS
Galena	PbS
Millerite	NiS
Bravoite	$(Ni,Fe)S_2$
Sphalerite	ZnS
Metallic Silver	Ag
Metallic Gold	Au
Metallic Copper	Cu
Tetrahedrite	$Cu_{12}Sb_4S_{13}$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4

Appendix C

Montgomery Watson, Memoranda
(As obtained from MDEQ through FOIA)

Montgomery Watson, January 20, 1993 Memorandum: Humboldt Mill Tailing Pond Sediments Characterization and Evaluation of Metal Leachate Potential

MEMORANDUM

MONTGOMERY WATSON

To:	Rick Morh, Callahan Mining	**Date:**	April 2, 1993
	Ed Cryer, MW-Boise	**Reference:**	1389.0170
From:	Gil Crozes		
Subject:	Addendum to Memorandum		
	Dated Jan. 20, 1993		

Humboldt Mill Tailing Pond Sediments Characterization and Evaluation of Metal Leachate Potential

INTRODUCTION

This addendum memorandum presents additional data for Humboldt Pit sediments characterization. As requested by the Michigan Department of Natural Resources, a total assay of metals was performed on sediment samples collected as described in a previous memorandum dated January 20, 1993. In comparison to previous experiments, which evaluated metals leachability from sediments under various pH and dissolved oxygen conditions, the analytical procedure used in the present tests consisted of a complete digestion of the sediment sample by nitric acid, followed by metals concentration analyses. The final results are expressed in milligrams of a given metal per kilogram of raw sediment.

RESULTS AND DISCUSSION

All metals listed in Table 1 were analyzed using the atomic adsorption technique. However, the analysis for Cd, Hg, Se, and Ag indicated that the level of these metals was very low in the tailings sediments. Data for low level metals are reported in Table 3.

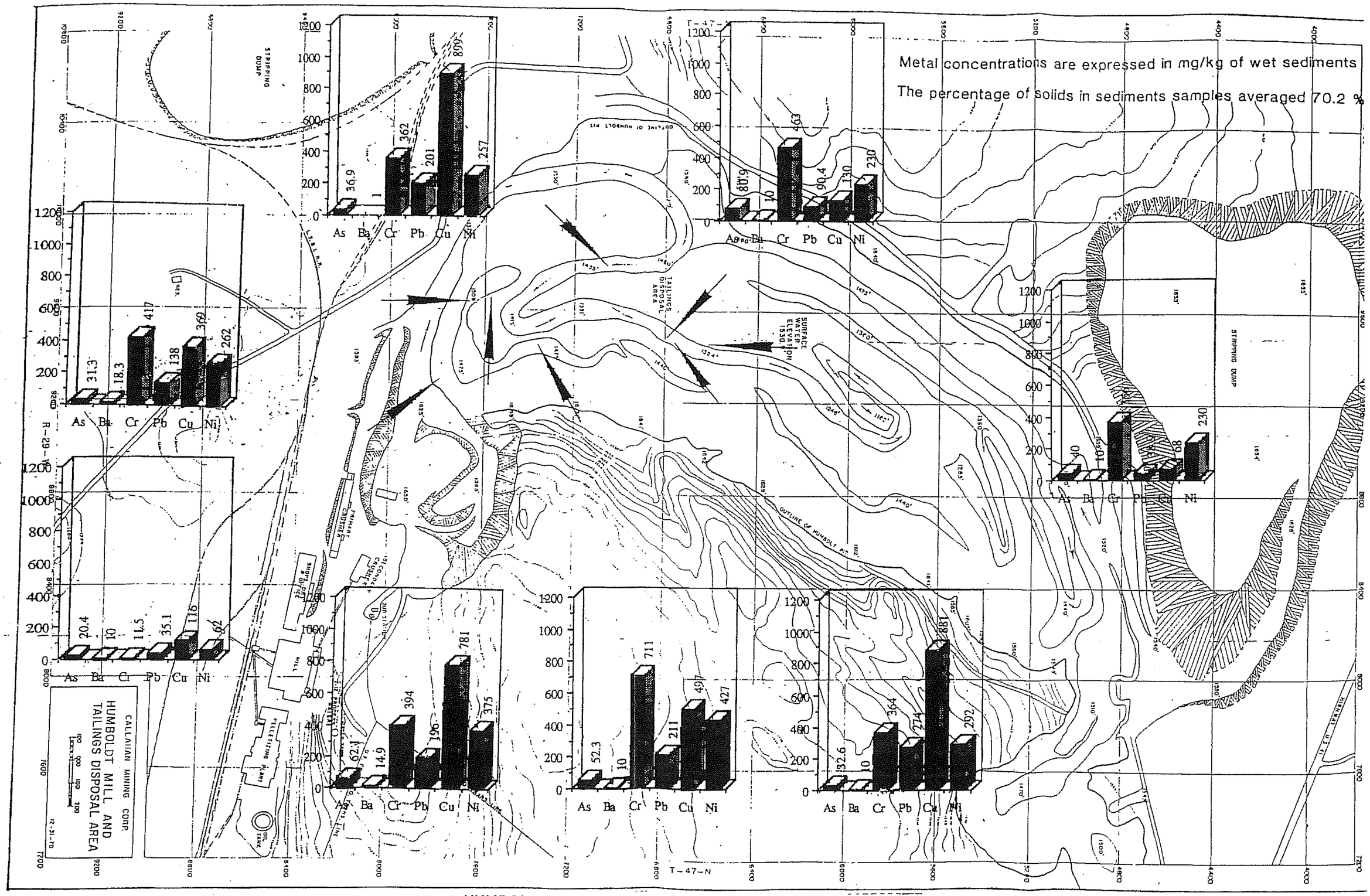
TABLE 3

LOW LEVEL METALS TOTAL ASSAY
IN HUMBOLDT PIT SEDIMENTS

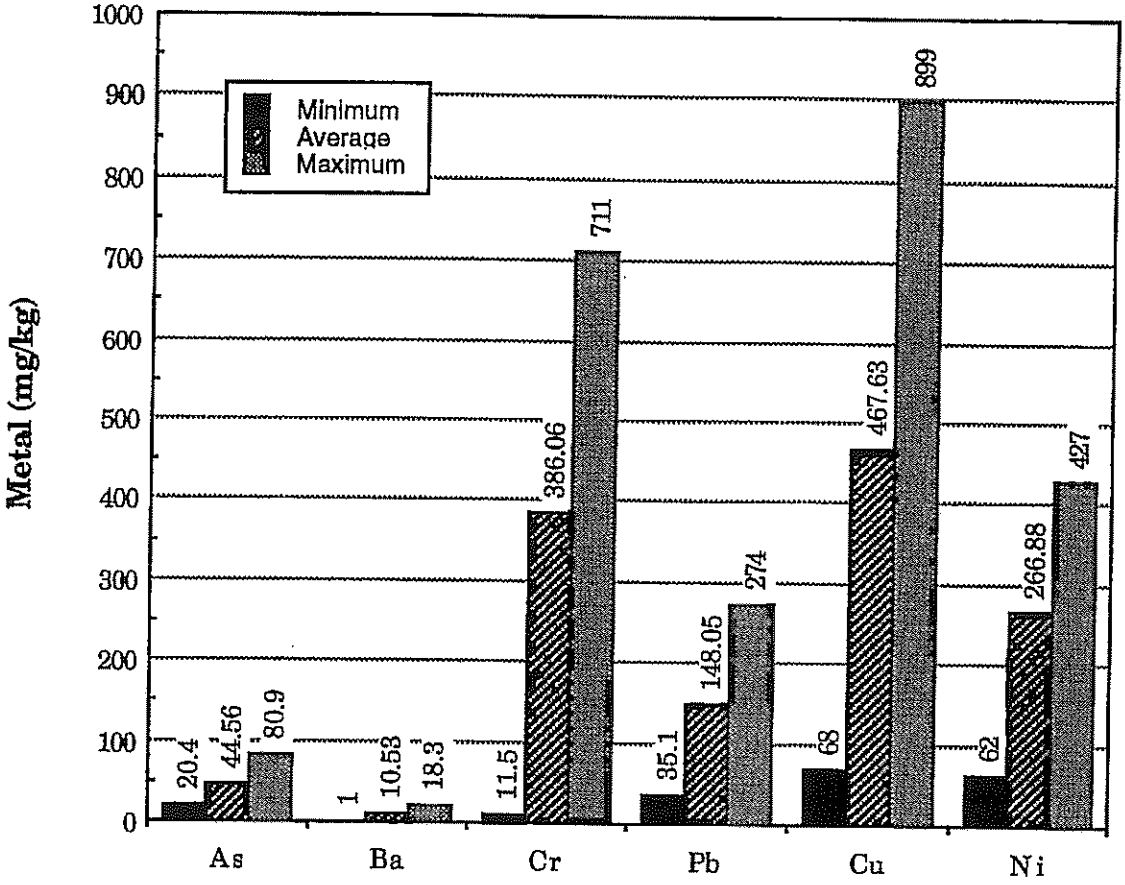
Metal	Minimum (mg/kg)	Average (mg/kg)	Maximum (mg/kg)
Cd	0.94	2.29	6.75
Hg	0.22	0.35	0.47
Se	NA	NA	<1.00
Ag	1.47	3.32	6.60

The results for metals exhibiting an average level in sediments exceeding 5 mg/kg are presented in Figure 8. All results are expressed in milligrams of metal per kilogram of wet sediment. To complete the data interpretation, total solids in sediments were evaluated. The average total solid level was found to average 70.2 percent in the 8 Humboldt Pit sediment samples. Figure 8 shows that the distribution of metals in the sediments is not homogenous. Metals levels as well as their relative composition greatly varied with the sampling location throughout the Humboldt Pit. Figure 9 presents a summary of metals levels in the sediments and provides an average, a minimum and a maximum value for each metal contents. The standard deviation is as high as 365 mg/kg for nickel and 831 mg/kg for copper. Since metal composition in the sediments is far from being homogenous, rigorous quantitative data analysis is difficult. However, average values of the sediment concentrations in metals of concern (copper and nickel) were used to establish a mass balance of these metals in the Humboldt Pit.

Between the year 1984, when Callahan Mining Corporation acquired the Ropes Mine, and December 31, 1988, date at which production was stopped, a total of 1.92 million tons of ore was processed. Milling tailings which represent 95 percent of the ore, were discharged in the Humboldt Pit. Thus, 1.82 million tons is the estimated amount of tailings present in the pit. However, it was found during sediment sampling that only the top 6 inches of the tailings were not yet cemented or conglomerated. This observation, coupled with conservative assumptions, led to the conclusion that only 21,728 tons of tailings remain in contact with the pit water. The confidence level on this number does not exceed 50 percent and it is prudent to consider that the estimated amount of nonconglomerated tailings is within the range of 10,000 to 30,000 tons. Table 4 describes the Humboldt Pit metals input through the disposal of the Humboldt mill tailings during the Ropes Mine operation by Callahan Mining Corporation.



HUMBOLDT PIT SEDIMENTS TOTAL METALS ASSAY



HUMBOLDT PIT
SUMMARY OF TAILINGS METAL CONTENTS

FIGURE 9

TABLE 4

METAL INPUT IN THE HUMBOLDT PIT

Metal	Average Metal Level in Sediments (mg/kg)	Average Percentage of Solids in Sediments	Average Metal Level in Dry Sediment (mg/kg - dry)	Total Metal Amount[a] (ton)	Metal Amount in Noncemented Tailings (ton)
Nickel	467.6	70.2	666.0	1,215	6.6 - 20.0
Copper	267.0	70.2	380.0	694	3.8 - 11.4

[a] 1.824 million tons of tailings were discharged in the Humboldt Pit.

Table 5 presents an estimate of metals output from the Humboldt Pit by water seepage through the north embankment into the marsh and water seepage into the shallow groundwater system. Based upon data reported in Tables 4 and 5, the amount of nickel and copper residual in the sediment were evaluated. Estimated metals residuals in the entire volume of tailings and in the fraction of tailings not yet cemented are reported in Table 6.

TABLE 5

METAL OUTPUT FROM THE HUMBOLDT PIT SEDIMENTS

	Pit Water Outflow		Current Pit Water		
Metal	Estimated Average Metal Concentration (mg/l)	Total Metal Amount[a] (ton)	Average Metal Concentration (mg/l0	Total Metal Amount[b] (ton)	Total Leached Metal Amount
Nickel	0.80	2.50	0.665	6.78	9.28
Copper	0.10	0.31	0.042	0.43	0.74

[a] 315 gpm of water leaving the pit through seepage over 5 years (1987 to 1992).
[b] Pit water volume estimated at 10.2×10^6 m^3.

TABLE 6

METAL RESIDUAL IN HUMBOLDT PIT SEDIMENTS

	Residual in Total Sediments		Residual in Estimated Noncemented Tailings[a]	
Metal	Metal Amount (ton)	Percentage from Initial Metal Amount	Metal Amount (ton)	Percentage from Initial Metal Amount
Nickel	1,205.7	99.2%	10.72	53%
Copper	693.2	99.8%	10.66	93%

[a] The higher range of 30,000 tons was used for calculation.

Copper and nickel mass balance data show that only a very small fraction (<1%) of the metals contained in the tailings disposed in the pit have leached. Such a low percentage is essentially explained by the cementation and conglomeration of the majority of the tailings which are no longer in contact with the pit water. The same mass balance was conducted for the estimated fraction of tailings not yet cemented, and still potentially releasing metals through leaching and diffusion phenomena. Table 6 shows that about 50 percent of nickel has already been leached from the noncemented tailings. On the other hand, only 7 percent of copper has been leached under similar conditions. It should be noted that these estimations are not precise. Only a thorough evaluation of the amount of noncemented tailings, as well as a comparison of metal composition of both cemented and noncemented tailings will provide a more precise metal mass balance. Moreover, it should be noted that total metal assay using tailings and digestion do not represent the availability of metal for leaching in the pit water.

CONCLUSION

Total metal assays showed that although 1,215 tons of nickel and 694 of copper are estimated to be present in the Humboldt Pit sediments, only an insignificant amount of metals have leached in the pit water. Metals were prevented from leaching by the compaction, conglomeration and cementation of the majority of the tailings. Moreover, it is very unlikely that the total amount of metals present in the noncemented tailings will leach, due to mild leaching conditions, continuous tailings cementation process and poor metal accessibility in relatively coarse tailings granules. Previous leachability tests showed that only 101 milligrams of the 380 milligrams of copper remaining per kilograms of noncemented tailings were leachable. Similarly, 23.5 mg of the 666 milligrams of nickel remaining in average per kilograms of tailings could potentially be further leached.

/db

Montgomery Watson, August 25, 1995 Comparison of Total Phosphorus and Algal Enumeration after Phosphorus Application to Humboldt Pit

MONTGOMERY WATSON

August 25, 1995

Mr. Bill Scarffe
Callahan Mining Corporation
PO Box 508
Negaunee, MI 49866

SUBJECT: Comparison of Total Phosphorous and Algal Enumeration after phosphorous application to Humbolt Pit.

Dear Mr. Scarffe:

In July and September of 1993, and again in April of 1994, phosphorous was applied to the Humbolt Pit in an effort to see if increased phosphorus concentrations in the photic zone could increase algae growth, and thereby reduce the nickel and copper concentrations of the pit water by metal-algae sorption.

Pit water quality samples that were collected on October 19, 1993 (see attached report), approximately one month after the second phosphorous application, show an average total phosphorous concentration of 0.04 mg/l. The algal enumeration average was 1,650,000 cells/ml.

Pit water quality samples were also collected on May 4, 1994 (see attached report), one week after ice out, phosphorous had previously been applied on top of ice. Results show an average of 0.06 mg/l for total phosphorous and an average algal enumeration concentration of 11,390 cell/ml.

Pit water quality samples were also collected on June 9, 1995 (see attached report). More than one year after any phosphorous application. The total phosphorous concentrations average was 0.03 mg/l, the algal enumeration concentration was 20,354 cells/ml.

These three water quality sampling events show that the total phosphorous concentrations are within 0.03 mg/l of each other. This suggests that the phosphorous application may increase the total phosphorous concentration of the pit water immediately, but that the concentration drops down to "normal" levels shortly after application.

545 Indian Mound
Wayzata, Minnesota
55391

Tel: 612 473 4224
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The algal enumeration concentrations are similar for the May 4, 1994 and June 9, 1995 samples. An explanation for a slightly higher concentration in the June sample may be due to warmer water temperatures and one additional month of algae accumulation. The October 19, 1993 sample had much higher algal enumeration concentrations. This again may be explained by warmer water temperatures and several months of algae accumulation over the summer months. It may have also been collected during an autumn bloom of algae. However, the nickel concentrations of the October 19, 1993 sample had elevated to near the pretreatment concentration levels of the pit water.

It should also be pointed out that the data are inconclusive as to whether the algae did or did not "take up" (sorb) any significant amount of the nickel or copper of the pit water. It may have been that the temporary reduction of nickel concentrations were a result of precipitation when the phosphorous was applied (chemical bonding or localized increased pH levels).

Please do not hesitate to contact Steve Kloiber or myself should you have any questions regarding this report. Montgomery Watson appreciates the opportunity to provide you with this service.

Sincerely,

Mark Allen
Environmental Scientist

MA:jn

cc: Steve Kloiber

MONTGOMERY WATSON

November 2, 1993

Mr. Edward Cryer
Montgomery Watson
161 Mallard Drive
Boise, ID 83706-3974

Re: Water Samples Analyzed by our Laboratory:
Ropes Mine Project
Project Number: 1389.0170
Sample Dates: October 19, 1993

Dear Mr. Cryer:

The above referenced samples have been analyzed with the results as follows:

Site HP-1	Oct. 19
Total Phosphorus, mg/l	0.04
Temperature, °F	46
Secchi Depth, feet	2.0
NO_2 + NO_3, mg/l	6.4
Total Kjeldahl N., mg/l	1.5
Total Nitrogen, mg/l	7.9
Total Nickel, ug/l	350
Dissolved Nickel, ug/l	330

Site HP-2	Oct. 19
Total Phosphorus, mg/l	0.04
Temperature, °F	46
Secchi Depth, feet	2.0
NO_2 + NO_3, mg/l	6.4
Total Kjeldahl N., mg/l	1.7
Total Nitrogen, mg/l	8.1
Total Nickel, ug/l	360
Dissolved Nickel, ug/l	330

Site HP-3	Oct. 19
Total Phosphorus, mg/l	0.05
Temperature, °F	46
Secchi Depth, feet	2.0
NO_2 + NO_3, mg/l	6.4
Total Kjeldahl N., mg/l	1.7
Total Nitrogen, mg/l	8.1
Total Nickel, ug/l	350
Dissolved Nickel, ug/l	340

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Site HP-4	Oct. 19
Total Phosphorus, mg/l	0.04
Temperature, °F	46
Secchi Depth, feet	1.8
NO_2 + NO_3, mg/l	6.4
Total Kjeldahl N., mg/l	1.2
Total Nitrogen, mg/l	7.6
Total Nickel, ug/l	360
Dissolved Nickel, ug/l	320

Site HP-5	Oct. 19
Total Phosphorus, mg/l	0.05
Temperature, °F	46
Secchi Depth, feet	1.8
NO_2 + NO_3, mg/l	6.4
Total Kjeldahl N., mg/l	2.1
Total Nitrogen, mg/l	8.5
Total Nickel, ug/l	360
Dissolved Nickel, ug/l	330

Site HP-6	Oct. 19
Total Phosphorus, mg/l	0.04
Temperature, °F	46.5
Secchi Depth, feet	2.0
NO_2 + NO_3, mg/l	6.4
Total Kjeldahl N., mg/l	2.0
Total Nitrogen, mg/l	8.4
Total Nickel, ug/l	370
Dissolved Nickel, ug/l	350

Travel Blank	Oct. 19
Total Nickel, ug/l	<2
Dissolved Nickel, ug/l	<2

Phytoplankton enumeration for those sites specified in the work plan for these dates accompany this report package. Cell count estimates for the sites are as follows:

Site HP-1 Surface:	1710000 cells/ml
Site HP-1 2m Composite	1680000 cells/ml
Site HP-3 Surface	1780000 cells/ml
Site HP-3 2m Composite	1680000 cells/ml
Site HP-6 Surface	1490000 cells/ml
Site HP-6 2m Composite	1560000 cells/ml

Montgomery Watson Water Quality Laboratory appreciates the opportunity to provide you with this analytical service. If you have any questions, please do not hesitate to contact us.

Sincerely,

MONTGOMERY WATSON

Frank De Steno,
Laboratory Manager

enclosures

MONTGOMERY WATSON

May 24, 1994

Mr. Edward Cryer
Montgomery Watson
161 Mallard Drive
Boise, ID 83706-3974

Re: Water Samples Analyzed by our Laboratory:
Ropes Mine Project
Metals Profile
Project Number: 1389.0100
Sample Date: May 4, 1994

Dear Mr. Cryer:

The above referenced samples have been analyzed with the results as follows:

Site HP-1: Surface Sample ID: 053-118	**Results**
Secchi, ft	5.0
Temperature, °C	not reported
Total Phosphorus, mg/l	0.06
$NO_2 + NO_3$, mg/l	7.0
TKN, mg/l	1.2
Total Nitrogen, mg/l	8.2
Total Copper, µg/l	15
Dissolved Copper, µg/l	10
Total Nickel, µg/l	450
Dissolved Nickel, µg/l	440

Site HP-3: Surface Sample ID: 053-119	**Results**
Secchi, ft	5.0
Temperature, °C	4.5
Total Phosphorus, mg/l	0.06
$NO_2 + NO_3$, mg/l	6.9
TKN, mg/l	1.2
Total Nitrogen, mg/l	8.1
Total Copper, µg/l	11
Dissolved Copper, µg/l	10
Total Nickel, µg/l	460
Dissolved Nickel, µg/l	450

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Site HP-6: Surface Sample ID: 053-120	**Results**
Secchi, ft	6.5
Temperature, °C	5.0
Total Phosphorus, mg/l	0.06
$NO_2 + NO_3$, mg/l	6.9
TKN, mg/l	1.1
Total Nitrogen, mg/l	8.0
Total Copper, µg/l	12
Dissolved Copper, µg/l	10
Total Nickel, µg/l	440
Dissolved Nickel, µg/l	440

Site HP-3 Metals Profile:

HP-3 10 meters Sample ID: 053-121	**Results**
Total Copper, µg/l	13
Total Nickel, µg/l	520
HP-3 20 meters Sample ID: 053-122	
Total Copper, µg/l	12
Total Nickel, µg/l	510
HP-3 30 meters Sample ID: 053-123	
Total Copper, µg/l	32
Total Nickel, µg/l	910
HP-3 40 meters Sample ID: 053-124	
Total Copper, µg/l	57
Total Nickel, µg/l	990

HP-3 50 meters
Sample ID: 053-125

	Results
Total Copper, µg/l	70
Total Nickel, µg/l	1000

In addition to the above analyses, algal identification and enumeration was performed on the three surface samples. Only one algal taxon was observed in the three samples and could be identified only as a small, green coccoid. Cell count estimates for the sites are as follows:

Site HP-1 - 9470 cells/ml
Site HP-3 - 11400 cells/ml
Site HP-6 - 13300 cells/ml

Montgomery Watson Water Quality Laboratory appreciates the opportunity to provide you with this analytical service. If you have any questions, please do not hesitate to contact us.

Sincerely,

MONTGOMERY WATSON
Water Quality Laboratory

Frank De Steno,
Laboratory Manager

Copy: Bill Scarffe

MONTGOMERY WATSON

July 5, 1995

Mr. Bill Scarffe
Callahan Mining Corporation
4547 County Road 601
Champion, MI 49814

Re: Analysis of water samples: Pit Mine
Sample Date: June 9, 1995
Sample ID: 092-205; 092-206; 092-207

Dear Mr. Scarffe:

The above referenced samples have been analyzed with the results as follows:

PARAMETER	RESULT Pit North 092-205	RESULT Pit Center 092-206	RESULT Pit South 092-207
Total Phosphorus, mg/L	0.03	0.03	0.03
Sol. Reactive Phosphorus, mg/L	0.01	0.01	0.01
Ortho Phosphorus, mg/L	0.01	0.01	0.01
Corrected Chlorophyll-a, µg/L	-----	4	-----
Corrected Pheophytin-a, µg/L	-----	2	-----
Algal Enumeration	-----	See Attached Report	-----

Please do not hesitate to contact me should you have any questions regarding this report. Montgomery Watson appreciates the opportunity to provide you with this service.

Sincerely,

MONTGOMERY WATSON
Laboratory and Field Services

Frank De Steno,
Laboratory Manager

Copy: Steve Kloiber, Montgomery Watson

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PHYTOPLANKTON ENUMERATION

Sample Date: June 8, 1995 **Station:** Humboldt Pit **Sample Number:** 092-206

Center - 2 meter composite

Organism	Total cells/ml	Cell Volume, cc		Cell Volume cc/L
Fragilaria	923	9.00E-15		8.31E-09
Nitzchia	415	4.59E-11		1.91E-05
Euglena	385	3.53E-11		1.36E-05
green coccoids	17923	1.41E-11		2.53E-04
microflagellates	708	3.53E-11		2.50E-05

	% by Biovolume	% by Number
Diatoms	6.1	6.6
Blue-Green Algae	0	0
Green Algae	81.5	88.1
Dinoflagellates	0	0
Euglenoids	4.4	1.9
Other	8.0	3.5
Total	**100**	**100**

Total cells/ml 20354

Total Biovolume, cc/L 3.11E-04

Seen in sample but not counted: Trachelomonas
Closteriopsis
Gymnodinium

Appendix D

Results of Bench Scale Lock Cycle Testing of Mill Tailings
SBS Lakefield Research, February 2007

November 22, 2007

Mr. Jon B. Manchester
Foth Infrastructure & Environment, LLC
1402 Pankratz St. Suite 300
Madison, WI 53704

Dear Mr. Manchester,

Please find attached, files providing the assay results of chemical analyses performed by SGS Lakefield Research of process water from locked cycle testing of ore from the KEMC Eagle mine. The process water data information can be used in an engineering analysis of a tailings disposal facility.

The assays provided include:

- Effluent 2010 – Batch Test Assays
- Effluent 2011 – LCT 6
- Effluent 2012 – LCT 7
- Effluent 2013 – LCT 5
- Effluent Sample 1 – Same-massive

This information was provided via email from Mr. Oliver Peters on February 24, 2007 to the attention of Ms. Alicia Duex of KMC.

I am writing this letter on behalf of Mr. Peters and SGS Lakefield Research.

Dan Imeson, MSc.
Flotation Group Leader

Client	(2736) B Wakeford	Received	15-Feb-07 15:54
Reference		Requested	17-Feb-07 15:54
Project	CALR-11237-002	Created	15-Feb-07 15:54
Batch	Env ICP-MS Metals	Finished	21-Feb-07 14:38
Supervisor	bgraham	Samples	1,0,0 - 40

Notes:
ckd bg

Tag	Type	Sample ID	pH units	Conductivity uS/cm	Acidity mg/L as CaCO3	Alkalinity mg/L as CaCO3	Carbonate mg/L as CaCO3
1	NOS	~Analysis Start Date	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07
2	NOS	~Analysis Start Time	07:39	07:39	07:39	07:39	07:39
3	NOS	~Analysis Approval Date	20-Feb-07	20-Feb-07	20-Feb-07	20-Feb-07	20-Feb-07
4	NOS	~Analysis Approval Time	11:31	11:31	11:31	11:31	11:31
5	SMP	11237-002 F18	12.1	1870	< 2	816	686

Tag	HCO3 mg/L as CaCO3	Tot.Dissolved Solids mg/L	F mg/L	Fe2 mg/L	Tot Suspended Solids	SO4 mg/L	Cl mg/L	NO2 as N mg/L
1	19-Feb-07	16-Feb-07	19-Feb-07	16-Feb-07	16-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07
2	07:39	09:16	07:35	11:59	11:00	13:43	13:43	13:43
3	20-Feb-07	21-Feb-07	19-Feb-07	19-Feb-07	20-Feb-07	21-Feb-07	21-Feb-07	21-Feb-07
4	11:31	08:20	11:37	11:14	11:00	14:33	14:33	14:33
5	130	563	0.07	< 0.5	596	37	44	< 0.06

Tag	NO3 as N mg/L	NO2+NO3 as N mg/L	Si mg/L	Tot.Reactive P mg/L	Hg mg/L	Al mg/L	As mg/L	Ba mg/L
1	19-Feb-07	19-Feb-07	21-Feb-07	16-Feb-07	20-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07
2	13:43	13:43	07:00	08:50	08:00	11:40	19:00	19:00
3	21-Feb-07	21-Feb-07	21-Feb-07	19-Feb-07	20-Feb-07	19-Feb-07	21-Feb-07	21-Feb-07
4	14:33	14:33	08:23	12:49	15:23	15:37	08:21	08:21
5	0.24	0.24	12.5	< 0.03	0.0002	0.43	0.0621	0.0197

Tag	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L
1	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07
2	11:40	30-Dec-0/	19:00	19:00	11:40	11:40	11:40	11:40
3	19-Feb-07	21-Feb-07	21-Feb-07	21-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07
4	15:37	08:21	08:21	08:21	15:37	15:37	15:37	15:37
5	208	0.00184	0.0304	0.0495	3.43	8.50	6.47	9.36

Tag	Mn mg/L	Mo mg/L	Na mg/L	Ni mg/L	Pb mg/L	Se mg/L	Sr mg/L	Zn mg/L
1	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07	19-Feb-07
2	19:00	19:00	11:40	11:40	19:00	19:00	11:40	19:00
3	21-Feb-07	21-Feb-07	19-Feb-07	19-Feb-07	21-Feb-07	21-Feb-07	19-Feb-07	21-Feb-07
4	08:21	08:21	15:36	15:37	08:21	08:21	15:36	08:21
5	0.0439	0.0121	194	1.24	0.142	0.015	0.115	0.0492

Tag	Total Recov.Metals	Hg Prep
1	16-Feb-07	19-Feb-07
2	15:17	09:39
3	16-Feb-07	19-Feb-07
4	15:17	09:39
5	1	1

Client	(2736) BJW	Received	07-Dec-06 14:11
Reference		Requested	09-Dec-06 14:11
Project	CALR-11237-002	Created	07-Dec-06 14:11
Batch		Finished	15-Jan-07 15:39
Supervisor	bgraham	Samples	2,0,0 - 12

Notes:
limited sample volume in own login cooler shelf must share portion
ckd ks

Tag	Type	Sample ID	pH units	Conductivity uS/cm	Alkalinity mg/L as CaCO3	Acidity mg/L as CaCO3
1	NOS	~Analysis Start Date	11-Dec-06	11-Dec-06	11-Dec-06	11-Dec-06
2	NOS	~Analysis Start Time	15:00	15:00	15:00	15:00
3	NOS	~Analysis Approval Date	12-Dec-06	12-Dec-06	12-Dec-06	12-Dec-06
4	NOS	~Analysis Approval Time	16:06	16:06	16:06	16:06
5	SMP	Bulk Ro Tail G Effluent Sub Sample	9.70	1393	362	< 2
6	SMP	Bulk 1rt Cl Scav Tail Effluent (Water) Sub Sample	9.76	1188	255	< 2

Tag	HCO3 mg/L as CaCO3	Carbonate mg/L as CaCO3	Tot.Reactive P mg/L	Cl mg/L	SO4 mg/L	NO2 as N mg/L	NO3 as N mg/L	NO2+NO3 as N mg/L
1	11-Dec-06	11-Dec-06	08-Dec-06	08-Dec-06	08-Dec-06	08-Dec-06	08-Dec-06	08-Dec-06
2	15:00	15:00	08:21	09:32	09:32	09:32	09:32	09:32
3	12-Dec-06	12-Dec-06	11-Dec-06	15-Jan-07	15-Jan-07	15-Jan-07	15-Jan-07	15-Jan-07
4	16:06	16:06	17:10	14:29	14:29	14:29	14:29	14:29
5	172	190	< 0.03	33	180	< 0.06	< 0.05	< 0.06
6	114	141	< 0.03	29	130	< 0.06	< 0.05	< 0.06

Client	(2736) Brian Wakeford	Received	24-Jan-07 15:14
Reference		Requested	26-Jan-07 15:14
Project	CALR-11237-002	Created	24-Jan-07 15:14
Batch	Env ICP-MS Metals	Finished	31-Jan-07 11:39
Supervisor	bgraham	Samples	1,0,0 - 40

Notes:
ckd ks-please chekc pricing

Tag	Type	Sample ID	pH units	Conductivity uS/cm	Acidity mg/L as CaCO3	Alkalinity mg/L as CaCO3
1	NOS	~Analysis Start Date	26-Jan-07	26-Jan-07	26-Jan-07	26-Jan-07
2	NOS	~Analysis Start Time	09:38	09:38	09:38	09:38
3	NOS	~Analysis Approval Date	29-Jan-07	29-Jan-07	29-Jan-07	29-Jan-07
4	NOS	~Analysis Approval Time	12:29	12:29	12:29	12:29
5	SMP	LCT-6 Flotation Water Process Water	11.4	2080	< 2	724

Tag	Carbonate mg/L as CaCO3	HCO3 mg/L as CaCO3	Tot.Dissolved Solids mg/L	F mg/L	Fe2 mg/L	Tot Suspended Solids	SO4 mg/L	Cl mg/L
1	26-Jan-07	26-Jan-07	26-Jan-07	25-Jan-07	25-Jan-07	26-Jan-07	24-Jan-07	24-Jan-07
2	09:38	09:38	07:19	07:35	13:03	07:06	20:17	20:17
3	29-Jan-07	29-Jan-07	30-Jan-07	26-Jan-07	26-Jan-07	29-Jan-07	29-Jan-07	29-Jan-07
4	12:29	12:29	10:25	09:50	09:57	15:27	09:48	09:48
5	713	11	1030	0.12	< 0.5	288	71	55

Tag	NO2 as N mg/L	NO3 as N mg/L	NO2+NO3 as N mg/L	Si mg/L	Tot.Reactive P mg/L	Hg mg/L	Al mg/L	As mg/L
1	24-Jan-07	24-Jan-07	24-Jan-07	26-Jan-07	26-Jan-07	26-Jan-07	26-Jan-07	29-Jan-07
2	20:17	20:17	20:17	09:45	09:37	14:00	09:45	10:06
3	29-Jan-07	29-Jan-07	29-Jan-07	31-Jan-07	29-Jan-07	30-Jan-07	31-Jan-07	31-Jan-07
4	09:48	12:54	12:54	07:19	07:54	08:32	07:19	07:19
5	0.07	0.24	0.31	22.6	< 0.03	0.0003	0.63	0.0074

Tag	Ba mg/L	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L
1	29-Jan-07	26-Jan-07	29-Jan-07	29-Jan-07	29-Jan-07	26-Jan-07	26-Jan-07	26-Jan-07
2	10:06	09:45	10:06	10:06	10:06	09:45	09:45	09:45
3	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07
4	07:19	07:19	07:19	07:19	07:19	07:19	07:19	07:19
5	0.0127	85.0	0.00105	0.0959	0.0165	2.70	14.7	12.3

OnLine L

Tag	Mg mg/L	Mn mg/L	Mo mg/L	Na mg/L	Ni mg/L	Pb mg/L	Se mg/L	Sr mg/L
1	26-Jan-07	29-Jan-07	29-Jan-07	26-Jan-07	26-Jan-07	29-Jan-07	29-Jan-07	26-Jan-07
2	09:45	10:06	10:06	09:45	09:45	10:06	10:06	09:45
3	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07
4	07:19	07:19	07:19	07:19	07:19	07:19	07:19	07:19
5	11.3	0.0948	0.0232	362	2.83	0.0504	0.012	0.0916

Tag	Zn mg/L
1	29-Jan-07
2	10:06
3	31-Jan-07
4	07:19
5	0.112

Client	(2736) Jenn Labelle	Received	25-Jan-07 08:38
Reference		Requested	27-Jan-07 08:38
Project	CALR-11237-002	Created	25-Jan-07 08:38
Batch		Finished	02-Feb-07 15:37
Supervisor	bgraham	Samples	1,0,0 - 40

Notes:
ckd ks

Tag	Type	Sample ID	pH units	Conductivity uS/cm	Acidity mg/L as CaCO3	Alkalinity mg/L as CaCO3
1	NOS	~Analysis Approval Date	29-Jan-07	29-Jan-07	29-Jan-07	29-Jan-07
2	NOS	~Analysis Approval Time	12:29	12:29	12:29	12:29
3	SMP	LCT-7 Flotation Water Process Water Cycles F+G	11.8	2990	< 2	1010

Tag	Carbonate mg/L as CaCO3	HCO3 mg/L as CaCO3	Tot.Dissolved Solids mg/L	F mg/L	Fe2 mg/L	Tot Suspended Solids	SO4 mg/L	Cl mg/L
1	29-Jan-07	29-Jan-07	30-Jan-07	26-Jan-07	26-Jan-07	29-Jan-07	29-Jan-07	29-Jan-07
2	12:29	12:29	10:26	09:51	09:58	15:27	14:38	14:38
3	933	< 2	1360	0.15	< 0.5	406	110	30

Tag	NO2 as N mg/L	NO3 as N mg/L	NO2+NO3 as N mg/L	Si mg/L	Tot.Reactive P mg/L	Hg mg/L	Al mg/L	As mg/L
1	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	29-Jan-07	02-Feb-07	31-Jan-07	31-Jan-07
2	09:04	09:04	09:04	08:10	07:55	07:39	10:21	10:21
3	0.09	0.23	0.32	11.9	< 0.03	0.0002	0.68	0.0087

Tag	Ba mg/L	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L
1	31-Jan-07	02-Feb-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07
2	10:21	14:47	10:21	10:21	10:21	08:10	08:10	08:10
3	0.0162	113	0.00104	0.0543	0.0170	3.00	9.76	23.1

Tag	Mg mg/L	Mn mg/L	Mo mg/L	Na mg/L	Ni mg/L	Pb mg/L	Se mg/L	Sr mg/L
1	31-Jan-07	31-Jan-07	31-Jan-07	02-Feb-07	31-Jan-07	31-Jan-07	31-Jan-07	31-Jan-07
2	08:10	10:21	10:21	14:47	08:10	10:21	10:21	08:10
3	5.73	0.0608	0.0461	720	2.00	0.0349	0.028	0.0963

OnLine L

CA10413-JAN07

Tag	Zn mg/L
1	31-Jan-07
2	10:21
3	0.0398

OnLine I

Client	(2736) Brian Wakeford	Received	18-Jan-07 16:16
Reference		Requested	20-Jan-07 16:16
Project	CALR-11237-002	Created	18-Jan-07 16:16
Batch	Env ICP-MS Metals	Finished	30-Jan-07 10:55
Supervisor	bgraham	Samples	1,0,0 - 40

Notes:
ckdk s-plese check $
Cl, SO4, NO2, NO3 first run on 19 Jan 07. However, there was a hole in the sample bottle
and therefore the results were rejected due to the possibility of contamination. Another
portion of sample was provided and the analysis run on that. ruth 23 Jan 07

Tag	Type	Sample ID	pH units	Conductivity uS/cm	Acidity mg/L as CaCO3	Alkalinity mg/L as CaCO3	Carbonate mg/L as CaCO3
1	NOS	~Analysis Start Date	19-Jan-07	19-Jan-07	19-Jan-07	19-Jan-07	19-Jan-07
2	NOS	~Analysis Start Time	11:36	11:36	11:36	11:36	11:36
3	NOS	~Analysis Approval Date	22-Jan-07	22-Jan-07	22-Jan-07	22-Jan-07	22-Jan-07
4	NOS	~Analysis Approval Time	10:05	10:05	10:05	10:05	10:05
5	SMP	LCTS Process Water	11.9	2600	< 2	966	907

Tag	HCO3 mg/L as CaCO3	Tot.Dissolved Solids mg/L	F mg/L	Fe2 mg/L	Tot Suspended Solids	SO4 mg/L	Cl mg/L	NO2 as N mg/L
1	19-Jan-07	19-Jan-07	19-Jan-07	19-Jan-07	19-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07
2	11:36	07:39	07:43	08:41	08:00	20:10	20:10	20:10
3	22-Jan-07	23-Jan-07	22-Jan-07	19-Jan-07	23-Jan-07	25-Jan-07	25-Jan-07	25-Jan-07
4	10:05	10:40	09:37	14:12	10:29	20:24	20:24	20:24
5	< 2	1050	0.09	< 0.5	429	64	67	< 0.06

Tag	NO3 as N mg/L	NO2+NO3 as N mg/L	Si mg/L	Tot.Reactive P mg/L	Hg mg/L	Al mg/L	As mg/L	Ba mg/L
1	23-Jan-07	23-Jan-07	22-Jan-07	19-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07
2	20:10	20:10	15:30	09:27	07:30	09:28	09:28	09:28
3	29-Jan-07	29-Jan-07	23-Jan-07	22-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07
4	13:41	13:41	11:19	10:52	11:14	13:08	13:08	13:08
5	0.24	0.24	21.2	< 0.03	0.0001	0.747	0.0155	0.0148

Tag	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L
1	22-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	22-Jan-07	22-Jan-07	22-Jan-07	22-Jan-07
2	12:58	09:28	09:28	09:28	12:58	12:58	12:58	12:58
3	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07

Tag	Ca mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	Fe mg/L	K mg/L	Mg mg/L
4	11:18	13:08	13:08	13:08	13:08	11:18	11:18	11:18
5	144	0.00086	0.0532	0.0216	2.58	14.6	10.6	13.0

Tag	Mn mg/L	Mo mg/L	Na mg/L	Ni mg/L	Pb mg/L	Se mg/L	Sr mg/L	Zn mg/L
1	23-Jan-07	23-Jan-07	22-Jan-07	22-Jan-07	23-Jan-07	23-Jan-07	22-Jan-07	23-Jan-07
2	09:28	09:28	12:58	12:58	09:28	09:28	12:58	09:28
3	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07	23-Jan-07
4	13:08	13:08	13:08	13:08	13:08	13:08	11:18	13:08
5	0.0844	0.0244	544	1.78	0.0742	0.024	0.0995	0.0594

OnLine I

Appendix E

Calculation of Preliminary Effluent Limits for Wetland EE

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJFI	Date:	10/18/07

Calculations

Table of Contents

	Page
Summary	1
Development of Wasteload Allocations for Toxic Substances - R323.1209 - Non-Lotic Waters	2
Receiving Water Data	4
Rule 57 Values for Each Parameter	5
Rule 57 Minimum Water Quality Values	5
Rule 57 Calculations for Cadmium, Copper, Nickel	6

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJF1	Date:	10/18/07

Summary Table - Preliminary Effluent Limits (PELs) for Wetlands (HMP-009)

Parameter	PEL [1] (ug/L)	PEL Basis [2]	WLA Formula
Aluminum	n.a.		
Antimony	130	HNV	
Arsenic	150	FCV	
Barium	1012	FCV	WLA = FCV = EXP(1.0629*LN(HMP_009_Hardness)+1.1869)
Beryllium	18	FCV	WLA = FCV = EXP(2.5279*LN(HMP_009_Hardness)-10.7689)
Boron	1900	FCV	
Cadmium	8.4	FCV	WLA = FCV*T =(EXP(0.7852*LN(HMP_009_Hardness)-2.715))*(1.101672-((LN(HMP_009_Hardness)*0.04184)))*2.1
Chloride	n.a.		
Chromium	212	FCV	WLA = FCV*T = (EXP(0.819*LN(HMP_009_Hardness)+0.6848))*0.86*1.5
Cobalt	100	FCV	
Copper	26	FCV	WLA = FCV*T =(EXP(0.8545*LN(HMP_009_Hardness)-1.702))*0.96*1.5
Fluoride	n.a.		
Iron	n.a.		
Lead	108	FCV	WLA = FCV*T =(EXP(1.273*LN(HMP_009_Hardness)-3.296))*(1.46203-((LN(HMP_009_Hardness)*0.14571)))*4.5
Lithium	96	FCV	
Manganese	3857	FCV	WLA = FCV = EXP(0.8784*LN(HMP_009_Hardness)+3.5199)
Mercury	0.0013	WV	
Molybdenum	3200	FCV	
Nickel	111	FCV	WLA = FCV*T= (EXP(0.846*LN(HMP_009_Hardness)+0.0584)*.997)*1.1
Nitrogen	n.a.		
Phosphorus	n.a.		
Potassium	n.a.		
Selenium	5.0	FCV	
Sodium	n.a.		
Strontium	8300	FCV	
Sulfate	n.a.		
Thallium	3.7	HNV	
Vanadium	12	FCV	
Zinc	484	FCV	WLA=FCV*T= (EXP(0.8473*LN(HMP_009_Hardness)+0.884)*0.986)*2.1

Notes

General Preliminary effluent limits (PELs) were developed for all contaminants listed in the summary table, however, six parameters were selected to show methodology. Three of the six parameters are hardness dependent, the remaining three are table values with no calculation involved. See the following pages for development methodologies on the six selected parameters. A total of nine parameters are hardness dependent: barium, beryllium, cadmium, chromium, copper, lead, manganese, nickel, and zinc.

[1] PEL is based on the number of parts of receiving water available for mixing (Q) of 0 for wetlands.

[2] PEL basis is lowest value considering HNV, WV, HCV Non-drink, FCV, AMV from the MDEQ Rule 57 table titled "Rule 57 Water Quality Values, Surface Water Assessment Section, Michigan DEQ". This value is compared against the FAV to obtain the WLA and PEL.

Abbreviations:

AMV	Aquatic maximum value	HNV	Human non-cancer value, non-drinking water
FAV	Final acute value	n.a.	Not applicable
FCV	Final chronic value	T	Dissolved to total metal translators for aquatic life wasteload allocations.
HCV	Human cancer value	WLA	Waste load allocation
		WV	Wildlife value

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJF1	Date:	10/18/07

The following presents detailed calculations for six select parameters. Although receiving water flows and water quality are not required for discharge to wetlands, these calculations show the impact of receiving water flows and water quality and provide detailed MDEQ rule documentation.

Development of Wasteload Allocations for Toxic Substances - R323.1209 - Non-Lotic Waters

Locations with no flow R 323.1209 (1)(b) Chronic WLAs for discharges to inland lakes

for total or total recoverable: WLA= Zt(1+Q) - Cr Q
For aquatic life values expressed as dissolved metal: WLA= Zd T(1+Q) - CrQ

Where:

Zt - the lowest water quality value developed for the toxic substance expressed as total or total recoverable

Zd - water quality value for aquatic life expressed as dissolved metal.

T - dissolved to total translator for aquatic life from Table 2. Cd=2.1, Cu=1.5, Ni=1.1, Cr = 1.5, Zn = 2.1, Pb = 4.5

Q - number of parts of receiving water allocated for mixing under R 323.1082 (5), <=1 in 10

Cr - receiving water background concentration developed under R 323.1207(1)(g), 2-4 data points for this.

WLA - waste load allocation for an individual point source that ensures WQ is maintained

Arsenic, total	(ug/L)	
Zt	150	
Q	0	
Cr	0.69	
calculated WLA in ug/L	150	
Compare with FAV	680	
Lowest compared value	150.0	R 323.1082 (1), This is allowable WLA

Cadmium, total	(ug/L)	
Zd	4.01	FCV, Lowest value for aquatic life
T	2.1	
Q	0	
Cr	0.097	
calculated WLA in ug/L	8.4	
Compare with FAV	20	
Lowest compared value	8.4	R 323.1082 (1), This is allowable WLA

Copper, total	(ug/L)	
Zd	17.57	FCV
T	1.5	
Q	0	
Cr	6.0	
calculated WLA in ug/L	26.4	
Compare with FAV	56.5	
Lowest compared value	26.4	R 323.1082 (1), This is allowable WLA

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJF1	Date:	10/18/07

Development of Wasteload Allocations for Toxic Substances - R323.1209 - Non-Lotic Waters (continued)

Mercury	(ug/L)	
Zt	0.00130	
Q	0	
Cr	0.00136	
calculated WLA in ug/L	0.00130	
Compare with FAV	2.8	
Lowest compared value	0.00130	R 323.1082 (1), This is allowable WLA

Nickel, total	(ug/L)	
Zd	101.33	
T	1.1	
Q	0	
Cr	14.0	
calculated WLA in ug/L	111	
Compare with FAV	1825	
Lowest compared value	111.5	R 323.1082 (1), This is allowable WLA

Selenium, total	(ug/L)	
Zt	5	
Q	0	
Cr	0.25	
calculated WLA in ug/L	5.0	
Compare with FAV	120	
Lowest compared value	5.0	
Compare with Zt	5.0	R 323.1082 (1), This is allowable WLA

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJF1	Date:	10/18/07

Receiving Water Data

Location of surface water collection point HMP-009 is shown on attached Figure 1.

Note: Table values for pollutants are "Cr" values used in the calculations to determine WLAs.

Arsenic, total	HMP-009	
	0.69	ug/L
Cadmium, total	HMP-009	
	0.097	ug/L
Copper, total	HMP-009	
	6.0	mg/L
Mercury - low level	HMP-009	
	1.36	ng/L
Mercury - low level	HMP-009	
	0.00136	ug/L
Nickel, total	HMP-009	
	14.0	ug/L
Selenium, total	HMP-009	
	0.25	ug/L

Note: These table values are "Qr" in the calculations for WLAs.

Flow	HMP-009	
	n/a	cfs
Total Hardness	HMP-009	
	220000	ug/L

Note: These table values are "H" in the calculations for Rule 57.

Total Hardness	HMP-009	
	220	mg/L

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJFI	Date:	10/18/07

Rule 57 Values for Each Parameter

Note: these values become Zt or Zd values in WLA calculations.

	Arsenic, total Lowest Value	HNV Non-drink	WV	HCV Non-drink	FCV	AMV	FAV
HMP-009	150	280	NA	NA	150	340	680

	Cadmium, total Lowest Value	HNV Non-drink	WV	HCV Non-drink	FCV	AMV	FAV
HMP-009	4.0	130	NA	NA	4.0	10.0	20.0

	Copper, total Lowest Value	HNV Non-drink	WV	HCV Non-drink	FCV	AMV	FAV
HMP-009	17.6	38000	NA	NA	17.6	28.2	56.5

	Mercury - low level Lowest Value	HNV Non-drink	WV	HCV Non-drink	FCV	AMV	FAV
HMP-009	0.0013	0.0018	0.0013	NA	0.77	1.4	2.8

	Nickel, total Lowest Value	HNV Non-drink	WV	HCV Non-drink	FCV	AMV	FAV
HMP-009	101	210000	NA	NA	101	912	1825

	Selenium, total Lowest Value	HNV Non-drink	WV	HCV Non-drink	FCV	AMV	FAV
HMP-009	5	2700	NA	NA	5	62	120

Rule 57 Minimum Water Quality Values

	HMP-009
Arsenic, total	150
Cadmium, total	4.0
Copper, total	17.6
Mercury - low level	0.0013
Nickel, total	101.33
Selenium, total	5.0

Lowest Rule 57 value is based on protection of:

Paramater	
Arsenic	FCV
Cadmium	FCV
Copper	FCV
Mercury	WV
Nickel	FCV
Selenium	FCV

Where:

NA not applicable
FCV Final Chronic Value - no injury to aquatic organisms
WV Wildlife protection value
HNV Human non-cancer value, non-drinking water
HCV Human cancer value, non-drinking water

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project - Surface Water Discharge Standards		
Prepared by:	AKM	Date:	10/18/07
Checked by:	JJF1	Date:	10/18/07

Rule 57 Calculations for Cadmium, Copper, Nickel

FCV, AMV, FAV have formulae based on Hardness. (Links to Tables sheet for Rule 57 values).

Cadmium

CFa=acute conversion value for Cadmium = 1.136672-(ln H x 0.04184)
CFa=acute conversion value for Cadmium = 1.136672 -ln H x 0.04184
CFb=chronic conversion value for Cadmium = 1.101672-(ln H x 0.04184)
CFb=chronic conversion value for Cadmium = 1.101672 -ln H x 0.04184

Form: exp(A*Ln H + B) * C * D

HMP-009	A	average H mg/L	B	CFa	CFb	D	Calculated Value
Cadmium							
FCV	0.7852	220	-2.715		0.8760	1	4.0
AMV	1.128	220	-3.6867	0.9110		1	10.0
FAV	1.128	220	-3.6867	0.9110		2	20.0

Copper

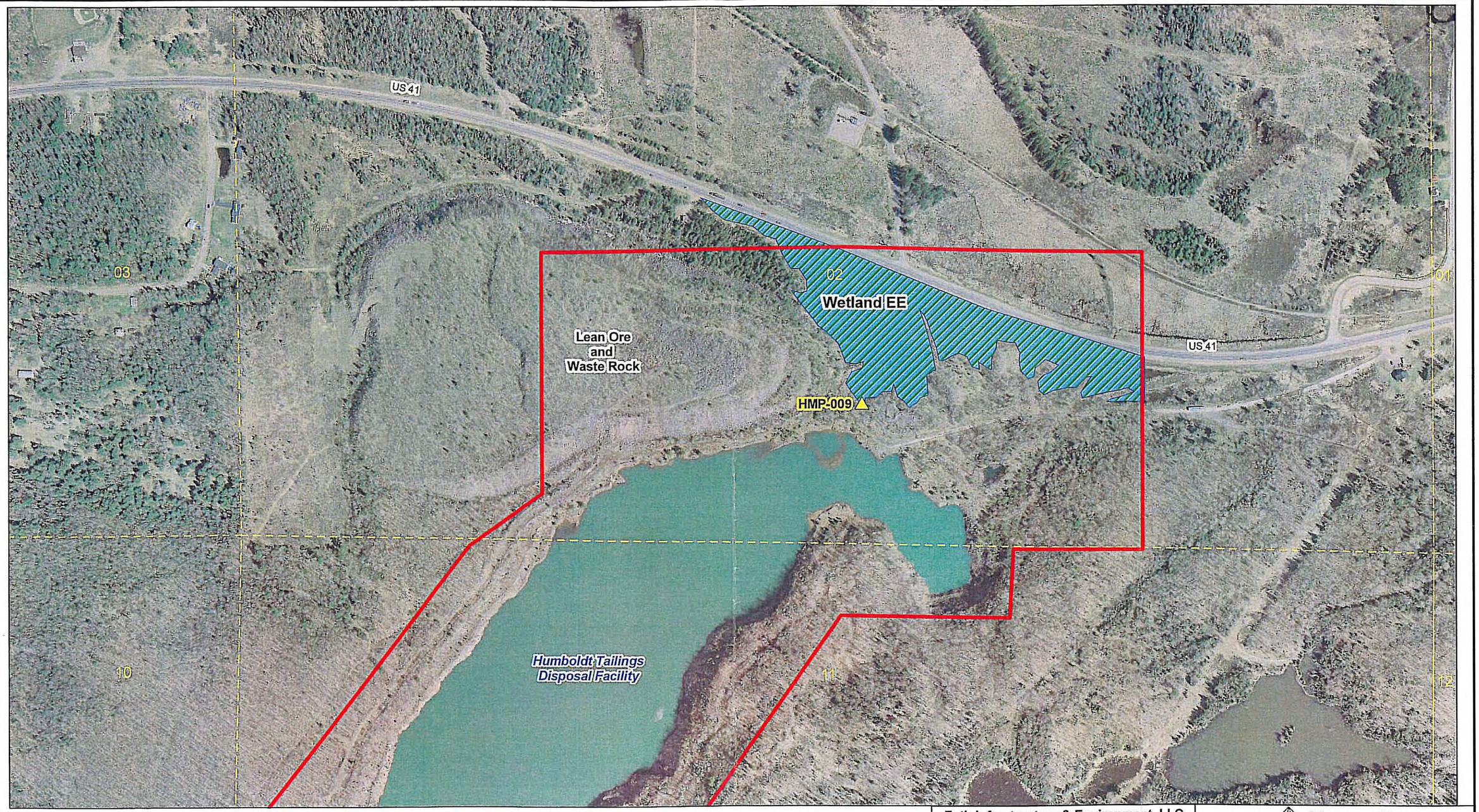
Form: exp(A*Ln H + B) * C * D

HMP-009	A	average H mg/L	B	C	D	Calculated Value
FCV	0.8545	220.0	-1.702	0.96	1	17.6
AMV	0.9422	220.0	-1.7	0.96	1	28.2
FAV	0.9422	220.0	-1.7	0.96	2	56.5

Nickel

Form: exp(A*Ln H + B) * C * D

HMP-009	A	average H mg/L	B	C	D	Calculated Value
FCV	0.846	220.0	0.0584	0.997	1	101.3
AMV	0.846	220.0	2.255	0.998	1	912.3
FAV	0.846	220.0	2.255	0.998	2	1824.7



NOTES

1. Orthophotography supplied by Aero-Metric Engineering, Sheboygan, Wisconsin. Date of photography: April 27, 2006.
2. Horizontal datum based on NAD 83/96. Horizontal coordinates based on Michigan State Plane North.
3. Site Location - Project Site within Sections 2 and 11, T47N, R29W, Humboldt Township, Marquette County, Michigan.
4. Revised Wetland Boundary GPS data supplied by King & MacGregor Environmental, Inc. via email on 09/25/2007.

M:\06w003\mxd\EIA\HTDF\kmc_humboldt_Wetland_point_hmp009_11x17.mxd October 19, 2007

LEGEND

PLSS Sections
Wetland
KEMC Property Boundary

N

Foth
Foth Infrastructure & Environment, LLC

Foth Infrastructure & Environment, LLC

REVISED	DATE	BY	DESCRIPTION

CHECKED BY:	AKM	DATE: OCT. '07	
APPROVED BY:	SVD1	DATE: OCT. '07	
APPROVED BY:		DATE:	

Kennecott
Eagle Minerals

FIGURE 1
HUMBOLDT MILL PROJECT
WETLAND SAMPLING POINT

Scale: 0 200 400 Feet
Date: OCTOBER 2007
Prepared by: DAT
Project No: 06W003

Appendix F

Multi-Compartment Model:
Definition of Flows, Variables, and Compartment Mass Balances

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	Initial value	Equations
Alkbed	Y					Y		Alkalinity of Tails Bed	160	dAlkbed/dt = (Alk_plume*Q5pw-FAlkpw5-FAlkburial-Alkbed*VolRateActiveTails)/100 for ActivePoreVolTails <100
Alkbed	Y					Y			160	= (Alk_plume*Q5pw-FAlkpw5-FAlkburial-Alkbed*VolRateActiveTails)/ActivePoreVolTails by default
Alk_burial	Y						Y	Mass (kg) of Alkalinity buried in deeper tails	0	dAlk_burial/dt = +FAlkburial/1000000
Alk_NHTDF	Y							Alkalinity N HTDF (mg/L CaCO3)	100	dAlk_NHTDF/dt = (Alk_background*NaturalFlowNHTDF-kdNPN*AlkDemandParam+FAlk1N-FAlkN1-FAlkNout-Alk_NHTDF*VolRateN)/Vol_NHTDF
Alk_Output	Y								0	dAlk_Output/dt = +FAlkNout+FAlk1out
Alk1	Y						Y	Alkalinity 1 (mg/L CaCO3)	100	dAlk1/dt = (Alk_background*NaturalFlowMainHTDF+Alk_plume*QP1-FAlk1out-kd1P1*AlkDemandParam-FAlk12-FAlk1N+FAlkN1+FAlk21-Alk1*VolRate1)/Vol1
Alk2	Y						Y	Alkalinity 2 (mg/L CaCO3)	100	dAlk2/dt = (Alk_plume*QP2+Qgw2*Alk_background-kd2P2*AlkDemandParam+FAlk12+FAlk32-FAlk21-FAlk23-Alk2*VolRate2)/Vol2
Alk3	Y						Y	Alkalinity 3 (mg/L)	100	dAlk3/dt = (Alk_plume*QP3+(FeRdxn3-kd3P3)*AlkDemandParam+FAlk23+FAlk43-FAlk32-FAlk34-Alk3*Q3R-Alk3*VolRate3)/Vol3
Alk4	Y						Y	Alkalinity 4 (mg/L CaCO3)	140	dAlk4/dt = (Alk_plume*QP4+(FeRdxn4-kd4P4)*AlkDemandParam+FAlk54-FAlk43+FAlk34-FAlk45-Alk4*Q4R-Alk4*VolRate4)/Vol4
Alk5	Y						Y	Alkalinity 5 (mg/L CaCO3)	160	dAlk5/dt = (Alk_plume*QP5_water+(FeRdxn5-kd5P5-FDO5bed)*AlkDemandParam-FAlk54+FAlk45+FAlkpw5-Alk5*Q5P-Alk5*VolRate5)/Vol5
BuriedHeat	Y							Heat (GJ) buried in deeper tails (pore water + solid tails)	0	dBuriedHeat/dt = +Hburial
Cbed	Y					Y		Tracked metal concentration (ug/L) in bed pore water, initial value is for nickel case.	280	dCbed/dt = (C_plume*Q5pw+F5bed-Fpw5-Fburial-Cbed*VolRateActiveTails)/100 for ActivePoreVolTails <100
Cbed	Y					Y				= (C_plume*Q5pw+F5bed-Fpw5-Fburial-Cbed*VolRateActiveTails)/ActivePoreVolTails by default
C_burial	Y						Y	Mass (kg) of C buried in deeper tails	0	dC_burial/dt = +Fburial/1000000
C_NHTDF	Y							Tracked metal concentration (ug/L) in N HTDF, initial value is for nickel case.	14	dC_NHTDF/dt = (C_background*NaturalFlowNHTDF+F1N-FN1-C_NHTDF*QNout-C_NHTDF*VolRateN)/Vol_NHTDF
C_treated	Y						Y		0	dC_treated/dt = Total_Outflow*Cinfluent/1000000
C1	Y							Tracked metal concentration (ug/L) in 1, initial value is for nickel case.	14	dC1/dt = (C_background*NaturalFlowMainHTDF+C_plume*QP1-F12-F1N+FN1+F21-Q1out*C1-C1*VolRate1)/Vol1
C2	Y							Tracked metal concentration (ug/L) in 2, initial value is for nickel case.	13	dC2/dt = (C_plume*QP2+Qgw2*C_background+F12+F32-F21-F23-C2*VolRate2)/Vol2
C3	Y							Tracked metal concentration (ug/L) in 3, initial value is for nickel case.	17	dC3/dt = (C_plume*QP3+F23+F43-F32-F34-C3*Q3R-C3*VolRate3)/Vol3
C4	Y							Tracked metal concentration (ug/L) in 4, initial value is for nickel case.	210	dC4/dt = (C_plume*QP4+F54-F43+F34-F45-C4*Q4R-C4*VolRate4)/Vol4
C5	Y							Tracked metal concentration (ug/L) in 5, initial value is for nickel case.	280	dC5/dt = (C_plume*QP5_water-F5bed-F54+F45+Fpw5-C5*Q5P-C5*VolRate5)/Vol5
DischargeMass	Y						Y	Simple discharge mass to HTDF (kg)	0	dDischargeMass/dt = load*2203*QDwt/1000000
DO_bed_spent	Y							Mass of Dissolved O2 lost to bed by diffusion. Rate is tracked for alkalinity adjustment. Bed DO concentration is set by parameter DObed (typically =0).	0	dDO_bed_spent/dt = +FDO5bed/1000000
DO_NHTDF	Y						Y	Dissolved O2 Concentration in Northern HTDF (mg/L)DO	10	dDO_NHTDF/dt = (ka_N*(DOsat_N-DO_NHTDF)-kdNPN+DO_bckgnd*NaturalFlowNHTDF+FDO1N-FDON1-FDONout-DO_NHTDF*VolRateN)/Vol_NHTDF
DO1	Y						Y	Dissolved O2 Concentration 1 (mg/L)	10	dDO1/dt = (ka1*(DOsat1-DO1)-kd1P1-FDO1out+DO_bckgnd*NaturalFlowMainHTDF+DO_plume*QP1-FDO12-FDO1N+FDON1+FDO21-DO1*VolRate1)/Vol1
DO2	Y						Y	DO 2 (mg/L)	10	dDO2/dt =(DO_plume*QP2+Qgw2*DO_bckgnd-kd2P2+FDO12+FDO32-FDO21-FDO23-DO2*VolRate2)/Vol2
DO3	Y						Y	DO 3 (mg/L)	8	dDO3/dt = (DO_plume*QP3-kd3P3+FDO23+FDO43-FDO32-FDO34-DO3*Q3R-DO3*VolRate3)/Vol3
DO4	Y						Y	DO 4 (mg/L)	0	dDO4/dt = (DO_plume*QP4-kd4P4+FDO54-FDO43+FDO34-FDO45-DO4*Q4R-DO4*VolRate4)/Vol4
DO5	Y						Y	DO conc. 5 (mg/L)	0	dDO5/dt = (DO_plume*QP5_water-kd5P5-FDO54-Q5P*DO5-FDO5bed+FDO45-DO5*VolRate5)/Vol5
DOout	Y							DO mass out (g)	0	dDOout/dt = +FDONout+FDO1out
Heat_out	Y							Total Heat in Outflow (GJ)	0	dHeat_out/dt = +H1out+HNout
ICE_N	Y						Y	Tonnes of Ice in N HTDF	0	dICE_N/dt = -(HN_MELT-HN_ICE)/LatentHeatIce
ICE1	Y						Y	Tonnes of Ice in 1	0	dICE1/dt = -(H1_MELT-H1_ICE)/LatentHeatIce
OxFe_burial	Y						Y	Mass (kg) of FeOx buried in tails	0	dOxFe_burial/dt = FOxFe5Bed/1000000
OxFe_N	Y							Ferric iron in Northern HTDF (mg/L)	0.42	dOxFe_N/dt = (P_background*NaturalFlowNHTDF+FOxFe1N-FOxFeN1-FOxFeout+kdNPN*6.98-OxFe_N*VolRateN)/Vol_NHTDF
OxFe_Output	Y							Ferric iron mass in output (g)	0	dOxFe_Output/dt = +FOxFeout+FP1out1
OxFe1	Y						Y	Ferric iron in 1 (mg/L)	0.42	dOxFe1/dt = (OxFe_background*NaturalFlowMainHTDF-FP1out1-FOxFe12-FOxFe1N+FOxFeN1+FOxFe21+kd1P1*6.98-OxFe1*VolRate1)/Vol1
OxFe2	Y						Y	Ferric iron in 2 (mg/L)	0.45	dOxFe2/dt = (FOxFe12+Qgw2*OxFe_background+FOxFe32-FOxFe21-FOxFe23+kd2P2*6.98-OxFe2*VolRate2)/Vol2

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
OxFe3	Y						Y	Ferric iron in 3 (mg/L)	0.39	dOxFe3/dt = (FOxFe23+FOxFe43-FOxFe32-FOxFe34-OxFe3*Q3R+(kd3P3-FeRdxn3)*6.98-OxFe3*VolRate3)/Vol3
OxFe4	Y						Y	Ferric iron in 4 (mg/L)	0.1	dOxFe4/dt = (FOxFe54-FOxFe43+FOxFe34-FOxFe45-OxFe4*Q4R+(kd4P4-FeRdxn4)*6.98-OxFe4*VolRate4)/Vol4
OxFe5	Y						Y	Ferric iron in 5 (mg/L)	0.1	dOxFe5/dt = ((kd5P5-FeRdxn5)*6.98-FOxFe54-FOxFe5Bed+FOxFe45-OxFe5*Q5P-OxFe5*VolRate5)/Vol5
Pbed	Y					Y		DO demand in bed (mg/L)	20	dPbed/dt = (P_plume*Q5pw-FPpw5-FPburial-Pbed*VolRateActiveTails)/100 for ActivePoreVolTails <100
Pbed	Y					Y		DO demand in bed (mg/L)	20	= (P_plume*Q5pw-FPpw5-FPburial-Pbed*VolRateActiveTails)/ActivePoreVolTails by default
P_burial	Y						Y	Mass (kg) of P buried in deeper tails	0	dP_burial/dt = +FPburial/1000000
P_NHTDF	Y							DO demand concentration, Northern HTDF (mg/L)	0	dP_NHTDF/dt = (P_background*NaturalFlowNHTDF+FP1N-FPN1-FPNout-kdNPN-P_NHTDF*VolRateN)/Vol_NHTDF
P_Output	Y							DO demand mass in output	0	dP_Output/dt = +FPNout+FP1out
P1	Y							DO demand concentration 1 (mg/L)	0	dP1/dt = (P_background*NaturalFlowMainHTDF-FP1out+P_plume*QP1-FP12-FP1N+FPN1+FP21-kd1P1-P1*VolRate1)/Vol1
P2	Y							DO demand concentration 2 (mg/L)	0	dP2/dt = (P_plume*QP2+Qgw2*P_background-kd2P2+FP12+FP32-FP21-FP23-P2*VolRate2)/Vol2
P3	Y							DO demand concentration 3 (mg/L)	0	dP3/dt = (P_plume*QP3+FeRdxn3-kd3P3+FP23+FP43-FP32-FP34-P3*Q3R-P3*VolRate3)/Vol3
P4	Y							DO demand concentration 4 (mg/L)	1	dP4/dt = (P_plume*QP4+FeRdxn4-kd4P4+FP54-FP43+FP34-FP45-P4*Q4R-P4*VolRate4)/Vol4
P5	Y							DO demand concentration 5 (mg/L)	1	dP5/dt = (P_plume*QP5_water+FeRdxn5-kd5P5-FP54+FP45+FPpw5-P5*Q5P-P5*VolRate5)/Vol5
RecycleMass	Y						Y	Accounting of mass of compound reclaimed to recycle stream, see RECYCLE	0	dRecycleMass/dt = (Q3R*C3+Q4R*C4)/1000000
Sbed	Y					Y		TDS in tails bed (mg/L)	460	dSbed/dt = (S_plume*Q5pw-FSpw5-FSburial-Sbed*VolRateActiveTails)/100 for ActivePoreVolTails <100
Sbed	Y					Y		TDS in tails bed (mg/L)	460	= (S_plume*Q5pw-FSpw5-FSburial-Sbed*VolRateActiveTails)/ActivePoreVolTails by default
S_burial	Y						Y	Mass (kg) of TDS buried in deeper tails	0	dS_burial/dt = +FSburial/1000000
S_NHTDF	Y								330	dS_NHTDF/dt = (S_background*NaturalFlowNHTDF-FSNout+FS1N-FSN1-S_NHTDF*VolRateN)/Vol_NHTDF
S1	Y						Y	Salt concentration 1 (TDS, mg/L)	330	dS1/dt = (S_background*NaturalFlowMainHTDF+S_plume*QP1-FS1out-FS12-FS1N+FSN1+FS21-S1*VolRate1)/Vol1
S2	Y						Y	Salt 2 (TDS, mg/L)	330	dS2/dt = (S_plume*QP2+Qgw2*S_background+FS12+FS32-FS21-FS23-S2*VolRate2)/Vol2
S3	Y						Y	Salt 3 (mg/L TDS)	340	dS3/dt = (S_plume*QP3+FS23+FS43-FS32-FS34-S3*Q3R-S3*VolRate3)/Vol3
S4	Y						Y	Salt 4 (mg/L TDS)	430	dS4/dt = (S_plume*QP4+FS54-FS43+FS34-FS45-S4*Q4R-S4*VolRate4)/Vol4
S5	Y						Y	Salt conc. 5 (mg/L TDS)	460	dS5/dt = (S_plume*QP5_water-FS54+FS45+FSpw5-S5*Q5P-S5*VolRate5)/Vol5
Sout	Y							Salt mass in output (TDS)	0	dSout/dt = +FS1out+FSNout
T1	Y					Y	Y	Temperature (C), compartment 1	0	dT1/dt = dT1_w_ICE + (H1_ICE-H1_MELT)/HeatFactor/Vol1_w_ICE for T1<0
T1	Y					Y	Y	Temperature (C), compartment 1	0	= dT1_wo_ICE by default
T2	Y					Y	Y	Temperature (C), compartment 2	8	dT2/dt = (+H12+H32-H21-H23+T_gw2*Qgw2*HeatFactor+T_plume*QP2*HeatFactor-T2*VolRate2*HeatFactor)/(Vol2*HeatFactor) for load = 0
T2	Y					Y	Y	Temperature (C), compartment 2	8	= (H12+H32-H21-H23+T_gw2*Qgw2*HeatFactor+T_plume*QP2*HeatFactor-T2*VolRate2*HeatFactor)/(Vol2*HeatFactor) by default
T3	Y					Y	Y	Temperature (C), compartment 3	5	dT3/dt = (+H23+H43-H32-H34-T3*VolRate3*HeatFactor)/(Vol3*HeatFactor) for load = 0
T3	Y					Y	Y	Temperature (C), compartment 3	5	= (T_plume*QP3*HeatFactor+H23+H43-H32-H34-Q3R*T3*HeatFactor-T3*VolRate3*HeatFactor)/(Vol3*HeatFactor) by default
T4	Y					Y	Y	Temperature (C), compartment 4	5.1	dT4/dt = (+H54-H43+H34-H45-T4*VolRate4*HeatFactor)/(Vol4*HeatFactor) for load = 0
T4	Y					Y	Y	Temperature (C), compartment 4	5.1	= (T_plume*QP4*HeatFactor+H54-H43+H34-H45-T4*Q4R*HeatFactor-T4*VolRate4*HeatFactor)/(Vol4*HeatFactor) by default
T5	Y					Y	Y	Temperature (C), compartment 5	5.5	dT5/dt = (-H54+H45+Hpw5-T5*VolRate5*HeatFactor)/(Vol5*HeatFactor) for load =0
T5	Y					Y	Y	Temperature (C), compartment 5	5.5	= (T_plume*(QP5_water)*HeatFactor-H54+H45+Hpw5-T5*Q5P*HeatFactor-T5*VolRate5*HeatFactor)/(Vol5*HeatFactor) by default
T_NHTDF	Y					Y	Y	Temperature (C), northern HTDF	13	dT_NHTDF/dt = dTN_w_ICE+ (HN_ICE-HN_MELT)/HeatFactor/VolN_w_ICE-HNout for T_NHTDF<0
T_NHTDF	Y					Y	Y	Temperature (C), northern HTDF	13	= dTN_wo_ICE by default
TailsInventory	Y							Total Dry Tonnes of Tails in Inventory (to be placed in HTDF)	2501969	dTailsInventory/dt = -TailsIn
TailsLowerHTDF	Y						Y	Total Dry Tonnes of Tails in Lower HTDF	0	dTailsLowerHTDF/dt = +TailsIn-TailsOut
TailsOutlet	Y							Dry Tails Loss (dry tonnes)	0	dTailsOutlet/dt = +TailsOut
Tbed	Y					Y		Temperature of Bed (C), heat balance includes solid phase in equilibrium with pore water	5.5	dTbed/dt = ((T_plume*Q5pw*HeatFactor-Hburial)*RH_bed-Hpw5-Tbed*HeatFactor*VolRateActiveTails*RH_bed)/(100*HeatFactor*RH_bed) for ActivePoreVolTails <100
Tbed	Y					Y		Temperature of Bed (degrees C)	5.5	= ((T_plume*Q5pw*HeatFactor-Hburial)*RH_bed-Hpw5-Tbed*HeatFactor*VolRateActiveTails*RH_bed)/(ActivePoreVolTails*HeatFactor*RH_bed) by default
WatElev	Y						Y	Water Elevation, dynamically adjusts to irregular flow and output (m)	468.7824	dWatElev/dt = ElevRate
F1N				Y				Flow from C1 to C_NHTDF		F1N = mix1N* C1
F12				Y		Y		Flow from C1 to C2		F12 = C1*mix12 for OxFe1 < 0.01
F12				Y		Y				= C1*mix12 + vsFe*Area12*AlkPvt1*min(OxFe1*1000/C1,1)/(1+K_complex1/OxFe1)*C1 by default

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
F21				Y				Flow from C2 to C1		F21 = Q21* C2
F23				Y		Y		Flow from C2 to C3		F23 = mix23*C2 for OxFe2 < 0.01
F23				Y		Y				= mix23*C2 + vsFe*Area23*AlkPvt2*min(OxFe2*1000/C2,1)/(1+K_complex2/OxFe2)*C2 by default
F32				Y				Flow from C3 to C2		F32 = Q32 * C3
F34				Y		Y		Flow from C3 to C4		F34 = mix34*C3 for OxFe3 < 0.01
F34				Y		Y				= mix34*C3 + vsFe*Area34*AlkPvt3*min(OxFe3*1000/C3,1)/(1+K_complex3/OxFe3)*C3 by default
F43				Y				Flow from C4 to C3		F43 = Q43* C4
F45				Y		Y		Flow from C4 to C5		F45 = mix45*C4 for OxFe4 < 0.01
F45				Y		Y				= mix45*C4 + vsFe*Area45*AlkPvt4*min(OxFe4*1000/C4,1)/(1+K_complex4/OxFe4)*C4 by default
F54				Y				Flow from C5 to C4		F54 = Q54* C5
F5bed				Y		Y		Flow from C5 to Cbed		F5bed = 0 for OxFe5 < 0.01
F5bed				Y		Y				= vsFe*TailsBedArea*AlkPvt5*min(OxFe5*1000/C5,1)/(1+K_complex5/OxFe5)*C5 by default
FAlk12				Y				Flow from S1 to S2		FAlk12 = Alk1*mix12
FAlk1N				Y				Flow from Alk1 to Alk_NHTDF		FAlk1N = mix1N * Alk1
FAlk1out				Y				Flow from Alk1 to Alk_Output		FAlk1out = Q1out * Alk1
FAlk21				Y				Flow from S2 to S1		FAlk21 = Q21* Alk2
FAlk23				Y				Flow from S2 to S3		FAlk23 = mix23*Alk2
FAlk32				Y				Flow from S3 to S2		FAlk32 = Q32 * Alk3
FAlk34				Y				Flow from S3 to S4		FAlk34 = mix34*Alk3
FAlk43				Y				Flow from S4 to S3		FAlk43 = Q43* Alk4
FAlk45				Y				Flow from S4 to S5		FAlk45 = mix45*Alk4
FAlk54				Y				Flow from Alk5 to Alk4		FAlk54 = Q54* Alk5
FAlkburial				Y				Flow from Alkbed to Alk_burial		FAlkburial = max(Q5pw-VolRateActiveTails,0)* Alkbed
FAlkN1				Y				Flow from Alk_NHTDF to Alk1		FAlkN1 = mix1N * Alk_NHTDF
FAlkNout				Y				Flow from Alk_NHTDF to Alk_Output		FAlkNout = QNout* Alk_NHTDF
FAlkpw5				Y				Flow from Alkbed to Alk5		FAlkpw5 = BedDiffusion * (Alkbed-Alk5) * TailsBedArea
Fburial				Y				Flow from Cbed to C_burial		Fburial = max(Q5pw-VolRateActiveTails,0)* Cbed
FDO12				Y				Flow from DO1 to DO2		FDO12 = DO1*mix12
FDO1N				Y				Flow from DO1 to DO_NHTDF		FDO1N = mix1N * DO1
FDO1out				Y				Flow from DO1 to DOout		FDO1out = Q1out * DO1
FDO21				Y				Flow from DO2 to DO1		FDO21 = Q21* DO2
FDO23				Y				Flow from DO2 to DO3		FDO23 = mix23*DO2
FDO32				Y				Flow from DO3 to DO2		FDO32 = Q32 * DO3
FDO34				Y				Flow from DO3 to DO4		FDO34 = mix34*DO3
FDO43				Y				Flow from S4 to S3		FDO43 = Q43* DO4
FDO45				Y				Flow from S4 to S5		FDO45 = mix45*DO4
FDO54				Y				Flow from S5 to S4		FDO54 = Q54* DO5
FDO5bed				Y			Y	Flow from DO5 to DO_bed_spent		FDO5bed = -BedDiffusion*TailsBedArea*(DObed-DO5)
FDON1				Y				Flow from DO_NHTDF to DO1		FDON1 = mix1N* DO_NHTDF
FDONout				Y				Flow from DO_NHTDF to DOout		FDONout = QNout* DO_NHTDF
FeRdxn3				Y		Y	Y	Flow from OxFe3 to P3		FeRdxn3 = 0.015*kd_basic*OxFe3*Vol3*1.024^(T3-20) for DO3 <= 0.5
FeRdxn3				Y		Y	Y			= 0 by default
FeRdxn4				Y		Y	Y	Flow from OxFe4 to P4		FeRdxn4 = 0.015*kd_basic*OxFe4*Vol4*1.024^(T4-20) for DO4 <= 0.5
FeRdxn4				Y		Y	Y			= 0 by default
FeRdxn5				Y		Y	Y	Flow from OxFe5 to P5		FeRdxn5 = 0.015*kd_basic*(OxFe5)*Vol5*1.024^(T5-20) for DO5 <= 0.5
FeRdxn5				Y		Y	Y			= 0 by default
FN1				Y				Flow from C_NHTDF to C1		FN1 = mix1N * C_NHTDF
FOxFe12				Y				Flow from OxFe1 to OxFe2		FOxFe12 = OxFe1*mix12 + vsFe*Area12*OxFe1*AlkPvt1
FOxFe1N				Y				Flow from P1 to P_NHTDF		FOxFe1N = mix1N * OxFe1
FOxFe21				Y				Flow from S2 to S1		FOxFe21 = Q21* OxFe2
FOxFe23				Y				Flow from OxFe2 to OxFe3		FOxFe23 = mix23*OxFe2+ vsFe*Area23*OxFe2*AlkPvt2
FOxFe32				Y				Flow from S3 to S2		FOxFe32 = Q32 * OxFe3
FOxFe34				Y				Flow from OxFe3 to OxFe4		FOxFe34 = mix34*OxFe3+ vsFe*Area34*OxFe3*AlkPvt3
FOxFe43				Y				Flow from OxFe4 to OxFe3		FOxFe43 = Q43* OxFe4
FOxFe45				Y				Flow from OxFe4 to OxFe5		FOxFe45 = mix45*OxFe4+ vsFe*Area45*OxFe4*AlkPvt4
FOxFe54				Y				Flow from S5 to S4		FOxFe54 = Q54* OxFe5
FOxFe5Bed				Y				Flow from OxFe5 to OxFe_burial		FOxFe5Bed = vsFe * TailsBedArea* OxFe5 * AlkPvt5
FOxFeN1				Y				Flow from P_NHTDF to P1		FOxFeN1 = mix1N * OxFe_N
FOxFeout				Y				Flow from P_NHTDF to P_Output		FOxFeout = QNout* OxFe_N
FP12				Y				Flow from S1 to S2		FP12 = P1*mix12
FP1N				Y				Flow from P1 to P_NHTDF		FP1N = mix1N * P1
FP1out				Y				Flow from P1 to P_Output		FP1out = Q1out * P1
FP1out1				Y				Flow from P1 to P_Output		FP1out1 = Q1out * OxFe1
FP21				Y				Flow from S2 to S1		FP21 = Q21* P2
FP23				Y				Flow from S2 to S3		FP23 = mix23*P2

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
FP32				Y				Flow from S3 to S2		FP32 = Q32 * P3
FP34				Y				Flow from S3 to S4		FP34 = mix34*P3
FP43				Y				Flow from S4 to S3		FP43 = Q43* P4
FP45				Y				Flow from S4 to S5		FP45 = mix45*P4
FP54				Y				Flow from S5 to S4		FP54 = Q54* P5
FPburial				Y				Flow from Pbed to P_burial		FPburial = max(Q5pw-VolRateActiveTails,0)* Pbed
FPN1				Y				Flow from P_NHTDF to P1		FPN1 = mix1N * P_NHTDF
FPNout				Y				Flow from P_NHTDF to P_Output		FPNout = QNout* P_NHTDF
FPpw5				Y				Flow from Pbed to P5		FPpw5 = BedDiffusion* (Pbed-P5)*TailsBedArea
Fpw5				Y				Flow from Cbed to C5		Fpw5 = BedDiffusion* (Cbed-C5) * TailsBedArea
FS12				Y				Flow from S1 to S2		FS12 = S1*mix12
FS1N				Y				Flow from S1 to S_NHTDF		FS1N = mix1N* S1
FS1out				Y				Flow from S1 to Sout		FS1out = Q1out * S1
FS21				Y				Flow from S2 to S1		FS21 = Q21* S2
FS23				Y				Flow from S2 to S3		FS23 = mix23*S2
FS32				Y				Flow from S3 to S2		FS32 = Q32 * S3
FS34				Y				Flow from S3 to S4		FS34 = mix34*S3
FS43				Y				Flow from S4 to S3		FS43 = Q43* S4
FS45				Y				Flow from S4 to S5		FS45 = mix45*S4
FS54				Y				Flow from S5 to S4		FS54 = Q54* S5
FSburial				Y				Flow from Sbed to S_burial		FSburial = max(Q5pw-VolRateActiveTails,0)* Sbed
FSN1				Y				Flow from S_NHTDF to S1		FSN1 = mix1N * S_NHTDF
FSNout				Y				Flow from S_NHTDF to Sout		FSNout = QNout * S_NHTDF
FSpw5				Y				Flow from Sbed to S5		FSpw5 = BedDiffusion* (Sbed-S5) * TailsBedArea
H12				Y			Y	Flow from T1 to T2		H12 = T1*mix12*HeatFactor
H1N				Y			Y	Flow from T1 to T_NHTDF		H1N = mix1N* T1 * HeatFactor
H1_ICE				Y		Y		Flow from ICE1 to T1		H1_ICE = max(-dT1_w_ICE*HeatFactor*Vol1_w_ICE,0) for T1<0
H1_ICE				Y		Y				= 0 by default
H1_MELT				Y		Y		Flow from T1 to ICE1		H1_MELT = max(dT1_w_ICE*HeatFactor*Vol1_w_ICE,0) for ICE1>0
H1_MELT				Y		Y				= 0 by default
H1out				Y			Y	Flow from T1 to Heat_out		H1out = HeatFactor*Q1out* T1
H21				Y			Y	Flow from T2 to T1		H21 = Q21* T2 *HeatFactor
H23				Y				Flow from T2 to T3		H23 = mix23*T2*HeatFactor
H32				Y				Flow from T3 to T2		H32 = Q32* T3*HeatFactor
H34				Y				Flow from T3 to T4		H34 = mix34*T3*HeatFactor
H43				Y				Flow from T4 to T3		H43 = Q43 * T4 *HeatFactor
H45				Y				Flow from T4 to T5		H45 = mix45*T4*HeatFactor
H54				Y				Flow from T5 to T4		H54 = Q54* T5 *HeatFactor
Hburial				Y				Flow from Tbed to BuriedHeat		Hburial = max(Q5pw-VolRateActiveTails,0) * Tbed * HeatFactor * RH_bed
HN1				Y			Y	Flow from T_NHTDF to T1		HN1 = mix1N * T_NHTDF * HeatFactor
HN_ICE				Y		Y		Flow from ICE_N to T_NHTDF		HN_ICE = max(-dTN_w_ICE*HeatFactor*VolN_w_ICE,0) for T_NHTDF<0
HN_ICE				Y		Y				= 0 by default
HN_MELT				Y		Y		Flow from T_NHTDF to ICE_N		HN_MELT = max(dTN_w_ICE*HeatFactor*VolN_w_ICE,0) for ICE_N>0
HN_MELT				Y		Y				= 0 by default
HNout				Y			Y	Flow from T_NHTDF to Heat_out		HNout = HeatFactor * T_NHTDF*QNout
HNout				Y			Y	Flow from T_NHTDF to Heat_out		HNout = HeatFactor * T_NHTDF*QNout
Hpw5				Y				Flow from Tbed to T5		Hpw5 = BedHeatTransfer*(Tbed-T5)*TailsBedArea
Hpw5				Y				Flow from Tbed to T5		Hpw5 = BedHeatTransfer*(Tbed-T5)*TailsBedArea
kd1P1				Y		Y	Y	Flow from P1 to OxFe1		kd1P1 = 0 for DO1 <0
kd1P1				Y		Y	Y			= kd_basic*P1*DO1*Vol1*1.024^(T1-20) for DO1 <1 and DO1>=0
kd1P1				Y		Y	Y			= kd_basic*P1*Vol1*1.024^(T1-20) by default
kd2P2				Y		Y	Y	Flow from P2 to OxFe2		kd2P2 = 0 for DO2 <0
kd2P2				Y		Y	Y			= kd_basic*P2*DO2*Vol2*1.024^(T2-20) for DO2 <1 and DO2 >=0
kd2P2				Y		Y	Y			= kd_basic*P2*Vol2*1.024^(T2-20) by default
kd3P3				Y		Y	Y	Flow from P3 to OxFe3		kd3P3 = 0 for DO3 <= 0.1
kd3P3				Y		Y	Y			= kd_basic*P3*DO3*Vol3*1.024^(T3-20) for DO3 <1 and DO3 > 0.1
kd3P3				Y		Y	Y			= kd_basic*P3*Vol3*1.024^(T3-20) by default
kd4P4				Y		Y	Y	Flow from P4 to OxFe4		kd4P4 = 0 for DO4 <= 0.1
kd4P4				Y		Y	Y			= kd_basic*P4*DO4*Vol4*1.024^(T4-20) for DO4 <1 and DO4 > 0.1
kd4P4				Y		Y	Y			= kd_basic*P4*Vol4*1.024^(T4-20) by default
kd5P5				Y		Y	Y	Flow from P5 to OxFe5		kd5P5 = 0 for DO5 <=0.1
kd5P5				Y		Y	Y			= kd_basic*P5*DO5*Vol5*1.024^(T5-20) for DO5 <1 and DO5>0.1
kd5P5				Y		Y	Y			= kd_basic*P5*Vol5*1.024^(T5-20) by default
kdNPN				Y		Y	Y	Flow from P_NHTDF to OxFe_N		kdNPN = 0 for DO_NHTDF<0
kdNPN				Y		Y	Y			= kd_basic*P_NHTDF*DO_NHTDF*Vol_NHTDF*1.024^(T_NHTDF-20) for DO_NHTDF<1 and DO_NHTDF>=0
kdNPN				Y		Y	Y			= kd_basic*P_NHTDF*Vol_NHTDF*1.024^(T_NHTDF-20) by default
TailsIn				Y			Y	Flow from TailsInventory to TailsLowerHTDF		TailsIn = TLR*load
TailsOut				Y				Flow from TailsLowerHTDF to TailsOutlet		TailsOut = 0* TLR

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	Initial value	Equations
ActivePoreVolTails		Y					Y	Active Pore Volume of Tails (cu. m) used for algorithm for burial and exchange		ActivePoreVolTails = ActiveBedThick*TailsBedArea*TailsPorosity
AirTemp		Y						Air Temperature (°C), from lookup table TempSolRad		AirTemp = T_air
AlkPvt1		Y					Y	Alkalinity pivot function (ranges from 0-1) that may govern OxFe and Metal fate		AlkPvt1 = 1/(1+(AlkPivot/max(Alk1,1))^3)
AlkPvt2		Y					Y	Alkalinity pivot function		AlkPvt2 = 1/(1+(AlkPivot/max(Alk2,1))^3)
AlkPvt3		Y					Y	Alkalinity pivot function		AlkPvt3 = 1/(1+(AlkPivot/max(Alk3,1))^3)
AlkPvt4		Y					Y	Alkalinity pivot function		AlkPvt4 = 1/(1+(AlkPivot/max(Alk4,1))^3)
AlkPvt5		Y					Y	Alkalinity pivot function		AlkPvt5 = 1/(1+(AlkPivot/max(Alk5,1))^3)
Alk_plume		Y				Y	Y	Alkalinity in discharge (mg/L CaCO3)		Alk_plume = Alk3 for load=0 (this is used only for convenient plotting - value not used by model)
Alk_plume		Y				Y	Y			= (860*QDwt + Q5P*Alk5 + RECYCLE*(Q3R*Alk3+Q4R*Alk4))/(QDwt+load*QDmisc+Q5P) by default
Area12		Y					Y	approx. interface area between compartments 1 and 2 (sq. m)		Area12 = 240000
Area23		Y					Y	approx. interface area between compartments 2 and 3 (sq. m)		Area23 = 218200
Area34		Y					Y	approx. interface area between compartments 3 and 4 (sq. m)		Area34 = 124000 + 31000*(VolTailsPoreWater/TailsPorosity/1740000)
Area45		Y					Y	approx. interface area between compartments 4 and 5 (sq. m)		Area45 = 88000 + 36000*(VolTailsPoreWater/TailsPorosity/1740000)
AvailWaterDepth		Y					Y	Available Maximum Water Depth (m) with Tails Loaded		AvailWaterDepth = WaterDepth+WatElev-468.7824 (WaterDepth from lookup table PitDepthAreaVolumeTable)
BoundTemp		Y				Y	Y	Negative air temperatures are dampened by empirical ice thickness insulation function to match ice formation		BoundTemp = T_air*exp(-Thickness_ICE1/60) for Thickness_ICE1 > 5
BoundTemp		Y				Y	Y			= T_air by default
C_mass		Y					Y	Accounting of mass of the tracked metal in HTDF and active tails bed		C_mass = (C1*Vol1+C2*Vol2+C3*Vol3+C4*Vol4+C5*Vol5+C_NHTDF*Vol_NHTDF+Cbed*ActivePoreVolTails)/1000000
Cinfluent		Y					Y	Concentration (ug/L) of tracked metal (such as nickel) in influent to wwtp, or outlet of HTDF.		Cinfluent = (Q1out*C1+QNout*C_NHTDF)/(Q1out+QNout)
C_plume		Y				Y		Concentration (ug/L) of tracked metal (such as nickel) in discharge plume, after initial contact with compartment 5.		C_plume = 0 for load=0
C_plume		Y				Y				= (2203*QDwt + Q5P*C5 + RECYCLE*(Q3R*C3+Q4R*C4))/(QDwt+load*QDmisc+Q5P) by default
DayOfYear		Y						Day of Year (Jan 1 = 1, t=0d for Ap. 4, of year 1), abs(error) < 0.8d		DayOfYear = (t+95) mod 365.25
density_discharge		Y					Y	Water density of distributed discharge (kg/cu m), function of temperature and salt (TDS) concentration		density_discharge = (wda+wdb*(T_plume-4)+wdc*(T_plume-4)^2+wdd*(T_plume-4)^3) + 0.00081*S_plume*(1-0.00243*T_plume)
density1		Y					Y	Water density of compartment 1 (kg/cu m)		density1 = (wda+wdb*(T1-4)+wdc*(T1-4)^2+wdd*(T1-4)^3) + 0.00081*S1*(1-0.00243*T1)
density2		Y					Y	Water density of compartment 2 (kg/cu m)		density2 = (wda+wdb*(T2-4)+wdc*(T2-4)^2+wdd*(T2-4)^3) + 0.00081*S2*(1-0.00243*T2)
density3		Y					Y	Water density of compartment 3 (kg/cu m)		density3 = (wda+wdb*(T3-4)+wdc*(T3-4)^2+wdd*(T3-4)^3) + 0.00081*S3*(1-0.00243*T3)
density4		Y					Y	Water density of compartment 4 (kg/cu m)		density4 = (wda+wdb*(T4-4)+wdc*(T4-4)^2+wdd*(T4-4)^3) + 0.00081*S4*(1-0.00243*T4)
density5		Y					Y	Water density of compartment 5 (kg/cu m)		density5 = (wda+wdb*(T5-4)+wdc*(T5-4)^2+wdd*(T5-4)^3) + 0.00081*S5*(1-0.00243*T5)
DO_bckgnd		Y					Y	Dissolved Oxygen at Saturation (mg/L, Chapra Eqn 19.32) minus 3 mg/L.		DO_bckgnd = exp((DOsat_p1+DOsat_p2/TKair+DOsat_p3/TKair^2+DOsat_p4/TKair^3+DOsat_p5/TKair^4)-S1/1000*(DOsat_p6+DOsat_p7/TKair+DOsat_p8/TKair^2)) - 3
DOsat_N		Y						Dissolved Oxygen at Saturation for Northern HTDF (mg/L) - Chapra Eqn 19.32		DOsat_N = exp((DOsat_p1+DOsat_p2/TK_N+DOsat_p3/TK_N^2+DOsat_p4/TK_N^3+DOsat_p5/TK_N^4)-S1/1000*(DOsat_p6+DOsat_p7/TK_N+DOsat_p8/TK_N^2))
DO_plume		Y				Y	Y	DO concentration in discharge plume (mg/L), after mixing. Note that RECYCLE may bring in considerable DO. Normal discharge DO is expected at 0.5 mg/L.		DO_plume = 0 for load=0
DO_plume		Y				Y	Y			= (0.5*QDwt + Q5P*DO5 + RECYCLE*(Q3R*DO3+Q4R*DO4))/(QDwt+load*QDmisc+Q5P) by default

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
DOsat1		Y						Dissolved Oxygen at Saturation for Compartment 1 (mg/L) - Chapra Eqn 19.32		DOsat1 = exp((DOsat_p1+DOsat_p2/TK1+DOsat_p3/TK1^2+DOsat_p4/TK1^3+DOsat_p5/TK1^4)-S1/1000*(DOsat_p6+DOsat_p7/TK1+DOsat_p8/TK1^2))
DryDensityLoad		Y					Y	dry density of tails in loading (kg/cu m)		DryDensityLoad = DensityWater/(1/SpecificGravityTails+1/PercentSolidsLoad-1)
DryDensityTailsBed		Y					Y	Dry density of tails in disposal (kg/cu m)		DryDensityTailsDisposal = DensityWater/(1/SpecificGravityTails+1/PercentSolidsTailsDisposal-1)
dT1_w_ICE		Y				Y	Y	rate equation used to develop heat balance and T1, for ice condition. Note that Heat_Surface and back radiation (26.4) are reduced by according to ice thickness. Heat_Surface is found from lookup table TempSolRad		dT1_w_ICE = ((Heat_Surface*exp(-Thickness_ICE1/85)-26.4*exp(-Thickness_ICE1/60)-0.55*(T1-BoundTemp))*HTDF_Area_Main/1000+(T_air)*NaturalFlowMainHTDF*HeatFactor -H12-H1N+HN1+H21-H1out-T1*HeatFactor*VolRate1)/((Vol1_w_ICE)*HeatFactor) for load = 0
dT1_w_ICE		Y			Y	Y				= ((Heat_Surface*exp(-Thickness_ICE1/85)-26.4*exp(-Thickness_ICE1/60)-0.55*(T1-BoundTemp))*HTDF_Area_Main/1000+(T_air)*NaturalFlowMainHTDF*HeatFactor +QP1/Qdist*Heat_dist_discharge-H12-H1N+HN1+H21-H1out-T1*HeatFactor*VolRate1)/((Vol1_w_ICE)*HeatFactor) by default
dT1_wo_ICE		Y			Y	Y		rate equation used to develop heat balance and T1, for ice-free condition. Heat_Surface is found from lookup table TempSolRad		dT1_wo_ICE = ((Heat_Surface-4.75e-09*(T1+273)^4-0.55*(T1-T_air))*HTDF_Area_Main/1000+(T_air)*NaturalFlowMainHTDF*HeatFactor -H12-H1N+HN1+H21-H1out-T1*HeatFactor*VolRate1)/(Vol1*HeatFactor) for load = 0
dT1_wo_ICE		Y			Y	Y				= ((Heat_Surface-4.75e-09*(T1+273)^4-0.55*(T1-T_air))*HTDF_Area_Main/1000+(T_air)*NaturalFlowMainHTDF*HeatFactor +QP1/Qdist*Heat_dist_discharge-H12-H1N+HN1+H21-H1out-T1*HeatFactor*VolRate1)/(Vol1*HeatFactor) by default
dTN_w_ICE		Y					Y	see note for dT1_w_ice.		dTN_w_ICE = ((Heat_Surface*exp(-Thickness_ICE_N/85)-26.4*exp(-Thickness_ICE_N/60)-0.55*(T_NHTDF-BoundTemp))*HTDF_Area_North/1000+(T_air)*NaturalFlowNHTDF*HeatFactor +H1N-HN1- HNout-T_NHTDF*HeatFactor*VolRateN)/(VolN_w_ICE*HeatFactor)
dTN_wo_ICE		Y					Y	see note for dT1_wo_ice.		dTN_wo_ICE = ((Heat_Surface-4.75e-09*(T_NHTDF+273)^4-0.55*(T_NHTDF-T_air))*HTDF_Area_North/1000+(T_air)*NaturalFlowNHTDF*HeatFactor+H1N-HN1-HNout-T_NHTDF*VolRateN*HeatFactor)/(Vol_NHTDF*HeatFactor)
ElevRate		Y					Y	dWatElev/dt in units of m per day		ElevRate = (NaturalFlowMainHTDF+NaturalFlowNHTDF+Qgw2+QD-QR-Total_Outflow)/(2*VE_a*WatElev+VE_b)
Heat_discharge_total		Y						Total heat discharge (GJ/d)		Heat_discharge_total = (T_dryTails*TailsIn*HeatFactorTails+(T3*Q3R+T4*Q4R+T_gw2*(QDwt-QR)+T_air*load*QDmisc)*HeatFactor)
Heat_dist_discharge		Y					Y	Distributed heat discharge to compartments in plume (GJ/d)		Heat_dist_discharge = T_plume*(QDwt+Q5P-Q5pw)*HeatFactor
ka1		Y				Y		Estimated rearation coeff (cu.m/d), compartment 1 (see Chapra 1997, Ch. 20).		ka1 = 0 for ICE1>0
ka1		Y				Y				= 156000*1.024^(T1-20) by default
ka_N		Y				Y		Estimated rearation coeff (cu. m/d), northern HTDF (see Chapra 1997, Ch. 20).		ka_N = 0 for ICE_N>0
ka_N		Y				Y				= 26000*1.024^(T_NHTDF-20) by default
load		Y					Y	Flag to allow loading of tails, LoadON comes from lookup table TailsLoading		load = LoadON*GlobalLoadSwitch
LookupBedArea		Y						Used for comparison to fitted curve only - seeTailsBedArea		LookupBedArea = Area
MassBalance		Y						Mass balance check, for nickel case		MassBalance = ((1-RECYCLE)*RecycleMass+C_mass+C_burial+C_treated)/(DischargeMass+663.5)
mix12		Y					Y	Intercompartment mixing between compartments 1 and 2 (cu m/d)		mix12 = max(mixQ*(min(1,sqrt(max((density1-density2),0)/(density1+density2))/DensityFactor)*(mixQmax-mixQmin)+mixQmin), mix12_wo_ice)
mix12_wo_ice		Y				Y		adjusts for ice and no ice periods		mix12_wo_ice = 0 for Thickness_ICE1 > 1
mix12_wo_ice		Y				Y				= WindMix12 by default
mix1N		Y					Y			mix1N = max(minMixQ1N,0.5*NaturalFlowNHTDF)
mix23		Y					Y	Intercompartment mixing between compartments 2 and 3 (cu m/d)		mix23 = mixQ*(min(1,sqrt(max((density2-density3),0)/(density2+density3))/DensityFactor)*(mixQmax-mixQmin)+mixQmin)+0.1*mix12
mix34		Y					Y	Intercompartment mixing between compartments 3 and 4 (cu m/d)		mix34 = mixQ*(min(1,sqrt(max((density3-density4),0)/(density3+density4))/DensityFactor)*(mixQmax-mixQmin)+mixQmin)
mix45		Y					Y	Intercompartment mixing between compartments 4 and 5 (cu m/d)		mix45 = mixQ*(min(1,sqrt(max((density4-density5),0)/(density4+density5))/DensityFactor)*(mixQmax-mixQmin)+mixQmin)
mix_pl2		Y				Y	Y	Proportional remaining plume flow bypassing compartment 2		mix_pl2 = 0 for load = 0
mix_pl2		Y				Y	Y			= min(1,sqrt(max(0,(density2-density_discharge))/(density2+density_discharge))/DensityFactor)*(mixQmax-mixQmin)+mixQmin by default
mix_pl3		Y				Y	Y	Proportional remaining plume flow bypassing compartment 3		mix_pl3 = 0 for load = 0

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
mix_pl3		Y				Y	Y			= min(1,sqrt(max(0,(density3-density_discharge))/(density3+density_discharge))/DensityFactor)*(mixQmax-mixQmin)+mixQmin by default
mix_pl4		Y				Y	Y	Proportional remaining plume flow bypassing compartment 4		mix_pl4 = 0 for load = 0
mix_pl4		Y				Y	Y			= min(1,sqrt(max(0,(density4-density_discharge))/(density4+density_discharge))/DensityFactor)*(mixQmax-mixQmin)+mixQmin by default
mix_pl5		Y				Y	Y	Proportional discharge plume flow bypassing compartment 5		mix_pl5 = 0 for load = 0
mix_pl5		Y				Y	Y			= min(1,sqrt(max(0,(density5-density_discharge))/(density5+density_discharge))/DensityFactor)*(mixQmax-mixQmin)+mixQmin by default
NaturalFlowMainHTDF		Y					Y	Converts net precip (mm/d) to flow in main pit lake (cu m/d). NetPrecipWithMelt comes from lookup table Runoff		NaturalFlowMainHTDF = NetPrecipWithMelt/1000*PercentBasinAreaToMainHTDF*TotalBasinArea
NaturalFlowNHTDF		Y					Y	Converts net precip (mm/d) to flow in northern HTDF (cu m/d), see lookup table Runoff		NaturalFlowNHTDF = NetPrecipWithMelt/1000*(1-PercentBasinAreaToMainHTDF)*TotalBasinArea
P_plume		Y				Y	Y	DO demand concentration in discharge plume, after plume mixing point (mg/L)		P_plume = 0 for load=0
P_plume		Y				Y	Y			= (3*QDwt + Q5P*P5 + RECYCLE*(Q3R*P3+Q4R*P4))/(QDwt+load*QDmisc+Q5P) by default
Q1out		Y					Y	Outflow from 1 to WWTP (cu m/d)		Q1out = NaturalFlowMainHTDF+QP1+Q21-mix12-VolRate1
Q21		Y					Y	Flow from compartment 3 to 2 (cu m/d)		Q21 = QP2+Qgw2+mix12+(Q32-mix23)-VolRate2
Q32		Y					Y	Flow from compartment 3 to 2 (cu m/d)		Q32 = QP3+mix23+(Q43-mix34)-Q3R-VolRate3
Q3R		Y					Y	Flow from Compartment 3 to Return Flow to Mill (cu m/d)		Q3R = QR*QR_portion3
Q43		Y					Y	Flow from compartment 4 to 3 (cu m/d)		Q43 = QP4+mix34+(Q54-mix45)-Q4R-VolRate4
Q4R		Y					Y	Flow from compartment 4 to mill return flow (cu m/d)		Q4R = QR*(1-QR_portion3)
Q54		Y					Y	Flow from compartment 5 to 4 (cu m/d)		Q54 = QP5_water+mix45-Q5P-VolRate5
Q5P		Y					Y	Flow from 5 to mix with discharge to form plume (cu m/d)		Q5P = Q5pw+DischargeMF*QD
Q5pw		Y					Y	Flow (cu m/d) from 5 to bed pore water		Q5pw = TailsPorosity*VolRateTails
QD		Y					Y	Total Flow Rate with Tails (cu m/d)		QD = load*(TailsIn*1000/DryDensityLoad + QDmisc)
Qdist		Y					Y	Plume flow, includes mix water from 5 if DischargeMF >0 (cu m/d)		Qdist = (1+DischargeMF)*QD-VolRateSolids
QDwt		Y					Y	Pore water associated with discharged tails, without QDmisc (cu m/d)		QDwt = (QD-load*QDmisc-VolRateSolids)
QNout		Y					Y	Outflow from N HTDF to WWTP (cu m/d)		QNout = NaturalFlowNHTDF-VolRateN
QP1		Y					Y	Flow bypassing compartment 2 in plume (cu m/d)		QP1 = QP32-QP2
QP2		Y					Y	Flow from plume to compartment 2 (cu m/d)		QP2 = QP32*(1-mix_pl2)
QP3		Y					Y	Flow from plume to compartment 3 (cu m/d)		QP3 = QP43*(1-mix_pl3)
QP32		Y						Flow bypassing compartment 3 in plume (cu m/d)		QP32 = QP43-QP3
QP4		Y					Y	Flow from plume to compartment 4 (cu m/d)		QP4 = QP54*(1-mix_pl4)
QP43		Y						Flow bypassing compartment 4 in plume (cu m/d)		QP43 = QP54-QP4
QP5		Y					Y	Flow from discharge proportioned to compartment 5 (cu m/d)		QP5 = Qdist*(1-mix_pl5)+VolRateSolids
QP5_water		Y					Y	Plume flow to compartment 5, water only (cu m)		QP5_water = QP5-VolRateSolids
QP54		Y						Flow bypassing compartment 5 in plume (cu m/d)		QP54 = Qdist*mix_pl5
QR		Y					Y	Reclaim Flow Rate from HTDF back to Mill (cu m/d)		QR = ReturnFlowPercent*QDwt
RH_bed		Y					Y	Dimensionless factor relating total heat and heat flows in bed to heat in bed pore water		RH_bed = 1+DryDensityTailsDisposal/1000/TailsPorosity*HeatFactorTails/HeatFactor

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
S_plume		Y				Y	Y	Salt concentration in discharge (mg/L TDS)		S_plume = 0 for load=0
S_plume		Y				Y				= (1000*QDwt + Q5P*S5 + RECYCLE*(Q3R*S3+Q4R*S4))/(QDwt+load*QDmisc+Q5P) by default
TailsBedArea		Y				Y	Y	Estimated Tails Bed Area (sq m) with Tails Loaded		TailsBedArea = Area45 for GlobalLoadSwitch = 0
TailsBedArea		Y				Y				= max(0,133060-AV1/AV2*exp(-AV2*TailsVolume)-AV3/Av4*exp(-AV4*TailsVolume)) by default
TailsPorosity		Y					Y	Porosity of Bed Tails		TailsPorosity = (1/PercentSolidsTailsDisposal-1)*DryDensityTailsDisposal/DensityWater
TailsVolume		Y						Volume of tails stored in HTDF (cu m), with use of metric tons to kg conversion		TailsVolume = TailsLowerHTDF*1000/DryDensityTailsDisposal
T_discharge		Y				Y		Temperature in discharge line (C)		T_discharge = T3 for load = 0
T_discharge		Y				Y				= Heat_discharge_total/(TailsIn*HeatFactorTails+(QDwt+load*QDmisc)*HeatFactor) by default
Thickness_ICE_N		Y					Y	Thickness of ICE (cm)		Thickness_ICE_N = ICE_N/Density_ICE/HTDF_Area_North*100
Thickness_ICE1		Y					Y	Thickness of ICE (cm)		Thickness_ICE1 = ICE1/Density_ICE/HTDF_Area_Main*100
TK_N		Y						Temperature of compartment N, in Kelvin		TK_N = T_NHTDF+273.15
TK1		Y						Temperature of compartment 1, in Kelvin		TK1 = T1+273.15
TKair		Y						Temperature of air, in Kelvin - limited to nonfreezing temps		TKair = max(BoundTemp,0)+273.15
Total_Outflow		Y				Y	Y	Future update may allow for other outflows, or adjustment to outflow for high or low water elevation conditions.		Total_Outflow = Q_wwtp_postload for t > 2608
Total_Outflow		Y				Y				= Q_wwtp * 0.1 for WatElev < 466.954
Total_Outflow		Y				Y				= Q_wwtp*GlobalLoadSwitch+ Q_wwtp_postload*(1-GlobalLoadSwitch) by default
T_plume		Y				Y	Y	Temperature of discharge plume, with mixing Q5m from compartment 5 (C)		T_plume = T5 for load = 0
T_plume		Y				Y				= (Heat_discharge_total+Q5P*T5*HeatFactor)/(HeatFactor*(QDwt+load*QDmisc+Q5P)+TailsIn*HeatFactorTails) by default
Vol_Full_HTDF		Y					Y	Relates water elevation (m) to unfilled volume (cu. m), for 1520 - 1542 ft. elevations		Vol_Full_HTDF = VE_a*WatElev^2 + VE_b*WatElev + VE_c1
Vol_NHTDF		Y					Y	Volume of Northern Pit Lake (cu. m), varies with water elevation		Vol_NHTDF = VE_N_a*WatElev^2 + VE_N_b*WatElev + VE_N_c1 -ICE_N
Vol1		Y					Y	Volume (cu. m) of top layer, main HTDF (0-6 ft), varies with water elevation.		Vol1 = (Vol_Full_HTDF-Vol_NHTDF-Vol_Lower_HTDF_init)*VolPortion1
Vol1_w_ICE		Y					Y	Volume of compartment 1, adjusted for ice volume - for heat balance only		Vol1_w_ICE = Vol1-ICE1/Density_ICE
Vol2		Y					Y	Volume (cu m) for Water Depth Range 6-24 ft. (1.83 - 7.32 m)		Vol2 = (Vol_Full_HTDF-Vol_NHTDF-Vol_Lower_HTDF_init)*(1-VolPortion1)
Vol3		Y					Y	variable volume occupied by 3rd compartment (cu m)		Vol3 = (VolumeRemaining-Vol1-Vol2-Vol_NHTDF)*VolPortion3
Vol4		Y					Y	variable Volume for compartment 4 (cu m)		Vol4 = (VolumeRemaining-Vol1-Vol2-Vol_NHTDF)*VolPortion4
Vol5		Y					Y	variable Volume for 5th compartment (cu m)		Vol5 = (VolumeRemaining-Vol1-Vol2-Vol_NHTDF)*(1-VolPortion3-VolPortion4)
VolN_w_ICE		Y					Y	Volume of Northern HTDF, adjusted for ice volume - for heat balance only		VolN_w_ICE = Vol_NHTDF-ICE1/Density_ICE
VolRate1		Y					Y	dVol1/dt in units of cu. m per day, due to changes in Water Elevation		VolRate1 = VolPortion1*(2*VE_main_a*WatElev + VE_main_b)*ElevRate
VolRate2		Y					Y	dVol2/dt in units of cu. m per day, from changes in Water elevation		VolRate2 = VolRate1 * (1-VolPortion1)/(VolPortion1)
VolRate3		Y					Y	dVol3/dt in units of cu. m per day, change due to tails loading		VolRate3 = -VolPortion3*VolRateTails
VolRate4		Y					Y	dVol4/dt in units of cu. m per day, change due to tails loading		VolRate4 = -VolPortion4*VolRateTails
VolRate5		Y					Y	dVol5/dt in units of cu. m per day, change due to tails loading		VolRate5 = -(1-VolPortion3-VolPortion4)*VolRateTails
VolRateActiveTails		Y					Y	Active Volume of Tails pore water (cu. m) used for algorithm for burial and exchange		VolRateActiveTails = ActiveBedThick*TailsPorosity*VolRateTails*(AV1*exp(-AV2*TailsVolume)+AV3*exp(-AV4*TailsVolume))
VolRateN		Y					Y	dVolN/dt in units of cu. m per day, due to changes in Water Elevation		VolRateN = (2*VE_N_a*WatElev + VE_N_b)*ElevRate

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
VolRateSolids		Y						Water Demand for Tailings Processing (cu m/day), TailsIn from lookup table TailsLoading		VolRateSolids = load*TailsIN*1000/SpecificGravityTails/DensityWater
VolRateTails		Y					Y	Volume rate of tails loading (cu m/d)		VolRateTails = TailsIn*1000/DryDensityTailsDisposal
VolTailsPoreWater		Y					Y	Pore water volume (cu. m) occupied by deposited tails		VolTailsPoreWater = TailsVolume*TailsPorosity
VolumeCheck		Y								VolumeCheck = Vol1+Vol2+Vol3+Vol4+Vol5+Vol_NHTDF+TailsVolume
VolumeRemaining		Y					Y	Total Volume Remaining in HTDF (cu m)		VolumeRemaining = Vol_Full_HTDF-TailsVolume
ActiveBedThick			Y					Active tails bed thickness, for burial and diffusion algorithm (m)	0.5	
Alk_background			Y					Alkalinity of runoff water (mg/L as CaCO3)	100	
AlkDemandParam			Y					Alkalinity demand from oxidation reaction. Assumes 8 equivalents of alkalinity consumed per mole of O2 reduced.	12.5	
AlkPivot			Y					Pivot Value for alkalinity (mg/L as CaCO3) used for metal scavenging and OxFe settling/dissolution	200	
AV1			Y					Coeff. for slope of TailsBedArea vs. TailsVolume curve	0.073667	
AV2			Y					Coeff. for slope of TailsBedArea vs. TailsVolume curve	8.13E-07	
AV3			Y					Coeff. for slope of TailsBedArea vs. TailsVolume curve	2.19558	
AV4			Y					Coeff. for slope of TailsBedArea vs. TailsVolume curve	5.18E-05	
BedDiffusion			Y					Diffusion mass transfer coeff from bed (m/d)	4.00E-05	
BedHeatTransfer			Y					Bed Heat Transfer Coeff (GJ/sq m-d-C)	0.05	
C_background			Y					Background concentration for natural flows (ug/L)	5	This parameter is for case of nickel run. Other modeled cases may vary.
Density_ICE			Y					Density of Ice (tonnes/cu. m)	0.9162	
DensityFactor			Y					Factor for mixing formula based on densities	0.02	
DensityWater			Y					Density of Water (kg/cu m)	1000	
DischargeMF			Y					Discharge Mix Flow Parameter, scales flow from compartment 5 to mix with discharge to form plume.	0.05	
DObed			Y					Dissolved Oxygen (mg/L) in bed porewater (usually zero).	0	
DOsat_p1			Y					DO saturation parameter (APHA 1992, Chapra 1997 - Eqn 19.32)	-139.344	
DOsat_p2			Y					DO saturation param, Chapra (1997) Eqn. 19.32.	157570	
DOsat_p3			Y					DO saturation param, Chapra (1997) Eqn. 19.32.	-6.64E+07	
DOsat_p4			Y					DO saturation param, Chapra (1997) Eqn. 19.32.	1.24E+10	
DOsat_p5			Y					DO saturation param, Chapra (1997) Eqn. 19.32.	-8.62E+11	
DOsat_p6			Y					DO saturation param, Chapra (1997) Eqn. 19.34	0.017674	
DOsat_p7			Y					DO saturation param, Chapra (1997) Eqn. 19.34	-10.754	
DOsat_p8			Y					DO saturation param, Chapra (1997) Eqn. 19.34	2140.7	
GlobalLoadSwitch			Y					Switch (0=off, 1=on) to determine if model run has HTDF tails loading	1	
HeatFactor			Y					Approx. heat capacity times density of water (GJ/cu.m/C)	0.00419	
HeatFactorTails			Y					heat capacity of tails (GJ/tonne/C)	0.00084	

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	Initial value	Equations
HTDF_Area_Main			Y					Area of Main HTDF surface (sq. m), used for heat balance	246837	
HTDF_Area_North			Y					Area of Northern HTDF surface (sq. m), used for heat balance	22569	
K_complex1			Y					Complexation constant for oxidized iron and C in compartment 1 (see F12)	0.01	This parameter is for case of nickel and similarly scavenged metals. Other cases may vary
K_complex2			Y					Complexation coeff for C2 and (see F23)	0.01	
K_complex3			Y					Complexation coeff for C3 and FeOX3 (see F34)	0.01	
K_complex4			Y					Complexation coeff for C4 and FeOX4 (see F45)	0.01	
K_complex5			Y					Complexation coeff for C5 and FeOX5 (see F5bed)	0.01	
kd_basic			Y					DO consumption rate constant (1/d) at 20C, relates to demand variable P	0.1	
LatentHeatIce			Y					Latent Heat of Melting, Ice (GJ/tonne)	0.334	
minMixQ1N			Y					Minimum flow rate (cu. m/d) used to simulate mixing between C1 and N	50	
mixQ			Y					Basis for mixing between compartments, subject to mixQmin and mixQmax	15000	
mixQmax			Y					Maximum portion of MixQ used for intercompartement mixing	0.99	
mixQmin			Y					Minimum portion of MixQ used for intercompartement mixing	0.03	
OxFe_background			Y					Ferric iron concentration in background input'	0.45	
P_Background			Y					DO demand concentration in background (mg/L)	0.1	
PercentBasinAreaToMainHTDF			Y					Percent of total basin area that is expected to drain to Main Pit Lake	0.866	
PercentSolidsLoad			Y					Percent Solids in Tails Loading to HTDF	0.6	
PercentSolidsTailsDisposal			Y					Percent Solids of Tails in HTDF	0.72	
Q_wwtp			Y					Flow rate for wastewater treatment and discharge, 420 gpm=2289	1816	
Q_wwtp_postload			Y					Flow Rate (m3/d) for wwtp after tails load complete	1340	
Qgw2			Y					Groundwater input flow to compartment 2 (cu. m/d). 234 cu.m/d = 43 gpm.	234	
QR_portion3			Y					Portion of return flow QR drawn from Compartment 3 (remainder from 4)	1	
RECYCLE			Y					Flag (0 or 1) for consideration of compartment 3 and 4 mass recycled back to discharge. Heat balance not affected by this parameter.	0	
ReturnFlowPercent			Y					Return flow percentage (of discharge water associated with tails, Qdwt) from HTDF (compartments 3 and/or 4) to Mill	0.827	
S_background			Y					Background salt concentration (TDS, mg/L)	200	
SpecificGravityTails			Y					Specific Gravity of Tails Solids	3.03	
T_dryTails			Y					Temperature of dry tails (C), used for heat balance	27	
T_gw2			Y					Temperature of groundwater for Qgw2 (C)	15	
TotalBasinArea			Y					Total Basin Area, including Main and Northern HTDF (cu. m)	857628	
TotalPitVolume			Y					Total HTDF Volume Prior to Loading, includes Northern End (cu m)	8.00E+06	

Name	Compartment	Variable	Parameter	Flow	Lookup Table	Conditional	Global	Description	initial value	Equations
VE_a			Y					coefficient for Full HTDF volume and elevation equation	2905.56	
VE_b			Y					coefficicent for Full HTDF volume and elevation equation	-2.45E+06	
VE_c1			Y					Part 1 of 2-part coefficient C of Full HTDF volume and elevation eqn.	5.19E+08	
VE_main_a			Y					coefficient for Main HTDF volume and elevation equation	2095.95	
VE_main_b			Y					coefficient for Main HTDF volume and elevation equation	-1.72E+06	
VE_main_c1			Y					coefficient for Main HTDF volume and elevation equation	3.52E+08	
VE_N_a			Y					coefficient for N HTDF volume and elevation equation	809.614	
VE_N_b			Y					coefficient for N HTDF volume and elevation equation	-735809	
VE_N_c1			Y					coefficient for N HTDF volume and elevation equation	1.67E+08	
Vol_Lower_HTDF_init			Y					Initial Volume (cu. m) of lower compartments C3-C4, elev = 1514 ft. (461.47 m)	6.09E+06	
VolPortion1			Y					Portion Vol1 in volume of compartments 1 and 2	0.26	
VolPortion3			Y					Portion of Lower Volume (3-5) Occupied by 3rd Compartment	0.6	
VolPortion4			Y					Portion of Lower Volume (3-5) Occupied by 4th Compartment	0.25	
vsFe			Y					Settling rate for oxidized iron particles (m/d)	0.08	
wda			Y					Water density function coeff a (density at 4C)	1000	
wdb			Y					water density coeff b	-0.00391	
wdc			Y					water density coeff c	-0.00725	
wdd			Y					water density coeff d	3.83E-05	
WindMix12			Y					Wind-induced mixing of 1 and 2 (cu m/d), only during ice-free periods	2000	
PitDepthAreaVolumeTable					Y			Pit Depth-Area-Volume Relationship (page 2 table w/o N HTDF)		Tails Volume Control, Area Controlled by TailsVolume, Elevation Controlled by TailsVolume, WaterDepth Controlled by TailsVolume. All table lookups based on linear interpolation.
TailsLoading					Y			Dry tonnes of tails loaded to HTDF (April start in year 1)		t Control, LoadON controlled by t (central value interpolation), TLR controlled by t (central value interpolation)
Runoff					Y			Precipitation minus expected evaportaion		DayOfYear Control, NetPrecipWithMet Controlled by DayOfYear (linear interpolation)
TempSolRad					Y			Temperature and Solar Radiation information for heat balance.		DayofYear Control, Heat_Surface Controlled by DayOfYear (central value interpolation), T_air controlled by DayOfYear (linear interpolation), e_sat controlled by DayOfYear (central value interpolation), e_air Controlled by Day of Year (central value interpolation)

Lookup Table **TempSolRad**

DayOfYear	Heat_Surface	T_air	e_sat	e_air
0	17.80722789	-10.7222	1.90717826	1.430384
10	17.80722789	-11.5	1.90717826	1.430384
20	17.80722789	-10.9583	1.90717826	1.430384
32	21.36519758	-9.875	2.2662442	1.835658
41	21.36519758	-9.33333	2.2662442	1.835658
51	21.36519758	-8.02778	2.2662442	1.835658
60	26.32776364	-5.41667	3.38961697	2.440524
69	26.32776364	-4.11111	3.38961697	2.440524
79	26.32776364	-2.29167	3.38961697	2.440524
91	30.37795043	1.34722	5.76965449	3.461793
100	30.37795043	3.16667	5.76965449	3.461793
110	30.37795043	5.04167	5.76965449	3.461793
121	34.97168925	8.79167	9.66085265	6.472771
130	34.97168925	10.6667	9.66085265	6.472771
140	34.97168925	11.8194	9.66085265	6.472771
152	37.08778479	14.125	13.0632648	8.752387
161	37.08778479	15.2778	13.0632648	8.752387
171	37.08778479	15.9444	13.0632648	8.752387
182	38.9292163	17.2778	15.4764387	11.60733
191	38.9292163	17.9444	15.4764387	11.60733
201	38.9292163	17.6944	15.4764387	11.60733
213	35.52497584	17.1944	14.5293026	10.89698
222	35.52497584	16.9444	14.5293026	10.89698
232	35.52497584	15.7917	14.5293026	10.89698
244	29.74107843	13.4861	10.7878925	7.767283
253	29.74107843	12.3333	10.7878925	7.767283
263	29.74107843	10.8472	10.7878925	7.767283
274	25.18270212	7.875	7.22798896	5.710111
283	25.18270212	6.38889	7.22798896	5.710111
293	25.18270212	4.43056	7.22798896	5.710111
305	19.97115355	0.513889	4.1347221	3.142389
314	19.97115355	-1.44444	4.1347221	3.142389
324	19.97115355	-3.18056	4.1347221	3.142389
335	18.21474959	-6.65278	2.44072206	2.123428
344	18.21474959	-8.38889	2.44072206	2.123428
354	18.21474959	-9.16667	2.44072206	2.123428
367	18.21474959	-9.944435	2.44072206	2.123428

Lookup Table **Runoff**

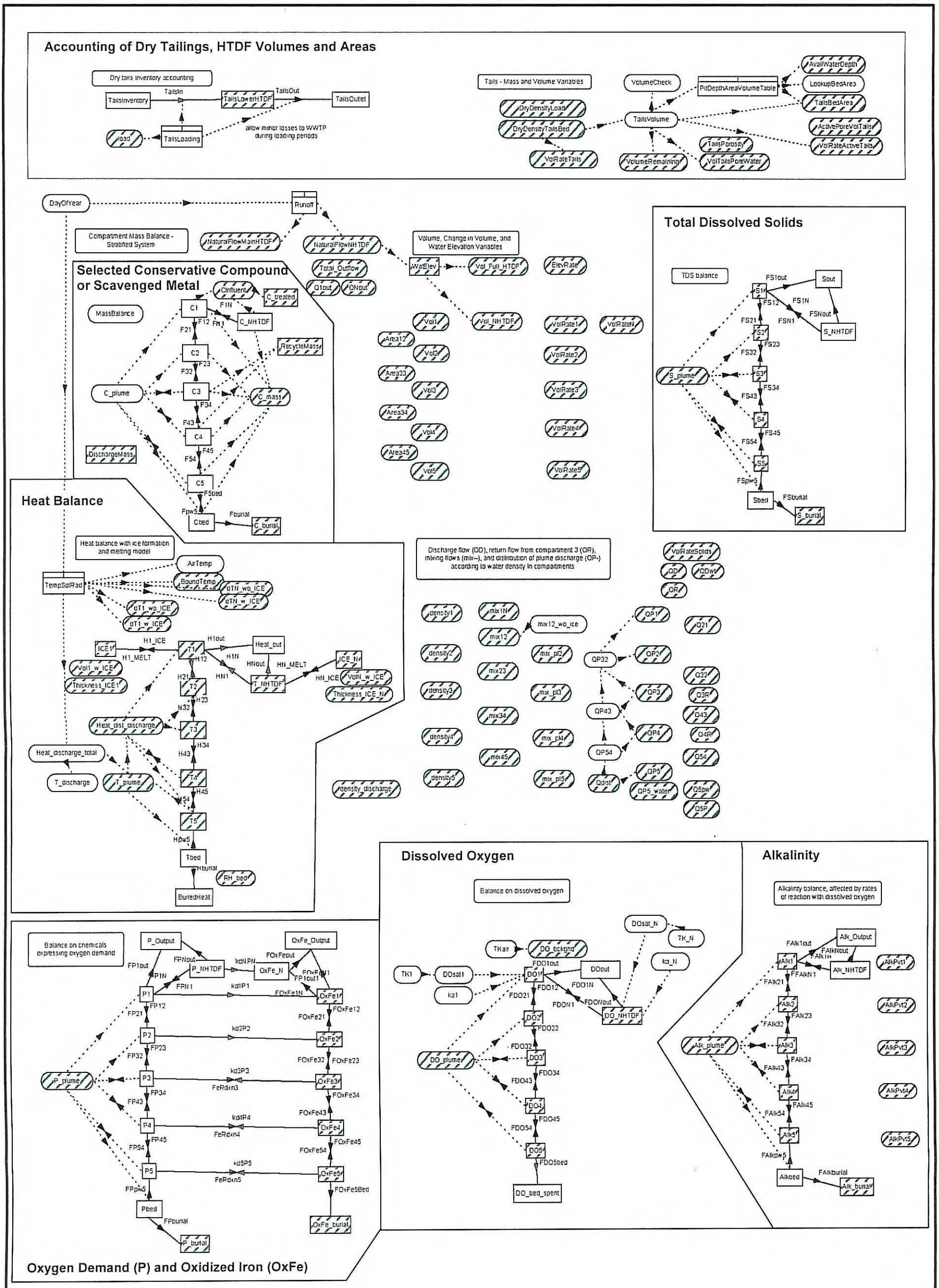
DayOfYear	NetPrecipWithMelt
0	0
10	0
20	0
32	0
41	0
51	0
60	1.073700934
69	1.073700934
79	1.073700934
91	3.752249476
100	3.752249476
110	3.752249476
121	2.763764889
130	2.763764889
140	2.763764889
152	1.083936533
161	1.083936533
171	1.083936533
182	0.812013419
191	0.812013419
201	0.812013419
213	0.883985548
222	0.883985548
232	0.883985548
244	1.783012267
253	1.783012267
263	1.783012267
274	2.090010323
283	2.090010323
293	2.090010323
305	1.180090773
314	1.180090773
324	1.180090773
335	0
344	0
354	0
367	0

Lookup Table **PitDepthAreaVolumeTable**

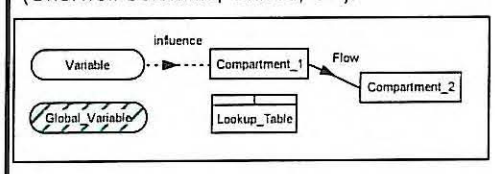
TailsVolume	Area	Elevation	WaterDepth
0	0	410.26	58.52
14049.6866	23047.4	411.48	57.3
123429.453	48724.1	414.53	54.25
292601.94	62281.5	417.58	51.21
504399.352	76693.2	420.62	48.16
750580.353	84842.9	423.67	45.11
1018645.6	91053	426.72	42.06
1306477.15	97812.9	429.77	39.01
1617660.6	106375.7	432.82	35.97
1955891.88	115560.8	435.86	32.92
2321258.49	124181.1	438.91	29.87
2721848.99	138673.6	441.96	26.82
3161544.35	149840.4	445.01	23.77
3632224.99	159005.1	448.06	20.73
4132386.16	169184.6	451.1	17.68
4664762.7	180143.8	454.15	14.63
5226645.67	188545.8	457.2	11.58
5834316.99	210188.7	460.25	8.53
6499726.64	226431.8	463.3	5.49
7206803.54	237529.4	466.34	2.44
7797434.03	246831.2	468.78	0
8103799	255735.5	470	-1.22

Lookup Table **TailsLoading**

t	LoadON	TLR
0	0	0
1	1	700
220	1	700
221	0	0
271	0	0
272	1	1159
591	1	1159
592	0	0
637	0	0
638	1	1159
957	1	1159
958	0	0
1003	0	0
1004	1	1159
1323	1	1159
1324	0	0
1369	0	0
1370	1	1159
1689	1	1159
1690	0	0
1735	0	0
1736	1	1159
2055	1	1159
2056	0	0
2101	0	0
2102	1	1159
2421	1	1159
2422	0	0
2472	0	0
2473	1	900
2608.3	1	900
2609	0	0
3609	0	0
1E+06	0	0



Model developed using ModelMaker, v. 4.0
(Cherwell Scientific, Oxford, UK).



Foth
Foth Infrastructure & Environment, LLC

Foth Infrastructure & Environment, LLC			
REVISED		BY	DESCRIPTION
DATE:			
DATE:			
DATE:			
CHECKED BY:	JBM	DATE:	OCT '07
APPROVED BY:	JBM	DATE:	OCT '07
APPROVED BY:		DATE:	

Kennecott
Eagle Minerals

FIGURE F-1
HTDF MULTI-COMPARTMENT MASS AND HEAT BALANCE SCHEMATIC

Scale:	NA	Date:	SEPT. 2007
Prepared by:	GRE	Project No:	06W003

M: \06W003\igr\HTDF_Model_Schematic.pxp