Application

Kennecott
Eagle Minerals

Humboldt Mill

Mining Permit Application
Volume IA

(Appendices A through G)

Project I.D.: 06W003

Kennecott Eagle Minerals Company
Ishpeming, Michigan

December 2008

Foth

Appendix A

Mining Permit Application Forms and Checklist

A-1

MDEQ Mining Permit Application

DEQ MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF GEOLOGICAL SURVEY

APPLICATION FOR PERMIT TO CONDUCT NONFERROUS METALLIC MINERAL MINING AND RECLAMATION OPERATIONS

By authority of Part 632 of Act 451 PA 1994, as amended. Non-submission and/or falsification of this information may result in civil or criminal penalties.

1. Applicant:

Company Name Kennecott Eagle Minerals Company

Address 504 Spruce Street Telephone (906) 486-1257

City Ishpeming State MI Zip 49849

Federal Employer ID. Number:

2. Contact person for correspondence and inquiries regarding application:

Name Vicky Peacey

Title Environmental Engineer email vpeacey@kennecott.com

Address 504 Spruce Street Telephone (906) 486-1257 x 229

City Ishpeming State MI Zip 49849

3. Name of proposed mine or project: Humboldt Mill Project

Primary target nonferrous metallic mineral(s) Cu and Ni

Any beneficiation activities not within or adjacent to the mine site or by an entity other than the applicant? Yes ☐ No ☒ (check one)

4. Section(s), Township and Range number(s), Township Name(s), and County(ies) of the proposed mining area (as defined in Part 632, Section 63201(h)) :

Section 2 and 11, T 47N 1229W Humboldt Township, Marquette County

Location from Major Highway Intersection (Describe): Intersection of Hwy 41 and 95

5. ☒ $5,000.00 permit application fee enclosed. Make checks payable to the **STATE OF MICHIGAN.**

6. Attachments (each attachment must show person who is responsible for its preparation):

☒ Environmental impact assessment *(Volume II series)*

☐ Mining, reclamation, and environmental protection plan *(Volume I)*

☐ Contingency plan *(Volume I)*

☒ Description of type or types and amount of financial assurance *(Volume I)*

☒ List of all other applicable permits and licenses anticipated to be required *(Volume I)*

☒ Organization report *(Volume IA)*

7. Person submitting application:

Name Jonathan C. Cherry

Title General Manager email cherryj@kennecott.com

Address 504 Spruce St Telephone (906) 486-1257 x 201

City Ishpeming State MI Zip 49849

CERTIFICATION: "I state that I am the applicant or an authorized representative of the applicant. This application was prepared under my supervision and direction. The facts stated herein are true, accurate, and complete to the best of my knowledge."

Signature Jonathan C. Cherry Date 12-15-08

File application and attachments as follows:

Original, 1 paper copy, and electronic file to:	8 paper copies to:
Michigan Department of Environmental Quality Office of Geological Survey 525 W. Allegan Lansing, MI 48909-7756	Michigan Department of Environmental Quality Upper Peninsula District Office 420 5th Street Gwinn, MI 49841

Office of Geological Survey use only		DEQ Cashier use only
Application Number:	*Date received:*	

EQP 7700 (8/2007)

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MPA Checklist

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
Part 1	General Provisions	
Rule 101	Purpose	Applied throughout MPA
Rule 102	Definitions (A to L)	Used throughout MPA
Rule 103	Definitions (M to Z)	Used throughout MPA
Part 2	Permits	
Rule 201	Permit Requirements	
1a	Application form	Volume I - Appendix A
1b	Application fee	included with cover letter
1c	Environmental Impact Assessment (EIA)	Volume II
1d	Mining, reclamation, environmental protection plan	Sections 4, 6 and 5 respectively
1e	Contingency plan	Section 7
1f	Financial assurance	Section 8
1g	List of other permits and licenses	Section 1.4
1h	Organization report	Volume I - Appendix B
2a/b	Beneficiation	Volume I
3	10 paper copies, and electronic format	Included with cover letter
4a - f	MDEQ MPA review timeframes defined	Department Actions
5	MDEQ impose permit conditions	Department Actions
6	Percolation leaching	Not applicable to this project
7a - b	MDEQ approval of mining permit	Department Actions
8	MDEQ denial of mining permit	Department Actions
9	Permit issuance non-issuance	Department Actions
Rule 203	Mining Plan	Note: mining is not applicable to this application
a	Mining methods, operating life, rate and schedule of mining	Section 3.2
b	Number of employees and variations over life	Section 3.2.6
c	Text descriptions including maps, photos, drawings, related to mining activities for items c(i) - c(xxiv):	
c(i)	Topsoil areas, thickness and characteristics, Plans for stockpiling and stabilizing until used for reclamation	Section 3.2.14
c(ii)	Development rock areas, volumes, characteristics, stockpiles, final placement	Not applicable
c(iii)	Ore area, volumes, types and mineralogy. Schedule for mining and stockpiling	Not applicable
c(iv)	Plans to prevent disposal of unauthorized materials (limit access to stockpiles)	Sections 3.2.18
c(v)	Geochemistry of ore, development rock, overburden and peripheral rock exposed for items c(v)(A) - c(v)(D)	
c(v)(A)	Chemical and physical testing and modeling to predict potential acid generation, dissolved metals, etc	Sections 3.2.4.2.1 and 3.2.4.2.2
c(v)(B)	Testing and modeling methods	Sections 4.1.1.1 and 4.1.1.2
c(v)(C)	Monitoring during operations to calibrate modeling	Section 5.3

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
c(v)(D)	Identification of ore, development rock and peripheral rocks that are reactive	Section 3.2.4.2.3 and 4.1
c(vi)	Lithology and thickness of rock surrounding and overlying the ore body	Not applicable
c(vii)	Locations, depths and contours of open pits	Not applicable
c(viii)	Locations of shafts, portals and other openings between the surface and underground mine	Not applicable
c(ix)	Areal extent, depth and dimensions of underground workings	Not applicable
c(x)	Types and uses of grouting	Not applicable
c(xi)	Subsidence - Plan to prevent damage to environment or H&S to public containing items c(xi)(A) - c(xi)(D)	Not applicable
c(xi)(A)	Description of planned or intential caving/subsidence	Not applicable
c(xi)(B)	Provisions to prevent adverse impacts to water supply wells or aquifers	Not applicable
c(xi)(C)	Provisions to assure u/g mining will not impact structures not owned by the Mine Operator	Not applicable
c(xi)(D)	Provisions to assure underground mining will not cause material damage to natural features on lands not owned by Mine Operator	Not applicable
c(xii)	Water usage during mining, sources, rates diversion or withdrawal	Sections 3.2.11 and 3.2.12
c(xiii)	Water storage, transfer and discharge including items c(xiii)(A) and c(xiii)(B)	
c(xiii)(A)	Location, size, capacity of dewatering, diversions, storage, and treatment facilities	Sections 4.1.2
c(xiii)(B)	Volumes, rates and water quality of discharges and discharge locations	Sections 3.2.12
c(xiv)	Storage areas for equipment and vehicles	Figure 3-1, Section 3.2.7
c(xv)	Buildings and other facilities/structures	Section 3.2.8 and Figure 3-1
c(xvi)	Areas for storage/transfer of chemicals, fuel and explosives	Section 3.2.9 and Fig 3-16
c(xvii)	Truck and mining equipment wash down areas	Section 3.2.10
c(xviii)	Roads, railroads, other transportation infrastructure and provisions to prevent release of contaminants from transport of ore and waste rock	Sections 3.2.13 and 3.2.25
c(xix)	Beneficiation processes including items c(xix)(A) - c(xix)(F)	Section 3.2.4
c(xix)(A)	Types, extent and sequence of beneficiation - physical and chemical characterization of all materials	Section 3.2.4.1
c(xix)(B)	Description of all beneficiation equipment/processes	Section 3.2.5
c(xix)(C)	Types/amounts of chemicals	Table 3-1
c(xix)(D)	Waste rock types, amounts, sequence, schedule and means of disposal	Section 3.2.26
c(xix)(E)	Provisions to prevent contamination release from beneficiation	Sections 3.2.13 and 3.2.20, Section 4
c(xix)(F)	Tailings transport systems	Section 4.1.2.2
c(xx)	Control of water drainage from tailings disposal areas (24 hr, 100 yr precipitation event)	Section 4.1.2.3
c(xxi)	Plans/schedules for contact water - reasonably minimize adverse impacts to groundwater and surface water	Section 3.2.15
c(xxii)	SESC that meets standards of Part 91 including items c(xxii)(A) - c(xxii)(G)	
c(xxii)(A)	Location, description and schedule for temporary SESC measures	Sections 3.2.15.1, Figure 3-20
c(xxii)(B)	Location, description and schedule for permanent SESC measures, established as soon as possible after an earth	Sections 3.2.15.2, Figure 3-22
c(xxii)(C)	Provisions to limit disturbed area exposure to shortest feasible time	Sections 3.2.15
c(xxii)(D)	Provisions to remove sediment caused by accelerated soil erosion before it leaves the mine site	Figures 3-20, 3-21

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
c(xxii)(E)	Temporary/permanent controls for conveyance of storm water, limit to non-erosive velocities	Figures 3-19, 3-20 and 3-21
c(xxii)(F)	Provisions for temporary SESC measures before earth change, daily maintenance, and removal once stabilized	Sections 3.2.15.1
c(xxii)(G)	Provisions for stabilizing earth change areas with permanent SESC measures as soon as possible	Sections 3.2.15.2
c(xxiii)	Plans for concurrent reclamation with mining operations to extent feasible	Sections 6.1 and 6.3
c(xxiv)	Plans for inspecting, monitoring, maintaining liners, covers, leachate collection systems, leak detection systems, berms and embankments. Defined frequency (> monthly)	Table 5-6
d	Maps and ownership of all tracts of land in the mining area and within 1320 ft of mining boundary including items	
d(i)	Ownership of surface rights	Section 2.2 and Fig 2-1
d(ii)	Ownership of mineral rights	Not applicable
d(iii)	Conservation easements per Section 2140 of Act	Section 2.4
d(iv)	Historic preservation easements per Section 2140 of Act	Section 2.4
e	Measure taken to prevent damage to property not owned by the operator within and adjacent to the mining area	Sections 2.5
f	Measures to minimize impacts to volume/rate of recharge, flow, discharge of g/w and s/w (accommodate seasonal and l/t variations)	Not applicable
g	Monitoring plan for monitoring of g/w & s/w quality, g/w levels, s/w stage and discharge during mining and post-closure - Need not include monitoring required in other permits	Section 5 and Section 6
g(i)	Monitoring location considerations to include items g(i)(E)	Section 5
g(i)(A)	Proximity to mining activity	Section 5 and Figs 5-1 and 5-2
g(i)(B)	Potential for diffusion/dispersion	Sections 5.1 and 5.2 and Figs 5-1 and 5-2
g(i)(C)	Horizontal/vertical g/w gradients	Figure 5-1
g(i)(D)	Seasonal variations in flow	Figure 5-1
g(i)(E)	Topography and access limitations	Figure 5-1 and 5-2
g(ii)	Monitoring Plan shall comply with R406	Section 5.4
g(iii)	Monitoring Plan shall includes items g(iii)(A) - g(iii)(G)	
g(iii)(A)	Number and locations of monitoring wells/structures	Section 5-1 and 5-2, Figs 5-1 and 5-2
g(iii)(B)	Frequency of sampling and procedures including items g(iii)(B)(aa) - g(iii)(B)(gg)	
g(iii)(B)(aa)	Sampling method/volume removed from each sampling point	Section 5.4
g(iii)(B)(bb)	Steps taken to prevent cross contamination	Section 5.4
g(iii)(B)(cc)	Sample handling/preservation methods	Section 5.4
g(iii)(B)(dd)	Lab analysis methods	Tables 5-2 and 5-3
g(iii)(B)(ee)	Lab method detection level	Tables 5-2 and 5-3
g(iii)(B)(ff)	QA/QC as approved by Department (MDEQ)	
g(iii)(B)(gg)	Provisions for routine monitoring at least every 3 months	Tables 5-2 and 5-3
g(iii)(C)	Sampling parameters including items g(iii)(C)(aa) - g(iii)(C)(gg)	
g(iii)(C)(aa-gg)	Specific conductance, temp, pH, DO, Ca, Na, Mg, K, Fe, Cl, SO4, CO3, and other parameters identified in the EIA	Tables 5-2 and 5-3
g(iii)(D)	Description of techniques used to present and evaluate presentation of water quality data	Section 5.4

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
g(iii)(E)	Methods for collection of static water levels (within 0.01 ft) and presentation of gw flow data	Section 5.4
g(iii)(F)	Depth/screen interval for each well	Section 5.4
g(iii)(G)	Design, construction, abandonment comply with R 406 (2)	Section 5.4
h	Treatment and containment plan to prevent contamination to g/w and s/w from leaching of acidic water or dissolved metals	Section 4
h(i)	T&C plan applies to earth materials determined to be reactive under R203 (3)(e), and includes h(i)(A) and h(i)(B):	
h(i)(A)	Design, construction, and operations of stockpiles and storage facilities for ore, development rock and overburden	Not applicable
h(i)(B)	Management of peripheral rock determined in the EIA to have potential to contaminate g/w or s/w	Not applicable
h(ii)	Account for volume, rate and movement of leachate, weather influence, including extreme conditions	Not applicable
h(iii)	T&C plan shall meet R 409	Section 4
i	A general description of blasting materials and methods	Not applicable
j	If T&E species may be impacted, a plan to protect the species that conforms to state and federal T&E species laws	Not impacted
k	Plans to minimize and mitigate adverse impacts of mining operation on flora, fauna, fish or wildlife habitats, and biodiversity	Not impacted
l	If percolation leaching is proposed, demonstrate compliance with R 403	Not applicable
m	Plan for inspection or monitoring (or both) of all mine related facilities at least monthly	Section 5
n	Name/qualifications of person(s) who prepare the mine plan	Section 1.5
Rule 204	Reclamation Plan	
a	Information in items a(i) - a(iv), including maps, appropriate scale, topo base maps, references to nearest section/1/4 section, cross sections, and engineering drawings, as appropriate	
a(i)	Final land contours	Fig. 6-1
a(ii)	Proposed final land use and relationship to surrounding land use	Section 6.2
a(iii)	Ponds, streams, wetlands, roads, dikes, ditches, SESC structures that will remain after reclamation	Section 6.2, Fig 6-1
a(iv)	Plans to stabilize waste rock piles, settling ponds, overburden banks, roads and plant site, including items a(iv)(A) - a(iv)(C).	
a(iv)(A)	Sloping/terracing of open pits	not applicable
a(iv)(B)	Topsoil replacement for disturbed surface areas	Section 6.4.4
a(iv)(C)	Vegetation species/quantities, seedbed prep, seeding/planting methods, mulching, fertilization, maintenance, plant	Section 6.4.5
b	Evidence satisfactory to the Department that reclamation will conform to the following items b(i) - b(vi):	
b(i)	Final disposition of wastes, refuse, shall be managed to protect H&S and environment, in accordance with state/federal laws	Sections 6.4
b(ii)	Shafts, portals and openings between surface and u/g workings shall be sealed to protect HSE in accordance with applicable laws/regs	not applicable
b(iii)	Surface structures, infrastructure, stockpiles shall be removed unless converted to alternate use, per final use plan	Section 6.4

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
b(iv)	Protect disturbed areas to prevent accelerated erosion by wind or water	Section 6.4.6
b(v)	Disturbed areas to be revegetated with a variety of native plants (non-native plants can be use if consistent with final land use)	Section 6.4.5
b(vi)	Goal to reclaim to self-sustaining ecosystem that does not require perpetual care, and to return to pre-mining conditions	Not applicable, historic mining uses
c	Post closure g/w and s/w monitoring plans	Section 6.5
d	Name and qualifications of person(s) who prepared the reclamation plan	Table 1-2
Rule 205	Contingency Plan	
1a	Assessment of risk to HSE and response measures for the following cases (items a(i) - a(xii):	
1a(i)	Release or threat of release of toxic or acid-forming materials	Section 7.1.1
1a(ii)	Storage, transport and handling of explosives	Not app
1a(iii)	Fuel storage and distribution	Section 7.1.3
a(iv)	Fires	Section 7.1.4
1a(v)	Wastewater collection and treatment system	Section 7.1.5
1a(vi)	Settling pond or tailings disposal embankment failure	Section 7.1.1.4
1a(vii)	Air emissions	Section 7.1.6
1a(viii))	Spills of hazardous substances	Section 7.1.7
1a(ix)	Other natural risks identified in the EIA	Section 7.1.8
1a(x)	Power disruption	Section 7.1.9
1a(xi)	Unplanned subsidence	Not applicable
1a(xii)	Leaks from containment systems for stockpiles or disposal/storage facilities	Section 7.1.1.2
1b	The contingency plan to include the following information (items b(i) - b(v)):	
1b(i)	Procedures for notifying public, authorities and safety agencies in the event of an emergency	Section 7.2
1b(ii)	A list, by title, of personnel to be contacted and their duties	Section 7.2
1b(iii)	Actions to limit nonessential personnel to the area	Section 7.2
1b(iv)	Procedures for evacuation of public, if needed	Section 7.2
1b(v)	List of emergency equipment and location	Section 7.2
1c	Emergency telephone numbers (including items c(i) and c(x)):	
1c(i)	Representatives of the operator (KEMC)	Section 7.2
1c(ii)	Emergency management coordinator (KEMC)	Section 7.2
1c(iii)	Local ambulance services	Section 7.2
1c(iv)	Local hospitals	Section 7.2
1c(v)	Local fire and police depts.	Section 7.2
1c(vi)	Dept of Environmental Quality	Section 7.2
1c(vii)	Pollution emergency alerting system	Section 7.2

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
1c(viii)	Federal regulatory agencies, as necessary	Section 7.2
1c(ix)	Dept. of Natural Resources	Section 7.2
1c(x)	Local unit of government (Michigamme Co.)	Section 7.2
1d	A plan for testing the Contingency Plan	Section 7.3
2	Applicant to submit copies of contingency plan to each emergency management coordinator with jurisdiction over the affected area at the time the application is submitted to the Dept., MDEQ	Will be submitted
Rule 206	Amendment of Permits	Not applicable
1	Permit to be amended to address changes or oversights including items 1a - 1f	Not applicable
1a	EIA	Not applicable
1b	Mining, reclamation and environmental protection plan	Not applicable
1c	Contingency plan	Not applicable
1d	Federal, state and local permits and licenses	Not applicable
1e	Provisions for financial assurance	Not applicable
1f	Other terms and conditions of the mining permit	Not applicable
2	Permittee may submit an application for amendment	Will be submitted
3	Dept may require an application for amendment if conditions of the mining permit are not meeting the intended protections	Not applicable
4	Within 30 days of request to amend a mining permit, the Dept shall determine if the request is a significant change; if it is a significant change then Dept review follows R201 (4)	Not applicable
Rule 207	Transfer of Permit	Not applicable
Part 3	Financial Assurance	
Rule 301	Financial Assurance Requirements	
1	Mining Permit not effective until Permittee establishes FA	Section 8
2	FA applies to mining and reclamation, covers 3rd Party cost to implement reclamation, remediation and post closure monitoring. Amount of FA determined as follows (items 2a - 2d):	Section 8
a	Itemized list of reclamation, remediation and post closure monitoring activities and costs associated with the following (items 2(a)(i) - 2a(ii)):	
a(i)	Mining activities where reclamation is not completed	Section 8
a(ii)	Mining activities anticipated to occur under the mining permit	Section 8
b	Dept may require FA larger than calculated under (a), based on projected costs under 2c.	Department Action
c	Cost estimate based on equipment, materials normally available to a third party contractor, and includes the following (items 2(c)(i) - 2(c)(v)):	
c(i)	Reclamation	Section 6.6

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
c(ii)	Remediation of air, s/w or g/w contamination	Section 8.3
c(iii)	Administrative oversight costs	Section 8.2
c(iv)	Reasonable contingency	Section 8-4
c(v)	Other necessary environmental protection measures	Included w/ FA
d	The amount of an assurance instrument shall cover potential assessment fees by the issuing institution	Discussion w/ MDEQ
3	FA shall cover at least 75% of total required. Balance covered by statement of financial responsibility. Dept will consider (items 3(a) - 3(c)):	TBD
3a	Ability of operator to pay for remediation costs, as demonstrated by the statement of financial responsibility	Department Determination
3b	Whether operator carries pollution prevention or environmental liability insurance and what amounts	Department Determination
3c	Whether the operator has received third-party certification of an environmental management system	
Rule 302	Assurance Instruments	TBD
Part 4	Mining Operations	
Rule 401	Notice of Commencement of Mining	KEMC Actions
Rule 402	Safety Measures	Section 3.2.8
Rule 403	Percolation Leaching Requirements	Not applicable
Rule 404	Commencement of Reclamation	KEMC Actions
Rule 405	Notice and Approval of Completed Reclamation	KEMC Actions
Rule 406	Protection of Water	
1	Permittee shall conduct g/w and s/w monitoring per R 203 (g) during mining operations and post closure	Sections 5.1, 5.2 and 6.5.2
2	Operator shall design, construct and abandon monitoring wells per R 323.2223	KEMC to comply
3	Water monitoring shall include g/w and s/w levels and discharge rates. Water monitoring systems based on the following items 3(a) - 3(c):	Sections 5.1, 5.2 and 6.5.2
3a	EIA	Volume II
3b	Local geology and hydrology	Volume II
3c	G/w and s/w conditions specific to each activity	Sections 5.1, 5.2 and 6.5.2
4	S/w monitoring sites designed and located to assess impact of mining activity on s/w	Sections 5.1 and 6.5.2
5	G/w monitoring sites located as follows:	Section 5.1
5a	Leachate monitoring wells shall be located within or as close a practicable to storage facility for reactive overburden, ore, waste rock or tailings to determine geochemical conditions of the facility	Section 5.1
5b	Compliance monitoring wells located as close a practical, but not more than 150 ft from mining activity being monitored	Section 5.1
6	Permittee to notify Dept and increase monitoring if concentrations are detected 2 std deviations above long term ave. background	KEMC Action

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
7	Action level reached when either of the following is reached:	Per Rules
7a	Concentrations >/= 1/2 long-term ave. background and the drinking water standard for 2 consecutive events	Per Rules
7b	pH differs from long-term ave. background by 0.5 units for 2 consecutive events	Per Rules
8	If action level per subrule (7) is exceeded, complete the following:	Per Rules
8a	Implement increased monitoring	Per Rules
8b	Conduct source investigation	Per Rules
8c	Implement plan for response activity per Part 201 of the Act, if change is from mining activities	Per Rules
9	Failure to meet 6 through 8 constitutes violation of this Part.	Per Rules
Rule 407	Postclosure monitoring (20 yrs after completion of reclamation, subject to following conditions 1-3)	Section 6.5.2
1	Written request not more than 18 months before termination date, along with technical information demonstrating	Not applicable to this MPA
2	Dept may shorten the post closure monitoring if no significant potential for water contamination	Not applicable to this MPA
3	Extension or shortening of post closure monitoring only after public hearing	Not applicable to this MPA
Rule 408	Inspections by Department	Department Actions
Rule 409	Treatment and Containment of Reactive Materials (Management of reactive ore, waste rock, periphery rock and tailings under R 203(c)(v) to reasonably minimize actual and potential adverse impacts on g/w and s/w by preventing leaching or runoff of acid-forming waste and other waste products from mining	Section 4
a	Design, construct and operate stockpiles for reactive overburden, ore, waste rock or tailings in accordance with a or b	Not applicable
a(i)	Stockpile or storage facility shall meet the following requirements:	
a(i)(A)	Composite liner with 60 mil synthetic liner and 3 ft of clay with max. k of 10-3 cm/sec	Not applicable
a(i)(B)	Alternate liner ok if demonstrated equivalent to (i) above	Not applicable
a(i)(C)	Stockpile or storage facility shall have a leachate collection system to maintain less than 1 ft of head on the liner system at the lowest point, excluding the sump, after construction	Not applicable
a(i)(D)	Stockpile or storage facility shall have a leak detection system	Not applicable
a(i)(E)	The liner, leachate collection system and leak detection system shall be tested before placement of materials into	Not applicable
a(i)(F)	A cover shall be employed to isolate reactive materials from precipitation and air as soon as practicable	Not applicable
a(i)(G)	Design, construction and testing of liners, covers, leachate collection systems certified by registered PE (or other	Not applicable
a(ii)	Alternate plan for reactive materials may be approved, if the following is incorporated	Not applicable
a(ii)(A)	Measures to prevent leachate generation by adding neutralizing materials	Not applicable
a(ii)(B)	Measures to neutralize leachate before it migrates outside the storage facility	Not applicable
a(ii)(C)	Measures to isolate the reactive materials from oxygen or oxidizing substances	Not applicable
a(ii)(D)	Measures to isolate the reactive materials from g/w or s/w through the use of physical barriers	Not applicable
b	Utilized disposal facility	Section 4

R 425.101 et. seq. - Mining Permit Application Checklist

Rule 425.101 Seq.	Rule 425.101 Seq. Requirements	Location in Application
c	Stockpile or storage facility shall be monitored per R 406	Section 5
d	Permittee shall maintain grading or diking to assure surface water drains away from the storage or disposal area	Section 4.1.2
Part 5	Reports	
Rule 501	Mining and Reclamation Report	KEMC Requirement
Rule 502	Update of Contingency Plan	KEMC Requirement
Rule 503	Report of Incident	KEMC Requirement
Part 6	Meetings and Hearings	
Rule 601	Public Meetings on Prospective Mining Operations	Department Action
Rule 602	Contested Case Hearing	Department Action

Appendix B

Kennecott Organization Report

DEQ MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF GEOLOGICAL SURVEY

Part 632 NONFERROUS MINING ORGANIZATION REPORT

Required by authority of Part 632 NON FERROUS MINING, Natural Resources and Environmental Protection Act, 1994 PA 451, as amended.
Non-submission and/or falsification of this information may result in fines and/or imprisonment.

PURPOSE FOR FILING:	☒ New Report	☐ Revised Report	
	☐ Change of Principal or Agent	☐ Address Correction	☐ Name Change

1. **ORGANIZATION** Enter the complete organization name (as shown on permit) and current business addresses and phone number.		**2.** If organization shown in 1 is a subsidiary or an assumed name (dba), give name and address of associated or parent company or person
Company name	Kennecott Eagle Minerals Company	
Mailing Address	504 Spruce Street	
City, State, Zip	Ishpeming, Michigan 49849	
Street Address	504 Spruce Street	
City, State, Zip	Ishpeming, Michigan 49849	
Telephone (with area code)	906-486-1257	
State or Federal ID	06-1690732	

3. Current Organization Plan (check only one)

☒ Corporation ☐ Joint Venture ☐ Limited Partnership ☐ Limited Liability Company
☐ Partnership ☐ Trust ☐ Sole Proprietorship ☐ Other

4. If reorganization or name change, name & address of previous organization

PRINCIPALS List all corporate officers, directors, incorporators, partners, or shareholders who have the authority to or responsibility for making operational decisions. Attach extra sheet if needed.

5. Full Name	Title	Address, if different from address in 1 above
Keith Calder	Director - Chairman	354-200 Granville St., Vancouver, BC V6C1S4, Canada
Jonathan C. Cherry	Director: President & CEO	
Bret Clayton	Director	5 Aldermanbury Square, London, EC2V7HR, UK
William Henry	Director: COO	
Stephen Swentik	Officer-CFO	
Shannon Crompton	Officer-Secretary	1343 South 1800 East, Salt Lake City, UT, 84108
Jack Welch	Officer-Treasurer	4700 Daybreak Parkway, South Jordan, UT 84095

AGENTS List names of persons, other than employees of the organization, who are authorized to submit applications, workplans, or records pursuant to the above cited Act.

6. Full Name	Company	Address and Telehone

Certification: "I state that I am authorized to make this report. This report was prepared under my supervision and direction. The facts stated herein are true, accurate and complete to the best of my knowledge."

Name & Title of Principal (printed or typed)	Authorized Signature	Date
Jonathan C. Cherry President & CEO - General Manager		12/22/2008

Part 632 Organizational Report

Mail original and one copy to: OFFICE OF GEOLOGICAL SURVEY
MICHIGAN DEPT OF ENVIRONMENTAL QUALITY
PO BOX 30256 LANSING MI 48909-7756

DEQ MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF GEOLOGICAL SURVEY

Part 632 NONFERROUS MINING ORGANIZATION REPORT

Required by authority of Part 632 NON FERROUS MINING, Natural Resources and Environmental Protection Act, 1994 PA 451, as amended.
Non-submission and/or falsification of this information may result in fines and/or imprisonment.

PURPOSE FOR FILING: ☐ New Report ☐ Revised Report ☐ Change of Principal or Agent ☐ Address Correction ☐ Name Change

1. **ORGANIZATION** Enter the complete organization name (as shown on permit) and current business addresses and phone number.	2. If organization shown in 1 is a subsidiary or an assumed name (dba), give name and address of associated or parent company or person
Company name	
Mailing Address	
City, State, Zip	
Street Address	
City, State, Zip	
Telephone (with area code)	
State or Federal ID	

3. Current Organization Plan (check only one)

☐ Corporation ☐ Joint Venture ☐ Limited Partnership ☐ Limited Liability Company
☐ Partnership ☐ Trust ☐ Sole Proprietorship ☐ Other

4. If reorganization or name change, name & address of previous organization

PRINCIPALS List all corporate officers, directors, incorporators, partners, or shareholders who have the authority to or responsibility for making operational decisions. Attach extra sheet if needed.

5. Full Name	Title	Address, if different from address in 1 above
Christopher Wykstra	Officer-Assistant Treasurer	4700 Daybreak Parkway, South Jordan, UT 84095
Julie Cummings	Tax Officer	4700 Daybreak Parkway, South Jordan, UT 84095
Brent Roper	Tax Officer	4700 Daybreak Parkway, South Jordan, UT 84095

AGENTS List names of persons, other than employees of the organization, who are authorized to submit applications, workplans, or records pursuant to the above cited Act.

6. Full Name	Company	Address and Telehone

Certification: "I state that I am authorized to make this report. This report was prepared under my supervision and direction. The facts stated herein are true, accurate and complete to the best of my knowledge."

Name & Title of Principal (printed or typed)	Authorized Signature	Date

Part 632 Organizational Report

Mail original and one copy to: OFFICE OF GEOLOGICAL SURVEY
MICHIGAN DEPT OF ENVIRONMENTAL QUALITY
PO BOX 30256 LANSING MI 48909-7756

Form EQP 7703 (10/2008)

DEQ MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY - OFFICE OF GEOLOGICAL SURVEY

Part 632 NONFERROUS MINING CONTACT LIST

ORGANIZATION Enter the organizational information requested below.		Date this list was prepared	12/22/2008
Company Name	Kennecott Eagle Minerals Company	State or Federal ID	06-1690732
Address line 1	504 Spruce Street	Telephone (with area code)	906-486-1257
Address line 2		Facimile (with area code)	906-486-1053
City, State Zip	Ishpeming, Michigan 49849	Corporate web site	www.eagle-project.com

EMPLOYEES List all emplyees of the organization who are authorized to submit applications, notices, plans or reports to the DEQ or to be contacted by the DEQ regarding requirements the above act. The list shold provide employee contacts before agents A contact might have many responsibilities just as one responsibily could have many contacts. Attach additional sheets if needed.

Name of Person	Responsibility	Telephone (with area code)	Email address
Jonathan C. Cherry	Director; Officer-President & CEO; General Manager	906-486-1257	Jonathan.Cherry@riotinto.com
Victoria Peacey	Environmental Affairs, Health & Safety Manager	906-486-1257 Ext. 229	Victoria.Peacey@riotinto.com
Alicia Duex	Sr. Environmental Advisor	906-486-1257 Ext. 230	Alicia.Duex@riotinto.com
William Henry	Officer-COO; Mine and Construction Manager	906-486-1257 Ext. 202	William.Henry@riotinto.com
Stephen Swentik	Officer-CFO; Controller	906-486-1257 Ext. 218	Stephen.Swentik@riotinto.com

Part 632 Organizational Report – Contact List

Mail original and one copy to: OFFICE OF GEOLOGICAL SURVEY
MICHIGAN DEPT OF ENVIRONMENTAL QUALITY
PO BOX 30256, LANSING, MI 48909-7756

R 425.103 Definitions; M to Z.
(c) "Organization report" means a certified statement, on a form prescribed by the department, giving the name, address, and plan of the business organization, and listing the following:
(i) All corporate officers, directors, incorporators, and limited liability company managers.

responsible for making, operational decisions, including the construction, operation, closure, postclosure monitoring, reclamation, and remediation of a mine.

Appendix C

Tailings Geochemical and Geotechnical Analysis Reports

C-1
Memorandum Summarizing Tailings Sample Selection for Analysis

Memorandum

January 3, 2008

TO: Steve Donohue, Foth Infrastructure & Environment

CC: Master File 06W003-6001

FR: John Starke, Foth

RE: Sample Selection for Ore Benefication and Tailings Analysis

This memorandum summarizes the procedures used for selecting ore samples for bench scale metallurgical testing and tailings analysis. The purpose of this memorandum is to document sample selection for metallurgical processing and subsequent geochemical and physical testing.

The process of sample selection begins with rock core (ore) selection used for metallurgical analysis. The resulting tailings of the metallurgical processes is then selected for chemical and physical testing. Results of these analyses are then used to gauge the performance of the benefication process and establish environmental control features based upon the tailings characteristics. The following paragraphs summarize the sample selection process from rock core (ore) selection through the process tailings used for geochemical testing and physical testing. The ore process sample selection flow chart is presented in the attached Figure 1.

Rock Core Selection for Benefication Process Analysis

Core samples were selected by KEMC based upon the following criteria:

- Operating years,
- Massive and semi-massive composition, and
- High end nickel and copper compositions.

Operating years included 2010, 2011, 2012 and 2013. Based on mineralogy and grades, these samples provided good representation of varying ore compositions on an annual basis during the facility operating period. These samples were sent to SGS Lakefield Research for metallurgical analysis.

Benefication Process and Analysis

SGS Lakefield Research received the core samples from KEMC on the following dates:

Date	Units	Sample Description
8/18/06	7 Pails	11237 - for 2010, 2011, 2012 and 2013
10/04/06	1 Pail	11237 - for 2010, 2011, 2012 and 2013
01/19/07	6 Pails	11237 - MSU/SMSU, High Ni/Cu
04/04/07	1 Pail	11237 - SMSU High Ni/High Cu

The cores were processed to develop optimum metal recovery through froth flotation. The results of the flotation studies were used to evaluate recovery grades and processes. The residual tailings from the process batches were then sent to CEMI for geochemical testing.

Tailings Geochemical Testing and Analysis

Tailing samples received by CEMI for geochemical testing were identified as process batch 11237. The 11237 samples were composited by CEMI for testing based upon the following batch inventory designation listed below.

Sample Designation	Sample Designation
11237-002 (year 2010/year 2011)	T1
11237-002 (year 2011)	T2
11237-002(year 2012)	T3
11237-002 (year 2013)	T4
11237-002 (MSU/SMSU)	T5-T10
11237-002 (High Ni/cu)	T11/T12

Upon receipt, the samples were composited and mixed then passed through a splitter box twice. Samples were composited based upon flotation circuit batch samples listed above.

From the composite, sufficient quantity was obtained for the geochemical test needs. The balance of the material was sent to Foth for geotechnical testing. The testing inventory for each sample is summarized in a table provided in Attachment A. Results of the geochemical tests were sent to Mark Logsdon at Geochimica, Inc. for post-testing analysis.

Tailings Geotechnical Testing and Analysis

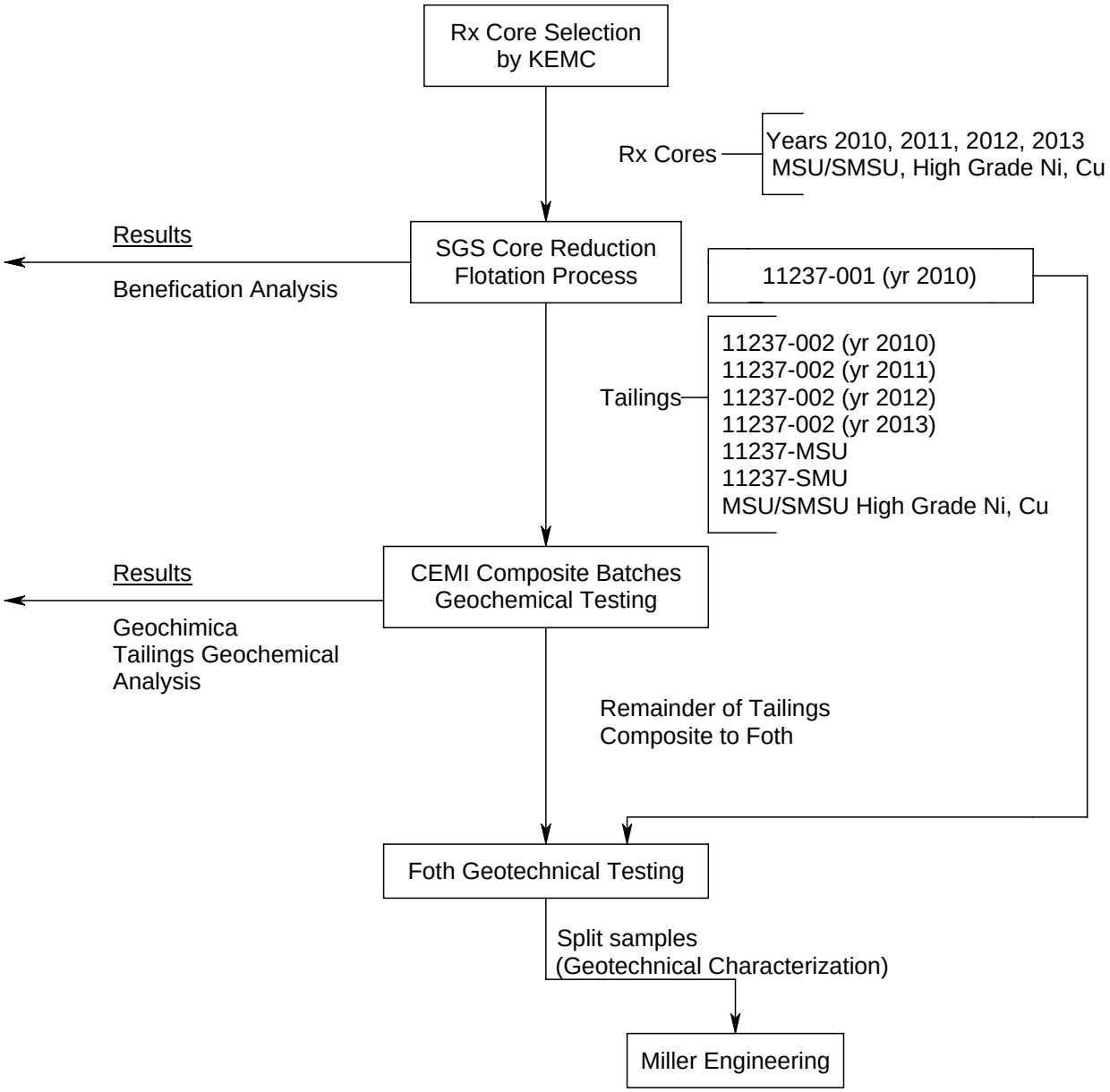
Listed below are the tailings samples received by Foth from CEMI and tested for geotechnical properties:

Sample Designation	Date Received	Weight (kg)	Test
11237-001 (year 2010)[1]	12/5/2006	≈12	Grain size/specific gravity
11237-002 (year 2011)	2/16/2007	≈6.4	Grain size/specific gravity
11237-002(year 2012)	2/16/2007	≈5.6	Grain size
11237-002 (year 2013)	2/16/2007	≈7.0	Grain size
11237-002 (SMSU)	4/6/2007	≈4.8	Grain size/specific gravity

[1] Received directly from SGS, testing not conducted by CEMI

At Foth, the geotechnical samples were prepared and sent to Miller Engineering & Scientists in Sheboygan, WI for testing.

Figure 1
KEMC
Ore Process Sample Selection



j:\scopes\06W003\6000 Internal Correspondence\Ore Process Sample Sel.flo

Attachment A

CEMI Test Inventory

Client:	Kennecott Eagle Minerals Company	Scope ID.:	06W003
Project:	Humboldt Mill Project		
Prepared by:	MJP1	Date:	01/03/08
Checked by:	JOS1	Date:	01/03/08

CEMI Tailings Sample Inventory

YEAR	SAMPLE NAME	DATE RECEIVED	SAMPLE DESCRIPTION	~ SAMPLE WEIGHT (g)	COMPOSITE TEST PROCEDURE
2010	**11237- 002 FLCT-4**	**12/15/06**			
	1ST CL SCA TAIL A		Float Test Products	45	Samples combined into one composite (Labeled: Eagle
	1ST CL SCA TAIL B		Float Test Products	80	Tailings 11237-002 Comp, T-1)
	1ST CL SCA TAIL C		Float Test Products	65	
	1ST CL SCA TAIL D		Float Test Products	80	Composite analyzed for:
	1ST CL SCA TAIL E		Float Test Products	90	Modified ABA - MEND
	1ST CL SCA TAIL F		Float Test Products	70	Total Sulphur - Leco sulphur analyzer
	1ST CL SCA TAIL G		Float Test Products	70	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
					Total Inorganic Carbon - HCl leach with CO_2 volume measurement
	RO-TAIL A		Float Test Products	750	Metals by Aqua Regia digestion with ICP-MS finish
	RO-TAIL B		Float Test Products	900	Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
	RO-TAIL C		Float Test Products	900	SPLP Method 1312
	RO-TAIL D		Float Test Products	950	NAG Test - Miller
	RO-TAIL E		Float Test Products	950	
	RO-TAIL F		Float Test Products	900	
	RO-TAIL G		Float Test Products	950	
			Total:	6800	
2011	**11237- 002**	**02/01/07**			
	Bulk 1st CL SCA Tails A Comp		Tailings	70	Samples combined into one composite (Labeled: Eagle
	Bulk 1st CL SCA Tails B Comp		Tailings	90	Tailings 2011, T-2).
	Bulk 1st CL SCA Tails C Comp		Tailings	60	
	Bulk 1st CL SCA Tails D Comp		Tailings	100	Composite analyzed for:
	Bulk 1st CL SCA Tails E Comp		Tailings	70	Modified ABA - MEND
	Bulk 1st CL SCA Tails F Comp		Tailings	80	Total Sulphur - Leco sulphur analyzer
	Bulk 1st CL SCA Tails G Comp		Tailings	50	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
					Total Inorganic Carbon - HCl leach with CO_2 volume measurement
	Bulk Ro Tails A		Tailings	1200	Metals by Aqua Regia digestion with ICP-MS finish
	Bulk Ro Tails B		Tailings	1000	Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
	Bulk Ro Tails C		Tailings	1200	SPLP Method 1312
	Bulk Ro Tails D		Tailings	1000	NAG Test - Miller
	Bulk Ro Tails E		Tailings	1200	
	Bulk Ro Tails F		Tailings	1000	
	Bulk Ro Tails G		Tailings	1200	
			Total:	8320	

Client:	Kennecott Eagle Minerals Company	Scope ID.:	06W003
Project:	Humboldt Mill Project		
Prepared by:	MJP1	Date:	01/03/08
Checked by:	JOS1	Date:	01/03/08

CEMI Tailings Sample Inventory

YEAR	SAMPLE NAME	DATE RECEIVED	SAMPLE DESCRIPTION	~ SAMPLE WEIGHT (g)	COMPOSITE TEST PROCEDURE
2012	**11237- 002**	**02/01/07**			
	Bulk 1st CL SCA Tails A Comp		Tailings	300	Samples combined into one composite (Labeled: Eagle Tailings 2012. T-3).
	Bulk 1st CL SCA Tails B Comp		Tailings	120	
	Bulk 1st CL SCA Tails C Comp		Tailings	250	Composite analyzed for:
	Bulk 1st CL SCA Tails D Comp		Tailings	320	Modified ABA - MEND
	Bulk 1st CL SCA Tails E Comp		Tailings	150	Total Sulphur - Leco sulphur analyzer
	Bulk 1st CL SCA Tails F Comp		Tailings	250	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
	Bulk 1st CL SCA Tails G Comp		Tailings	250	Total Inorganic Carbon - HCl leach with CO_2 volume measurement
					Metals by Aqua Regia digestion with ICP-MS finish
	Bulk Ro Tails A		Tailings	800	Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
	Bulk Ro Tails B		Tailings	1000	SPLP Method 1312
	Bulk Ro Tails C		Tailings	850	NAG Test - Miller
	Bulk Ro Tails D		Tailings	1000	
	Bulk Ro Tails E		Tailings	1000	
	Bulk Ro Tails F		Tailings	1000	
	Bulk Ro Tails G		Tailings	1200	
			Total:	8490	
2013	**11237- 002**	**02/01/07**			
	Bulk 1st CL SCA Tails A Comp		Tailings	80	Samples combined into one composite (Labeled: Eagle Tailings 2013, T-4).
	Bulk 1st CL SCA Tails B Comp		Tailings	120	
	Bulk 1st CL SCA Tails C Comp		Tailings	150	Composite analyzed for:
	Bulk 1st CL SCA Tails D Comp		Tailings	100	Modified ABA - MEND
	Bulk 1st CL SCA Tails E Comp		Tailings	100	Total Sulphur - Leco sulphur analyzer
	Bulk 1st CL SCA Tails F Comp		Tailings	80	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
	Bulk 1st CL SCA Tails G Comp		Tailings	70	Total Inorganic Carbon - HCl leach with CO_2 volume measurement
	Bulk 1st CL SCA Tails G SS Comp		Tailings	80	Metals by Aqua Regia digestion with ICP-MS finish
					Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
	Bulk Ro Tails A		Tailings	1000	SPLP Method 1312
	Bulk Ro Tails B		Tailings	1000	NAG Test - Miller
	Bulk Ro Tails C		Tailings	1000	
	Bulk Ro Tails D		Tailings	1200	
	Bulk Ro Tails E		Tailings	1000	
	Bulk Ro Tails F		Tailings	1200	
	Bulk Ro Tails G		Tailings	1000	
			Total:	8180	

Client: Kennecott Eagle Minerals Company Scope ID.: 06W003
Project: Humboldt Mill Project
Prepared by: MJP1 Date: 01/03/08
Checked by: JOS1 Date: 01/03/08

CEMI Tailings Sample Inventory

YEAR	SAMPLE NAME	DATE RECEIVED	SAMPLE DESCRIPTION	~ SAMPLE WEIGHT (g)	COMPOSITE TEST PROCEDURE
	11237 - 002 (Massive Ore)	**02/26/07**			
	F11 Bulk 1st Cl Scav Tail		Tailings	95	Samples combined into one composite, mixed and split into 3 samples, T-5,
	F12 Bulk 1st Cl Scav Tail		Tailings	90	T-6, and T-7.
	F13 Bulk 1st Cl Scav Tail		Tailings	95	
	F14 Bulk 1st Cl Scav Tail		Tailings	95	Each of the 3 Composite samples (11237-002 MSU-1, -2, and -3)
	F15 Bulk 1st Cl Scav Tail		Tailings	85	were analyzed for:
	F16 Bulk 1st Cl Scav Tail		Tailings	100	Modified ABA - MEND
	F18 Bulk 1st Cl Scav Tail		Tailings	85	Total Sulphur - Leco sulphur analyzer
					Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
	F11 Bulk Ro Tail		Tailings	1600	Total Inorganic Carbon - HCl leach with CO_2 volume measurement
	F12 Bulk Ro Tail		Tailings	1800	Metals by Aqua Regia digestion with ICP-MS finish
	F13 Bulk Ro Tail		Tailings	1600	Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
	F14 Bulk Ro Tail		Tailings	1550	SPLP Method 1312
	F15 Bulk Ro Tail		Tailings	1550	NAG Test - Miller
	F16 Bulk Ro Tail		Tailings	1500	Combined 0.500 kg from each of the 3 splits and conducted the following:
	F18 Bulk Ro Tail		Tailings	1400	
			Total:	11645	
	11237 - 002 (Semi-Massive Ore)	**02/26/07**			
	F17 Bulk 1st Cl Scav Tail		Tailings	45	Samples combined into one composite, mixed and split into 3 samples, T-8,
	F19 Bulk 1st Cl Scav Tail		Tailings	500	T-9, and T-10.
	F20 Bulk 1st Cl Scav Tail		Tailings	95	
	F21 Bulk 1st Cl Scav Tail		Tailings	300	Each of the 3 Composite samples (11237-002 Semi MSU-1, -2 and -3)
	F22 Bulk 1st Cl Scav Tail		Tailings	180	were analyzed for:
	F23 Bulk 1st Cl Scav Tail		Tailings	200	Modified ABA - MEND
	F24 Bulk 1st Cl Scav Tail		Tailings	135	Total Sulphur - Leco sulphur analyzer
	F25 Bulk 1st Cl Scav Tail		Tailings	65	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
	F26 Bulk 1st Cl Scav Tail		Tailings	80	Total Inorganic Carbon - HCl leach with CO_2 volume measurement
					Metals by Aqua Regia digestion with ICP-MS finish
	F17 Bulk Ro Tail		Tailings	800	Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
	F19 Bulk Ro Tail		Tailings	350	SPLP Method 1312
	F20 Bulk Ro Tail		Tailings	700	NAG Test - Miller
	F21 Bulk Ro Tail		Tailings	650	
	F22 Bulk Ro Tail		Tailings	800	
	F23 Bulk Ro Tail		Tailings	1050	
	F24 Bulk Ro Tail		Tailings	600	
	F25 Bulk Ro Tail		Tailings	1050	
	F26 Bulk Ro Tail		Tailings	900	
			Total:	8500	

Client: Kennecott Eagle Minerals Company Scope ID.: 06W003
Project: Humboldt Mill Project
Prepared by: MJP1 Date: 01/03/08
Checked by: JOS1 Date: 01/03/08

CEMI Tailings Sample Inventory

YEAR	SAMPLE NAME	DATE RECEIVED	SAMPLE DESCRIPTION	~ SAMPLE WEIGHT (g)	COMPOSITE TEST PROCEDURE
	112307 - 002 (High Ni/Cu)	**04/30/07**			
	F27 Bulk 1st Scav Tails		Float Test Products	220	Samples combined into one composite (Labeled: Eagle
	F28 Bulk 1st Scav Tails		Float Test Products	20	Tailings 112307-002 Comp, T-11)
	F27 Bulk Ro Tails Comp 4 High Ni		Float Test Products	430	
	F28 Bulk Ro Tails Comp 4		Float Test Products	910	Composite analyzed for:
	F29 Bulk Ro Tails Comp 1B		Float Test Products	400	Modified ABA - MEND
	F30 Bulk Ro Tails Comp 1B		Float Test Products	400	Total Sulphur - Leco sulphur analyzer
	F29 Bulk 1st Scav Tails		Float Test Products	40	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
	F30 Bulk 1st Scav Tails		Float Test Products	30	Total Inorganic Carbon - HCl leach with CO_2 volume measurement
					Metals by Aqua Regia digestion with ICP-MS finish
					Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
					SPLP Method 1312
					NAG Test - Miller
			Total:	2450	
	112307 - 002 (High Ni/Cu)	**04/30/07**			
	F36 Bulk 1st Scav Tails		Float Test Products	120	Samples combined into one composite (Labeled: Eagle
	F38 Bulk 1st Scav Tails		Float Test Products	140	Tailings 112307-002 Comp, T-12)
	F36 Bulk Ro Tails		Float Test Products	1120	
	F38 Bulk Ro Tails		Float Test Products	1320	Composite analyzed for:
	F37 Bulk 1st Scav Tails		Float Test Products	80	Modified ABA - MEND
	F39 Bulk 1st Scav Tails		Float Test Products	120	Total Sulphur - Leco sulphur analyzer
	F37 Bulk Ro Tails		Float Test Products	1500	Sulphate-sulphur -Sodium Carbonate leach with gravimetric finish
	F39 Bulk Ro Tails		Float Test Products	1700	Total Inorganic Carbon - HCl leach with CO_2 volume measurement
					Metals by Aqua Regia digestion with ICP-MS finish
					Whole Rock Analysis - Lithium Metaborate fusion with ICP finish
					SPLP Method 1312
					NAG Test - Miller
			Total:	6100	

C-2
Geochemical Test Results

TECHNICAL MEMORANDUM

DATE: **02 January 2008**

TO: **Kennecott Eagle Minerals Company**

FROM: Mark J. Logsdon (Geochimica)

SUBJECT: **GEOCHEMICAL TESTING OF BENCH-SCALE TAILINGS SAMPLES FOR KENNECOTT EAGLE MINING COMPANY – RESULTS AND IMPLICATIONS FOR MANAGING ACID-ROCK DRAINAGE RISK**

BACKGROUND

Project Description

The Kennecott Eagle Mining Company (KEMC) project, a nickel-mineralized peridotite occurrence, is located on the Yellow Dog plains in the Michigamme Township of Marquette County in the Upper Peninsula, Michigan, U.S.A. The Ni-Cu ores of the Eagle project are a magmatic sulfide deposit hosted in an ultramafic intrusive body. The ultramafic igneous rock intruded into pre-existing, Precambrian sedimentary rocks called sandstones and siltstone. Locally the sedimentary rocks have been thermally metamorphosed to a rock called hornfels. In standard geological nomenclature, one can distinguish two general rock types, intrusives and "country rock", the pre-existing rocks into which the peridotite intruded. A portion of the intrusive rock is ore, distinguished in the Eagle deposit as either Massive Sulfide Unit, Semi-Massive Sulfide Unit (net textured), or disseminated ore. The Eagle Project will be developed as an underground mine.

The two prior Geochimica reports addressed the geochemistry of development rock, that is, rock removed along the route of tunnels driven from surface toward the ore body. Development rock is not ore, but rather the unmineralized rock that must be developed to reach the ore. This technical memorandum is directed at the geochemistry of mine tailings. In the milling process, ore is crushed and washed, and the sulfide minerals of the target metals are physically separated from the rest of the rock. The metal-rich fraction is called "concentrate", and following milling it is transported to a facility that can separate the metals from the original mineralogy to produce high-purity metal. The fraction of the ore that is not metal-rich is called "tailings". Tailings are those portions of milled ore that are too low in metal-grade – in this case, nickel and copper – to produce economic value. The tailings, produced as a slurry of solid mineral and rock fragments in water, must be managed as a waste byproduct of the mining and milling process. Because the nickel-copper ore is located entirely inside the intrusive rocks, country rock will not be part of the tailings mixture.

Mineralogical analyses by Kennecott's and Geochimica's teams have identified the following principal sulfide minerals in the intrusive rocks and ores: pyrrhotite [$Fe_{1-x}S$], chalcopyrite [$CuFeS_2$], and pentlandite [$(Ni,Fe)_9S_8$]. Pentlandite and chalcopyrite are the principal ore

minerals, which would be separated preferentially into the concentrate stream in the metallurgical process. Pyrrhotite would report overwhelmingly to the tailings. The milling process is never 100% effective at separating all the target-metal sulfides, so small amounts (a few percent of the original proportion) of pentlandite and chalcopyrite also will remain in the tailings. Even in the Massive Sulfide Unit ores [and significantly in Semi-Massive Sulfide and run-of-mine disseminated ores], there are non-sulfide gangue minerals (chiefly the aluminosilicate minerals olivine and pyroxene and some of their deuteric alteration equivalents and some oxide minerals) that make up a large proportion (approximately 30% to 80%) of the tailings solids.

If exposed to atmospheric oxygen and modest fluxes of water, the sulfide minerals in the tailings will oxidize and dissolve, releasing sulfate and metals into solution and generating acidity. Unless there is adequate, readily-available neutralization potential in the rocks, the net effluent from surficial weathering could become acidic. Under low-pH conditions, most metals (e.g., Fe, Cu and Ni) and metalloids (e.g., As) are soluble, and so subject to leaching and transport as dissolved species. Thus, the acidity generated by oxidation of primary sulfides also may leach metals and metalloids from non-ore and even non-sulfide phases, including potentially from ferromagnesian silicates or even under extreme conditions from primary oxides.

Geologic Description

The geology of the deposit is described in *Report on the Geology of the Eagle Nickel-Copper Deposit* (Rossell and Coombes, 2005). The deposit is hosted by two peridotitic intrusions. Peridotites are intrusive, ultramafic igneous rocks composed chiefly of pyroxene and olivine. The rocks also contain variable amounts of plagioclase feldspar, accessory minerals such as biotite, amphibole, magnetite, ilmenite, and trace minerals such as sulfides, calcite, quartz, or clays. Depending on the local proportions of the major minerals, rocks may be called peridotite, feldspathic peridotite, pyroxenite, gabbro, or olivine gabbro. All six designations are very closely related rock types, and unless a specific point needs to be made, this report will call the intrusive rocks "peridotite", the dominant lithology. During intrusion to relatively shallow crustal depths, late-stage crystallization produced magmatic H_2O, which together with interactions with shallow meteoric waters typically altered some of the primary silicate minerals to hydrated secondary minerals called serpentine and talc, and iron and other metals in the original minerals partially converted to oxides such as magnetite (Fe_3O_4) and ilmenite (TiO_2). There is no "hydrothermal alteration" in the sense usually used for sulfide ore deposits in intermediate to acidic igneous rocks, such as porphyry or epithermal systems. Chemically, peridotites are low in silica (SiO_2) and alumina (Al_2O_3), but elevated in ferrous iron (FeO) and, particularly magnesia (MgO). Some ultramafic rocks develop immiscible iron, nickel and copper sulfides that can concentrate locally near the margins of the intrusions. The eastern and western intrusions are referred to as the East Eagle and Eagle deposits, respectively.

Three distinct types of sulfide mineralization occur in the Eagle deposit: massive, semi-massive (or net-textured) and disseminated. Whereas early exploratory drilling suggested two distinct sulfide zones, continued exploration has shown that these are continuous as a single, ore-grade mineralized zone.

Previous Geochemical Characterization

During the period form 2003 to 2005, KEMC commissioned a sequence of mineralogical and geochemical studies. The results of these evaluations are presented in Geochimica, 2004 and Geochimica, 2005, and those results showed that active management would be required for all development rock. As mentioned above, those studies focused on development rock, not ores. However, the basic mineralogical and geochemical data for the intrusive rocks and the samples of MSU and SMSU ores that were tested are directly applicable to this evaluation, also. The basic methodology for evaluating the likely risk of generating acid-rock drainage (ARD) if tailings were exposed to surficial weathering is the same as that used for evaluating ARD of development rock and the underground workings if those materials were exposed to near-surface weathering conditions.

Purpose and Objectives

The overall purpose of the geochemical characterization program for the Eagle Project is to produce the information and analyses necessary and sufficient to describe the environmental impacts to land and water, related to geochemical reactivity and the environmental mineralogy of the deposit, that could be anticipated if KEMC took no steps for active management to mitigate the geochemical risks. That is, these are scoping studies, the purpose of which is to determine the nature and extent of the ***unmitigated risk*** in order to provide guidance to KEMC on need for and selection of mitigation programs. The principal goal of the tailings study is to determine the ARD risk of Eagle tailings were they disposed to the ground surface where they would be subject to weathering in the presence of oxygen and water. This evaluation takes advantage of information concerning Eagle rocks that was developed during the development-rock evaluation, including the confirmatory results of the column tests compared to the static tests.

Surficial deposition of sulfide tailings, portions of which become unsaturated, has been practiced in the mining industry for hundreds of years with varying degrees of formality. In recent years, Rio Tinto and its daughter companies have identified the potential (and in some cases actual) impacts of this ARD on water-quality, and so have developed systematic procedures for evaluating such risks at new projects. KEMC directed Geochimica to undertake a program of static geochemical testing on a suite of samples developed by KEMC's metallurgical consultants in Canada. The metallurgists developed a suite of samples at bench-scale that simulate the grinding and concentrating processes that would be used in a full-scale operation. KEMC provided to us and our geochemical testing laboratory (CEMI, Vancouver, BC, Canada) a suite of samples that the metallurgists and mine planners selected as representative of the range of materials that could be produced during processing of the KEMC ores over the lifetime of the Eagle Project.

Specific objectives of the program for characterizing the ARD risk of Eagle tailings include:

- Coordinating the geochemical database with the evolving geologic models and mine plans for the Eagle project.
- Testing samples selected by KEMC mine planning and processed through the design-basis milling and concentrating system for Eagle. Because of the

control on sample selection and the care with which the bench-scale testing simulates the actual processes that will occur in a full-scale system, the total suite is representative of the range of tailings behaviors that can be anticipated over the lifetime of the Eagle Project.

- Determining the likelihood that tailings samples, were they exposed to surficial weathering under unsaturated conditions, would become acid generating and leach metals and other solutes.
- Developing initial conceptual models of waste-management units that are coupled to engineering plans and site hydrology in ways that allow robust decision-making with respect to water-quality impacts under general classes of waste-management alternatives for Eagle tailings.

GEOCHEMICAL CHARACTERIZATION PROGRAM

The mine-planning and metallurgical teams at KEMC selected a suite of samples for analysis and arranged for the samples to be processed at bench scale as they would be at full scale. The samples selected for analysis represented 4 classes of tailings:

- Annual composites for years 2011, 2012, and 2013, intended to illustrate the range of tailings compositions that might exist over a significant portion of the mining [Samples T2, T3, and T4]. Variations in the tailings represent the spatial range of samples over the entire planned set of mining horizons for each year.
- A single composite of two years of mining (2010 and 2011) to show the effects of mixing over adjacent annual cycles [Sample T1].
- Six samples – three each of MSU and SMSU – to represent maximum-probable sulfide contents that might be processed over short intervals in which mining was predominantly in high- and very-high-grade ores [Samples T5 through T10]
- Two additional samples – one each of MSU and SMSU – of High-Ni/Cu ore, the highest-grade ores that will be encountered even in small pockets [Samples T11 and T12]. These represent "worst-case" tailings in the sense that higher-sulfide and higher metal ore and tailings would not be produced on any sustained basis over the life of the mine.

Unlike the geochemical characterization program for development rock, where we strove for spatially representative samples because we would test them through the full sequence of kinetic tests, for the tailings we elected to take a maximum-likely impact case so that decision-making based on bounding results from static testing could be used reliably for KEMC's decision-making.

ISSUES

The testing program addressed the following issues:

- If subjected to subaerial weathering, would tailings be likely to generate acid-rock drainage (ARD)?
- What is the whole-rock chemistry of the tailings samples? This question addresses the type of metals and metalloids that might be released were ARD allowed to start.
- What is the initial leachability of the tailings samples when washed with a low ionic-strength solution like rainwater?
- How severe is the risk of ARD and metals leachability if tailings such as these were disposed at the land surface subject to unsaturated flow conditions of natural weathering?
- How might KEMC best mitigate the risk of ARD from tailings such as these?

TECHNICAL APPROACH

The tailings program used the static-testing strategies previously used in Geochimica's prior geochemical studies for Eagle:

- Static acid-base accounting, using the Modified Sobek method and CO_2 determination for calculation of Carbonate-Neutralization Potential.
- Single-addition Net Acid Generation Testing as a method for assessing the acid-base balance that is independent of the Sobek methodology.
- Determination of whole-rock chemistry, using X-ray florescence for major components and ICP-MS/OES for trace metals.
- Static leach testing using the Synthetic Precipitation Leaching Procedure (SPLP, EPA Method 1312).

Because long-term kinetic testing is available for some samples of MSU and SMSU ore samples, we use the results of those tests semi-quantitatively to infer the probable leaching behavior of tailings generated form such ores. We also make use of the mineralogical results from prior studies for interpretation of the underlying mineralogical controls that may affect weathering outcomes and rates.

RESULTS

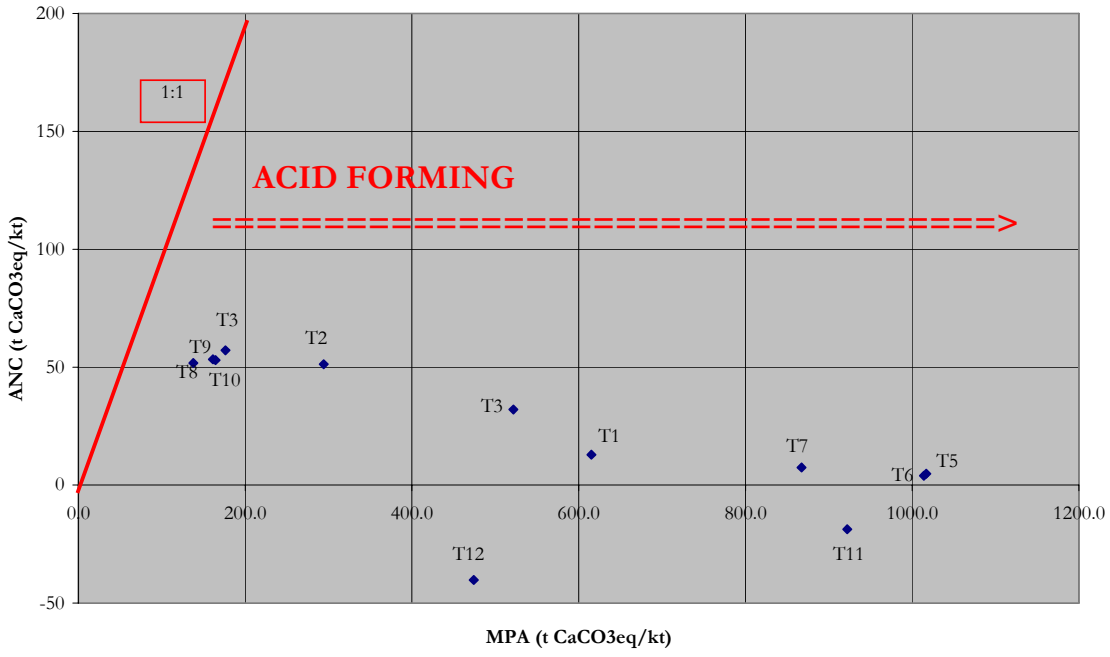
The analytical results for the four sets of tailings samples are compiled together in EXCEL workbooks that are presented as Attachments 1 to 5 to this technical memorandum. Key results are summarized below.

Static Acid-Base Accounting

Sobek acid-base accounting (ABA) data are presented in Attachment 1. As expected for tailings from a sulfide ore body, the total sulfur concentrations in the tailings samples are very high, ranging from 4.5% (Sample T8) to 32.8% (Sample T6). Sulfur speciation tests show that only negligible amounts of the total sulfur are present as sulfate, so essentially all that sulfur is present in sulfide minerals. Clearly, the samples have a very high potential for generating acidity. Mineralogical studies in Phases I and II of the Eagle studies (Geochimica, 2004 and 2005) show that much of the sulfide is present as pyrrhotite. On a proportional basis pyrrhotite would be even a greater part of total sulfide in the tailings because the other principal sulfides, pentlandite and chalcopyrite have been preferentially removed in the milling process. In many site-specific and laboratory studies, pyrrhotite is found to be a very fast-reacting sulfide, so KEMC should anticipate that, if allowed to oxidize, the tailings would become geochemically reactive (due to sulfide oxidation).

Figure 1 plots the Modified Sobek Neutralization Potential (as "ANC", acid neutralization capacity) versus Maximum Potential Acidity (MPA). Two of the samples, T 11 and T12 (the two high-Ni/Cu ore samples), were already net acidic when tested and so plot with negative ANC values. All of the samples plot far below the 1:1 line at which there would be a "factor of safety" of 1.0 for the ratio of ANC to MPA, and Net Neutralization Potential values (NNP) range from -86 tCaCO3eq/kt to -1012 tCaCO3eq/kt, consistent with the ratio method in indicating that the tailings should be expected to be strong acid generating if allowed to oxidize.

Figure 1 ANC vs MPA
KEMC Bench-Scale Tailings Samples

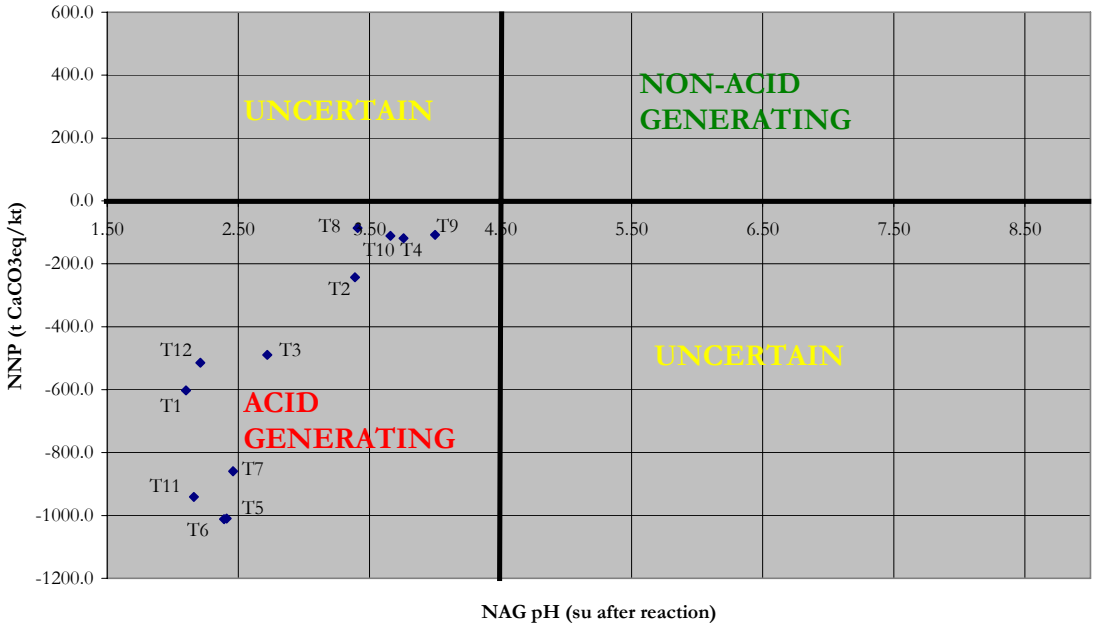


Except for the two high-metal ores (Samples T11 and T12), each of the samples has a discernible Sobek NP, ranging from 4 to 53 $tCaCO_3eq/kt$ of tailings. Semi-massive ores

(Samples T8 – T10) and run-of-mine ores for years 2010-2013 (Samples T1 – T4) have Sobek NP values > 10 $tCaCO_3eq/kt$, indicating that the sample may have a lag period before onset of acidification, but the rapid surface acidification of the two high-metal tailings suggests that the onset will be rapid if allowed to oxidize in moist air. The low value for Carbonate NP compared to Sobek NP indicates that most of the Sobek NP is provided by the olivine and serpentine in the rock matrix. Whereas these are rapid-reacting silicates, their neutralization potential still yields slowly compared to carbonates.

Finally, the results of the Net Acid Generation (NAG) tests (Attachment 4) are entirely consistent with the Modified Sobek ABA results. NAG-pH values for all samples are < 4, and these all correlate with strongly negative NNP values (Figure 2).

Figure 2 NNP vs NAG pH
KEMC Bench-Scale Tailkings Samples



Metals Values in Solid Phases

As shown in the attached data for whole-rock chemistry (Attachments 2 and 3), the iron concentration — dominantly present in pyrrhotite in the tailings — can range up to greater than 50% of the total sample (almost 80% when recalculated as Fe_2O_3 in the standard oxide formulation for whole-rock analyses). The most important trace metal in the tailings is nickel (Ni), present at thousands of parts per million (ppm, or mg/kg of rock), followed by copper (Cu) and manganese (both present in the high hundreds of ppm). As expected for ores containing pyrrhotite and the Ni/Cu ores, cobalt (Co) also is present in low hundreds of ppm, and other transition metals such as Cd, Pb, Mo, and Zn are moderately elevated above crustal abundances. Arsenic (As) and Selenium are present at a few to a few tens of ppm, and Hg is detectible, but present at more than 100 parts per billion (ppb) only in one sample of the 12 tested.

If the sulfide minerals in the tailings samples oxidized significantly, and certainly, if the samples became acid-generating, one should expect that significant portions of the trace metals would be solubilized, producing effluents that would quite certainly exceed many water-quality criteria. Nickel (Ni), cobalt (Co), manganese (Mn), and zinc (Zn) can be expected to solubilize during sulfide oxidation before effluents become strongly acidic and remain in solution even at neutral pH conditions once solubilized.

Initial Leachability of Metals from Fresh Tailings

The synthetic-precipitation leaching of bench-scale tailings samples that have not undergone significant oxidation (all samples were transported to minimize oxidation) show a range of outcomes (Attachment 5). In run-of-mine tailings samples (T1-T4), the SPLP solutions are slightly alkaline (pH 7.25 – 8.62 su), have discernible aqueous alkalinities, and low to moderate sulfate concentrations. Dissolved metals are low to non-detectible in these samples, which is consistent with the bicarbonate-buffered pH. Synthetic tailings from SMSU ores (Samples T8-T10) have circum-neutral pH (7.4 – 7.6 su), discernible alkalinities, and moderate sulfate concentrations. The SMSU sample of the high-Ni/Cu ore (Sample T12) has a slightly acidic pH (5.5 su) and low, but still measurable alkalinity, but leaches substantially more sulfate than do the other SMSU samples. This sample leaches much more Fe (33 mg/L) and Ni (20.5 mg/L) than do the SMSU ores that produce pH values two orders of magnitude higher (i.e., 7.5 vs. 5.5). The metals behavior is entirely as would be predicted by standard geochemical controls of metal solubility by pH.

The MSU ores used to generate synthetic tailings, on the other hand, are clearly more reactive, as can only be expected because of their higher sulfide content and therefore lower solid-phase alkalinity. The pH values for the synthetic tailings from MSU ores have lower pH (ca. 6.5 su, with the high-Ni/Cu sample having an SPLP pH of 4.96 su), lower alkalinities, and much higher sulfate values. They also consistently leach Fe and Ni at approximately 10 mg/L (much higher in the high-Ni/Cu ore, consistent with the lower pH); low levels of aluminum and other transition metals (especially Co) also are present in the SPLP sample for the high-Ni/Cu MSU sample.

CONCLUSION AND IMPLICATIONS

Risk of Acid-Rock Drainage and Metals Leachability

The static testing program clearly shows that all tailings that would be generated from milling of Eagle ores should be expected to produce ARD. Based on the mineralogy of ore samples determined in Phases I and II and the long-term kinetic leach-test data for the MSU and SMSU samples, it is likely that the pyrrhotite in the tailings would oxidize rapidly, releasing high levels of sulfate and TDS even during the lag period for onset of overall acidification. Once the samples are acidic, effluents from oxidized tailings would be low-pH solutions with elevated concentrations of dissolved metals, specifically of Ni, Cu and Co and probably of several other metals and metalloids. Such solutions could not be discharged directly to the environment.

Implications for Tailings Management

To mitigate the risk of adverse geochemical impacts to water resources, it is essential that KEMC develop and execute a program of active management of tailings from the Eagle deposit. Because the ARD and metals-leachability risk arises from oxidation of the sulfides minerals in the tailings, the most effective way to control the risk is to prevent or sharply reduce sulfide oxidation. The best available technology for this geochemical control is to dispose of all tailings below a permanent water cover. Isolation of mine wastes below a water cover has been rigorously demonstrated to lessen the effects of sulfide mineral oxidation in natural lakes (Pedersen et al., 1993, 1994) and in surface repositories (Davé and Vivyurka, 1994). The isolation of the sulfide minerals below a water cover limits the extent of sulfide oxidation to the solubility of dissolved oxygen, typically about 8 mg/L, which can be anticipated to generate minimal environmental impact. The effectiveness of the water cover increases with increasing water-cover depth, although the incremental effect decreases nonlinearly with additional depth.

Placement of Eagle tailings in a dedicated disposal facility, such as an already existing, flooded open-pit mine void would ensure that the tailings remain submerged, and is equivalent to international best practice for mine waste management. An additional benefit of using a mine pit is that there is no issue with geotechnical stability of the embankment as there might be for a permanently flooded tailings dam. Finally, re-use of an abandoned open pit is consistent with principles of sustainable mining by limiting the footprint of mine disturbance.

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Attachment 1
Acid Base Accounting Data

					22.7				31.25					
Sample	**Sample ID**	**Paste**	**Total C**	**CO2**	**CaCO3**	**S(T)**	**S(SO4)**	**S(S-2)**	**AP**	**NP**	**Net**	**Fizz Test**		AP NP
		pH	**%**	**%**	**NP**	**%**	**%**	**%**			**NP**			
T1	Eagle Tailings 11237-002 Comp.	8.0	0.24	0.9	20.5	19.75	0.06	19.69	615.3	12.9	-602.4	None		615.3 12.9
T2	Eagle Tailings 2011	9.71	0.06	0.2	4.5	9.43	0.02	9.41	294.1	51.3	-242.8	None		294.1 51.3
T3	Eagle Tailings 2012	8.90	0.08	0.3	6.8	16.75	0.06	16.69	521.6	32.1	-489.5	None		521.6 32.1
T3	Eagle Tailings 2013	9.35	0.09	0.3	6.8	5.66	0.02	5.64	176.3	57.2	-119.1	None		176.3 57.2
T5	11237-002 MSU-1	4.81	0.08	0.3	6.8	32.7	0.25	32.45	1014.1	4.0	-1010.1	None		1014.1 4
T6	11237-002 MSU-2	4.66	0.08	0.3	6.8	32.8	0.26	32.54	1016.9	4.8	-1012.1	None		1016.9 4.8
T7	11237-002 MSU-3	4.64	0.05	0.2	4.5	28.0	0.25	27.75	867.2	7.5	-859.7	None		867.2 7.5
T8	11237-002 Semi MSU-1	8.29	0.06	0.2	4.5	4.5	0.04	4.41	137.8	51.8	-86.0	None		137.8 51.8
T9	11237-002 Semi MSU-2	8.28	0.06	0.2	4.5	5.2	0.05	5.16	161.3	53.3	-108.0	None		161.3 53.3
T10	11237-002 Semi MSU-3	8.32	0.06	0.2	4.5	5.3	0.05	5.26	164.4	53.0	-111.4	None		164.4 53
T11	MSU (High Cu Ni) Apr 30 /07	3.90	<0.05	<0.2	<4.5	29.9	0.39	29.51	922.2	-18.7	-940.9	None		922.2 -18.7
T12	SMSU (High Cu Ni) Apr 30/07	4.45	0.05	0.2	4.5	15.45	0.28	15.17	474.1	-40.2	-514.3	None		474.1 -40.2

Min	3.90	0.05	0.20	4.54	4.45	0.02	4.41	137.81	-40.20	-1012.08
25%	4.66	0.06	0.20	4.54	5.57	0.05	5.55	173.28	4.60	-879.99
Median	8.14	0.06	0.20	4.54	16.10	0.06	15.93	497.81	22.50	-501.86
Average	6.94	0.08	0.30	6.81	17.12	0.14	16.97	530.42	22.42	-508.00
75%	8.47	0.08	0.30	6.81	28.48	0.25	28.19	880.94	52.10	-117.13
Max	9.71	0.24	0.90	20.45	32.80	0.39	32.54	1016.88	57.20	-86.01
Std Dev	2.22	0.05	0.20	4.66	11.33	0.13	11.23	350.79	32.28	374.60
IQR	3.81	0.02	0.10	2.27	22.90	0.21	22.65	707.66	47.50	762.86

Attachment 2
Tailings Trace Metals Analysis Data

Dark green: < detection at limit shown
Yellow: > Maximum quantitation limit for method

Sample	Sample ID	Ag ppm	Al %	As ppm	Au ppm	B ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hf ppm	Hg ppm	In ppm	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm
T1	Eagle Tailings 11237-002 Comp.	2.99	0.84	2.6	<0.2	<10	10	0.08	2.44	0.51	0.63	6.89	172	508	1.85	1595	44.1	4.42	0.9	0.3	0.03	0.088	0.11	3	5.3	2.12	769	8.88
T2	Eagle Tailings 2011	1.88	0.64	2.5	<0.2	70	10	0.09	2.03	0.33	0.67	4.81	137.5	793	0.78	749	26.1	2.7	0.4	0.14	0.02	0.081	0.09	2.3	9.7	8.93	1190	13.2
T3	Eagle Tailings 2012	3.02	0.67	5	<0.2	40	20	0.1	2.69	0.32	1.07	7.95	127.5	689	1.13	659	34.4	3.33	0.54	0.22	0.03	0.111	0.13	3.7	9.2	4.34	855	27.4
T4	Eagle Tailings 2013	2.59	0.74	2.1	<0.2	110	20	0.11	2.7	0.34	1.39	4.74	108.5	662	0.81	678	18.95	2.75	0.29	0.11	0.03	0.122	0.08	2.3	9.6	10.65	1180	10.3
T5	11237-002 MSU-1	2.39	0.17	5.2	<0.2	<10	10	<0.05	1.19	0.25	0.7	1.53	250	469	0.19	555	>50	1.22	1.14	0.03	0.09	0.048	0.02	0.8	1.1	1.33	395	11.55
T6	11237-002 MSU-2	2.31	0.15	5.7	<0.2	<10	10	<0.05	1.26	0.23	0.63	1.42	243	429	0.17	533	>50	1.08	1.14	0.02	0.07	0.045	0.01	0.7	1.1	1.16	373	10.7
T7	11237-002 MSU-3	2.32	0.16	5.2	<0.2	<10	10	<0.05	1.13	0.23	0.71	1.45	251	455	0.18	522	>50	1.11	1.1	0.03	0.08	0.046	0.02	0.7	1.1	1.21	403	11.15
T8	11237-002 Semi MSU-1	4.28	0.76	1.7	0.3	40	20	0.06	2.84	0.37	1.61	4.07	99.2	660	0.67	906	17.4	2.59	0.35	0.07	0.03	0.106	0.07	1.9	4.4	9.4	929	26.5
T9	11237-002 Semi MSU-2	4.29	0.79	1.7	<0.2	40	20	0.07	3.26	0.37	1.65	4.12	101.5	695	0.68	909	18.1	2.62	0.35	0.08	0.03	0.11	0.07	1.9	4.5	9.64	961	26.3
T10	11237-002 Semi MSU-3	4.21	0.77	1.6	<0.2	40	20	0.07	2.86	0.35	1.63	4.1	100.5	675	0.66	921	17.8	2.55	0.35	0.08	0.03	0.111	0.07	1.9	4.3	9.37	932	26.3
T11	MSU (High Cu Ni) Apr 30 /07	3.36	0.54	5	<0.2	<10	30	0.12	1.94	0.15	0.89	3.34	226	320	1.4	1610	>50	3.79	1.02	0.22	0.06	0.07	0.07	1.6	2.7	0.17	703	8.54
T12	SMSU (High Cu Ni) Apr 30/07	6.03	1.53	17.4	<0.2	60	10	0.3	3.57	0.24	2.3	10.6	334	936	0.87	1235	26.9	6.6	0.61	0.23	0.13	0.095	0.07	5.6	23.3	3.75	672	35.4
	Min	1.88	0.15	1.60	0.30	40.00	10.00	0.06	1.13	0.15	0.63	1.42	99.20	320.00	0.17	522.00	17.40	1.08	0.29	0.02	0.02	0.05	0.01	0.70	1.10	0.17	373.00	8.54
	25%	2.37	0.45	2.00	0.30	40.00	10.00	0.07	1.77	0.24	0.69	2.89	106.75	465.50	0.54	633.00	18.03	2.22	0.35	0.06	0.03	0.06	0.06	1.40	2.30	1.30	604.75	10.60
	Median	3.01	0.71	3.80	0.30	40.00	15.00	0.09	2.57	0.33	0.98	4.11	154.75	661.00	0.73	827.50	22.53	2.66	0.58	0.10	0.03	0.09	0.07	1.90	4.45	4.05	812.00	12.38
	Average	3.31	0.65	4.64	0.30	57.14	15.83	0.11	2.33	0.31	1.16	4.59	179.23	607.58	0.78	906.00	25.47	2.90	0.68	0.13	0.05	0.09	0.07	2.20	6.36	5.17	780.17	18.02
	75%	4.23	0.78	5.20	0.30	65.00	20.00	0.11	2.85	0.36	1.62	5.33	244.75	690.50	0.94	999.50	28.78	3.45	1.04	0.22	0.07	0.11	0.08	2.48	9.30	9.38	939.25	26.35
	Max	6.03	1.53	17.40	0.30	110.00	30.00	0.30	3.57	0.51	2.30	10.60	334.00	936.00	1.85	1610.00	>50	6.60	1.14	0.30	0.13	0.12	0.13	5.60	23.30	10.65	1190.00	35.40
	Std Dev	1.19	0.38	4.33	Not Appl	26.28	6.69	0.07	0.82	0.09	0.55	2.77	78.90	174.19	0.50	384.50	9.64	1.56	0.35	0.09	0.03	0.03	0.04	1.40	6.22	4.08	283.73	9.52
	IQR	1.86	0.33	3.20	0.00	25.00	10.00	0.04	1.08	0.12	0.92	2.44	138.00	225.00	0.39	366.50	10.75	1.23	0.69	0.16	0.04	0.05	0.03	1.08	7.00	8.08	334.50	15.75

Statistics exclude <, > values; No Standard deviation can be calculated for either Au or Ta because there is only one reportable value

Dark green: < detection at li
Yellow: > Maximum quantit

Sample	Sample ID	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Re ppm	S %	Sb ppm	Sc ppm	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
T1	Eagle Tailings 11237-002 Comp.	0.08	0.32	8310	260	31	6.8	0.103	>10.0	0.2	3.4	57.2	5.2	23.1	<0.01	3.46	0.5	0.114	0.38	0.15	137	0.27	3.96	55	7.8
T2	Eagle Tailings 2011	0.11	0.09	4400	180	24.3	5.7	0.045	5.72	0.15	5	24	2.9	20.8	<0.01	1.39	0.5	0.102	0.28	0.13	90	0.43	2.53	92	5.1
T3	Eagle Tailings 2012	0.11	0.22	5310	190	37.1	9.9	0.101	9.71	0.25	4.1	45.8	6.3	18	<0.01	2.22	0.8	0.092	0.64	0.34	77	0.95	3.36	62	7.6
T4	Eagle Tailings 2013	0.12	0.05	2840	170	37.4	4.9	0.031	3.89	0.18	6.1	15.8	4.7	24.6	<0.01	1.84	0.5	0.084	0.43	0.17	67	0.25	2.58	97	4.2
T5	11237-002 MSU-1	0.02	0.32	>10000	40	24.3	1	0.186	9.26	0.57	1	57.6	3.9	5.6	<0.01	2.4	<0.2	0.022	0.19	0.05	48	0.41	0.8	41	1.1
T6	11237-002 MSU-2	0.02	0.31	>10000	30	23.1	0.9	0.178	9.19	0.57	1	56.3	3.4	5	<0.01	2.36	<0.2	0.019	0.18	0.05	46	0.38	0.74	40	0.9
T7	11237-002 MSU-3	0.02	0.3	>10000	30	23.2	1	0.182	9.75	0.6	0.9	58.2	3.5	5	<0.01	2.47	<0.2	0.02	0.18	0.05	47	0.39	0.74	42	0.9
T8	11237-002 Semi MSU-1	0.09	0.13	2740	160	46.2	4.3	0.011	3.83	0.24	5.2	16.3	5.6	20.6	<0.01	2.19	0.4	0.072	0.48	0.15	39	0.74	2.07	87	3.2
T9	11237-002 Semi MSU-2	0.09	0.12	2890	160	46.5	4.1	0.013	4.43	0.24	5.1	16.9	6	20.9	<0.01	2.3	0.4	0.078	0.48	0.15	41	0.76	2.11	89	3.4
T10	11237-002 Semi MSU-3	0.09	0.11	2890	160	45	4.2	0.014	4.25	0.27	5.1	16.3	5.9	20.8	<0.01	2.28	0.4	0.075	0.46	0.15	41	0.7	2.11	88	3.3
T11	MSU (High Cu Ni) Apr 30 /07	0.01	0.48	>10000	40	8.8	7.5	0.128	8.62	0.21	2.1	66.5	5.1	4.9	0.01	3.02	0.5	0.076	0.25	0.35	158	0.33	1.79	36	7.5
T12	SMSU (High Cu Ni) Apr 30/07	0.05	0.18	9000	150	101	6.1	0.101	9.5	0.71	6.7	36.6	5.9	20.2	<0.01	2.43	1	0.05	1.05	0.34	84	1.11	3.88	203	7.2
Min		0.01	0.05	2740.00	30.00	8.80	0.90	0.01	3.83	0.15	0.90	15.80	2.90	4.90	0.01	1.39	0.40	0.02	0.18	0.05	39.00	0.25	0.74	36.00	0.90
25%		0.02	0.12	2877.50	40.00	24.03	3.33	0.03	4.34	0.21	1.83	16.75	3.80	5.45	0.01	2.21	0.40	0.04	0.24	0.11	44.75	0.37	1.54	41.75	2.68
Median		0.09	0.20	3645.00	160.00	34.05	4.60	0.10	8.62	0.25	4.55	41.20	5.15	20.40	0.01	2.33	0.50	0.08	0.41	0.15	57.50	0.42	2.11	74.50	3.80
Average		0.07	0.22	4797.50	130.83	37.33	4.70	0.09	7.10	0.35	3.81	38.96	4.87	15.79	0.01	2.36	0.56	0.07	0.42	0.17	72.92	0.56	2.22	77.67	4.35
75%		0.10	0.31	6060.00	172.50	45.30	6.28	0.14	9.38	0.57	5.13	57.30	5.90	20.83	0.01	2.44	0.50	0.09	0.48	0.21	85.50	0.75	2.78	89.75	7.28
Max		0.12	0.48	>10000	260.00	101.00	9.90	0.19	9.75	0.71	6.70	66.50	6.30	24.60	0.01	3.46	1.00	0.11	1.05	0.35	158.00	1.11	3.96	203.00	7.80
Std Dev		0.04	0.13	2556.83	76.21	23.10	2.78	0.07	2.63	0.20	2.08	20.08	1.17	8.03	Not Appl	0.52	0.21	0.03	0.25	0.11	39.33	0.28	1.13	45.87	2.68
IQR		0.08	0.20	3182.50	132.50	21.28	2.95	0.11	5.04	0.36	3.30	40.55	2.10	15.38	0.00	0.23	0.10	0.04	0.25	0.10	40.75	0.38	1.23	48.00	4.60

Statistics exclude <, > values; No Standard deviation can be calculated for either Au or Ta because there is only one reportable value

Attachment 3
Tailings Whole Rock Analysis Data

Dark Green: < detection at limit shown

Sample	Sample ID	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	MgO %	Na2O %	K2O %	Cr2O3 %	TiO2 %	MnO %	P2O5 %	SrO %	BaO %	LOI %	Total %
T1	Eagle Tailings 11237-002 Comp.	15.85	2.46	61.4	2.54	6.11	0.33	0.15	0.17	0.67	0.16	<0.01	<0.01	<0.01	9.28	99.1
T2	Eagle Tailings 2011	29	2.32	36.7	1.91	18.2	0.4	0.14	0.32	0.42	0.2	0.04	0.01	<0.01	8.41	98.1
T3	Eagle Tailings 2012	21.1	2.52	52.2	2.07	10.8	0.48	0.2	0.24	0.47	0.16	0.07	0.01	0.01	9.27	99.6
T4	Eagle Tailings 2013	31.9	2.4	29	1.8	22.5	0.35	0.13	0.35	0.44	0.21	0.05	0.01	0.01	8.8	98
T5	11237-002 MSU-1	5.44	0.44	76.1	0.68	3.38	0.04	0.03	0.17	0.11	0.09	<0.01	<0.01	<0.01	13.8	100.5
T6	11237-002 MSU-2	5.02	0.42	76.1	0.66	3.12	0.04	0.02	0.17	0.11	0.09	<0.01	<0.01	<0.01	14.1	99.9
T7	11237-002 MSU-3	5.55	0.45	73.7	0.79	3.01	0.06	0.02	0.17	0.07	0.09	0.08	0.01	<0.01	14.05	98.1
T8	11237-002 Semi MSU-1	33.7	2.58	28.6	2.92	23.9	0.34	0.12	0.38	0.54	0.21	0.1	0.01	<0.01	6.62	100
T9	11237-002 Semi MSU-2	34	2.5	28.7	2.84	23.5	0.32	0.1	0.37	0.53	0.21	0.02	0.01	<0.01	6.94	100
T10	11237-002 Semi MSU-3	34.7	2.43	28.2	2.82	23.1	0.32	0.11	0.37	0.5	0.2	0.07	0.01	<0.01	6.8	99.6
T11	MSU (High Cu Ni) Apr 3	3.27	1.02	79.3	0.2	0.34	0.05	0.11	0.08	0.23	0.12	<0.01	<0.01	<0.01	13.95	98.7
T12	SMSU (High Cu Ni) Apr	27.1	3.79	41.4	1.56	11.45	0.23	0.14	0.36	0.43	0.14	0.01	<0.01	<0.01	11.35	98
	Min	3.27	0.42	28.20	0.20	0.34	0.04	0.02	0.08	0.07	0.09	0.01	0.01	0.01	6.62	98.00
	25%	5.52	0.88	28.93	0.76	3.32	0.06	0.08	0.17	0.20	0.11	0.04	0.01	0.01	8.04	98.10
	Median	24.10	2.42	46.80	1.86	11.13	0.32	0.12	0.28	0.44	0.16	0.06	0.01	0.01	9.28	99.35
	Average	20.55	1.94	50.95	1.73	12.45	0.25	0.11	0.26	0.38	0.16	0.06	0.01	0.01	10.28	99.13
	75%	32.35	2.51	74.30	2.61	22.65	0.34	0.14	0.36	0.51	0.20	0.07	0.01	0.01	13.84	99.93
	Max	34.70	3.79	79.30	2.92	23.90	0.48	0.20	0.38	0.67	0.21	0.10	0.01	0.01	14.10	100.50
	Std Dev	12.84	1.09	21.29	0.96	9.29	0.16	0.06	0.11	0.20	0.05	0.03	0.00	0.00	3.02	0.92
	IQR	26.83	1.63	45.38	1.85	19.34	0.29	0.06	0.19	0.31	0.09	0.04	0.00	0.00	5.80	1.83

Statistics exclude <, > values

Attachment 4
Net Acid Generation Test Data

Sample	Sample ID	NAG pH after reaction	Vol. of NaOH		NAG (kg H2SO4/tonne)		NAGpH	NNP
			to pH 4.5	to pH 7.0	to pH 4.5	to pH 7.0		
T1	Eagle Tailings 11237-002 Comp.	2.10	26.80	108.30	52.53	212.27	2.10	-602.4
T2	Eagle Tailings 2011	3.39	3.50	30.50	6.86	59.78	3.39	-242.8
T3	Eagle Tailings 2012	2.72	37.80	91.95	74.09	180.22	2.72	-489.5
T4	Eagle Tailings 2013	3.76	1.20	15.55	2.35	30.48	3.76	-119.1
T5	11237-002 MSU-1	2.41	13.90	109.20	27.24	214.03	2.41	-1010.1
T6	11237-002 MSU-2	2.39	20.10	104.90	39.40	205.60	2.39	-1012.1
T7	11237-002 MSU-3	2.46	25.40	106.75	49.78	209.23	2.46	-859.7
T8	11237-002 Semi MSU-1	3.41	1.10	9.75	2.16	19.11	3.41	-86.0
T9	11237-002 Semi MSU-2	4.00	0.90	9.15	1.76	17.93	4.00	-108.0
T10	11237-002 Semi MSU-3	3.66	0.95	9.40	1.86	18.42	3.66	-111.4
T11	MSU (High Cu Ni) Apr 30 /07	2.16	42.70	78.35	83.69	153.57	2.16	-940.9
T12	SMSU (High Cu Ni) Apr 30/07	2.21	41.50	97.25	81.34	190.61	2.21	-514.3
	Min	2.10			1.76	17.93		
	25%	2.35			2.30	27.64		
	Median	2.59			33.32	166.89		
	Average	2.89			35.26	125.94		
	75%	3.47			57.92	206.51		
	Max	4.00			83.69	214.03		
	Std Dev	0.70			32.74	87.65		
	IQR	1.13			55.62	178.87		

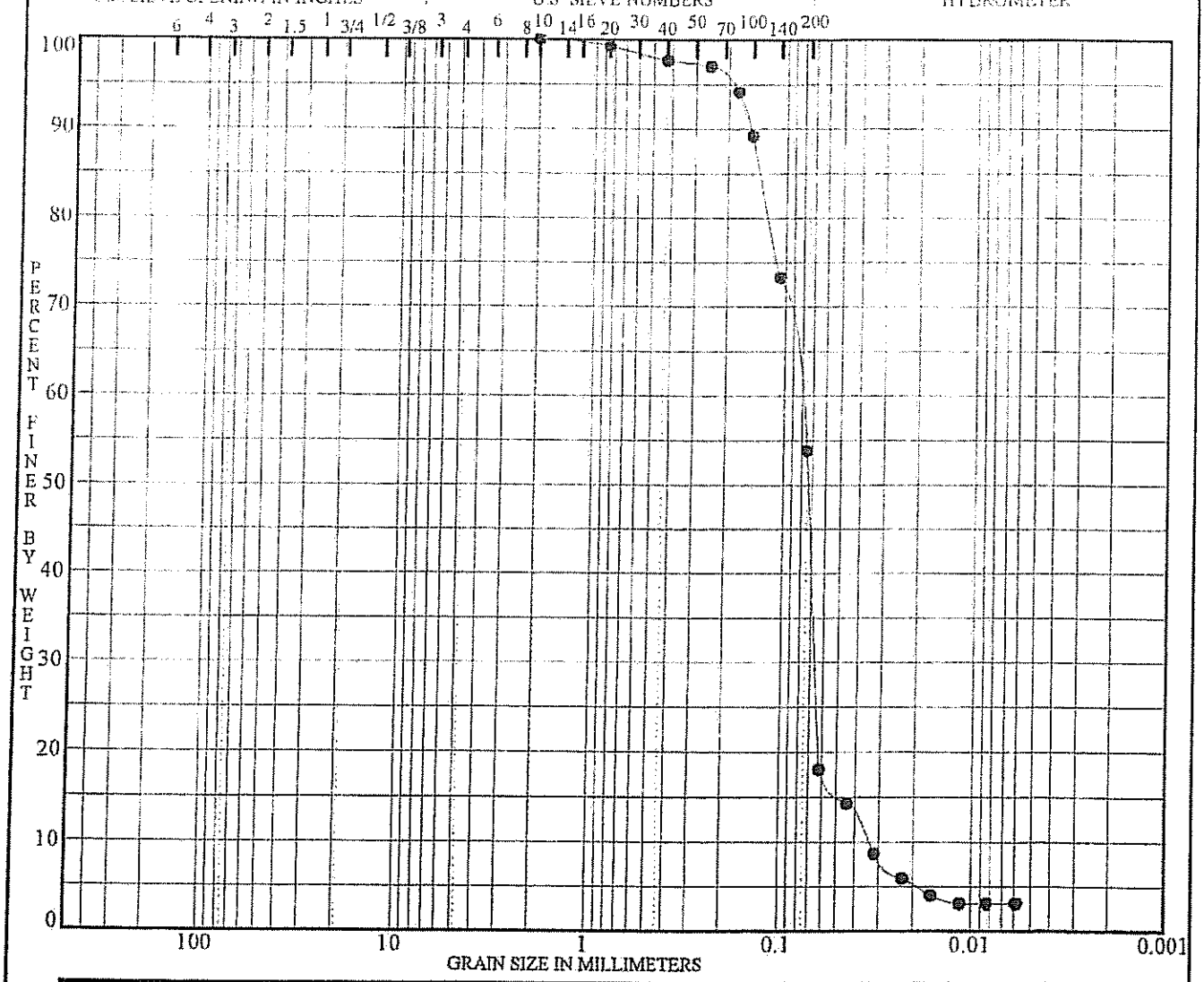
Attachment 5
Synthetic Precipitation Leaching Procedure Test Data

Sample ID:		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
		Tailing Composite	**Eagle Tailings 2011**	**Eagle Tailings 2012**	**Eagle Tailings 2013**	**11237-002 MSU-1**	**11237-002 MSU-2**	**11237-002 MSU-3**	**11237-002 Semi MSU-1**	**11237-002 Semi MSU-2**	**11237-002 Semi MSU-3**	**MSU (High Cu Ni) Apr 30/07 samples**	**SMSU (High Cu Ni) Apr 30/07 samples**
Parameter	Units												
Sample weight	grams	100	100	100	100	100	100	100	100	100	100	100	100
Extractant Volume	mL	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Extractant pH		4.17	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.24	4.24
Leachate pH (18 hours)		7.25	8.49	7.38	8.62	-	-	-	-	-	-	4.96	5.49
pH (titration)			7.76	7.44	8.34	6.19	6.08	6.30	7.52	7.40	7.56		
Redox	mV	347	374	376	331	157	113	97	142	230	271	295	71
Conductivity	uS/cm	241	203	338	177	576	589	588	188	191	192	825	791
Acidity (to pH 4.5)	mg CaCO3/L	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Total Acidity (to pH 8.3	mg CaCO3/L	3.1	1.9	2.8	#N/A	34.1	41.0	37.5	1.9	2.0	1.4	264.1	93.6
Alkalinity	mg CaCO3/L	25.8	23.4	27.4	31.6	7.8	5.9	8.4	21.9	20.8	20.1	<1.0	3.0
Sulphate	mg/L	34	55	93	20	213	217	217	45	49	49	614	457
Ion Balance													
Major Anions	meq/L	1.22	1.61	2.48	1.05	4.59	4.64	4.69	1.38	1.44	1.42	12.79	9.58
Major Cations	meq/L	2.19	1.87	3.19	1.81	6.82	6.95	6.75	1.89	1.89	1.92	10.36	9.85
Difference	meq/L	-1.0	-0.26	-0.70	-0.76	-2.22	-2.31	-2.06	-0.51	-0.45	-0.50	2.43	-0.27
Balance (%)	%	-28.4%	-7.4%	-12.4%	-26.7%	-19.5%	-19.9%	-18.0%	-15.8%	-13.6%	-14.9%	10.5%	-1.4%
Dissolved Metals													
Hardness CaCO3	mg/L					291	292	288	65.7	65.3	66.5	235	364
Aluminum	mg/L	0.0038	0.0034	0.0017	0.0030	<0.0050	<0.0050	<0.0050	0.0020	0.0038	0.0014	.0109	0.0132
Antimony	mg/L	<0.00010	0.00019	<0.00010	0.00048	<0.00050	<0.00050	<0.00050	0.00016	0.00016	0.00018	<.00050	<0.00020
Arsenic	mg/L	<0.00010	0.00011	<0.00010	0.00019	<0.00050	<0.00050	<0.00050	<0.00010	<0.00010	<0.00010	<.00050	<0.00020
Barium	mg/L	0.00401	0.00505	0.0120	0.00217	0.0426	0.0425	0.0431	0.00875	0.00868	0.00907	.0676	0.0541
Beryllium	mg/L	<0.00050	<0.00050	<0.00050	<0.00050	<0.0025	<0.0025	<0.0025	<0.00050	<0.00050	<0.00050	<.0025	<0.0010
Bismuth	mg/L	<0.00050	<0.00050	<0.00050	<0.00050	<0.0025	<0.0025	<0.0025	<0.00050	<0.00050	<0.00050	<.0025	<0.0010
Boron	mg/L	0.053	0.188	0.163	0.323	<0.050	<0.050	<0.050	0.108	0.110	0.113	.080	0.360
Cadmium	mg/L	<0.000050	<0.000050	<0.000050	<0.000050	0.00065	0.00064	0.00069	<0.000050	<0.000050	<0.000050	<.00025	0.00359
Calcium	mg/L	22.5	9.32	20.8	5.84	93.9	95.0	94.0	12.4	12.2	12.4	72.2	48.0
Chromium	mg/L	<0.00050	<0.00050	<0.00050	<0.00050	<0.0025	<0.0025	<0.0025	<0.00050	<0.00050	<0.00050	<0.0025	<0.0010
Cobalt	mg/L	0.00037	<0.00010	0.00078	<0.00010	0.125	0.128	0.132	0.00016	0.00014	0.00015	.134	0.173
Copper	mg/L	0.00089	0.00107	<0.0020	0.00159	0.00278	0.00113	0.00107	0.00113	0.00112	0.00039	0.00514	0.00109
Iron	mg/L	<0.030	<0.030	<0.030	<0.030	10.1	13.1	12.4	<0.030	<0.030	<0.030	130.0	33.2
Lead	mg/L	<0.000050	<0.000050	<0.000050	<0.000050	<0.00025	<0.00025	<0.00025	<0.000050	<0.000050	<0.000050	.00033	0.00056
Lithium	mg/L	<0.0050	<0.0050	0.0100	<0.0050	<0.025	<0.025	<0.025	<0.0050	<0.0050	<0.0050	.025	0.015
Magnesium	mg/L	5.31	5.72	10.2	4.75	13.8	13.4	12.8	8.47	8.46	8.61	13.2	59.3
Manganese	mg/L	0.00391	0.00171	0.0212	0.000588	1.44	1.43	1.47	0.00333	0.00327	0.00363	1.67	2.27
Mercury	mg/L	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<.000050	<0.000050
Molybdenum	mg/L	0.000778	0.00161	0.000583	0.00188	<0.00025	<0.00025	<0.00025	0.00286	0.00276	0.00288	<0.00025	<0.00010
Nickel	mg/L	0.0773	0.00870	0.152	0.00395	12.3	12.6	12.9	0.0132	0.0120	0.0130	20.7	20.5
Phosphorus	mg/L	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium	mg/L	5.1	6.8	11.3	4.6	2.7	2.6	2.5	6.0	6.2	6.2	9.6	10.4
Selenium	mg/L	<0.0010	<0.0010	0.0013	0.0013	0.0125	0.0122	0.0119	0.0011	0.0010	0.0010	<.0050	0.0136
Silicon	mg/L	0.803	1.40	0.886	1.45	0.678	0.705	0.761	1.16	1.20	1.15	2.34	4.19
Silver	mg/L	0.000033	0.000030	0.000085	0.000051	<0.000050	<0.000050	<0.000050	0.000064	0.000060	0.000085	<.000050	<0.000020
Sodium	mg/L	11.6	17.5	23.5	23.3	2.1	2.0	<2.0	9.7	9.8	10	<2.0	7.8
Strontium	mg/L	0.0980	0.0490	0.0794	0.0274	0.0712	0.0683	0.0701	0.0359	0.0358	0.0371	.0884	0.184
Thallium	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	<0.00050	<0.00050	<0.00050	<0.00010	<0.00010	<0.00010	<00050	<0.00020
Tin	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	<0.00050	<0.00050	<0.00050	<0.00010	<0.00010	<0.00010	<.00050	<0.00020
Titanium	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium	mg/L	<0.000010	<0.000010	<0.000010	<0.000010	<0.000050	<0.000050	<0.000050	<0.000010	<0.000010	<0.000010	<0.000050	<0.000020
Vanadium	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	<0.0050	<0.0050	<0.0050	<0.0010	<0.0010	<0.0010	<0.0050	<0.0020
Zinc	mg/L	0.0012	0.0098	0.0087	0.0085	<0.0050	0.0053	0.0056	<0.0010	<0.0010	<0.0010	0.0244	0.0227

Dark Green: < detection at liumit shown

N/A: Not applicable

C-3
Geotechnical Test Results



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		
☒									
▲									
★									
⊙									

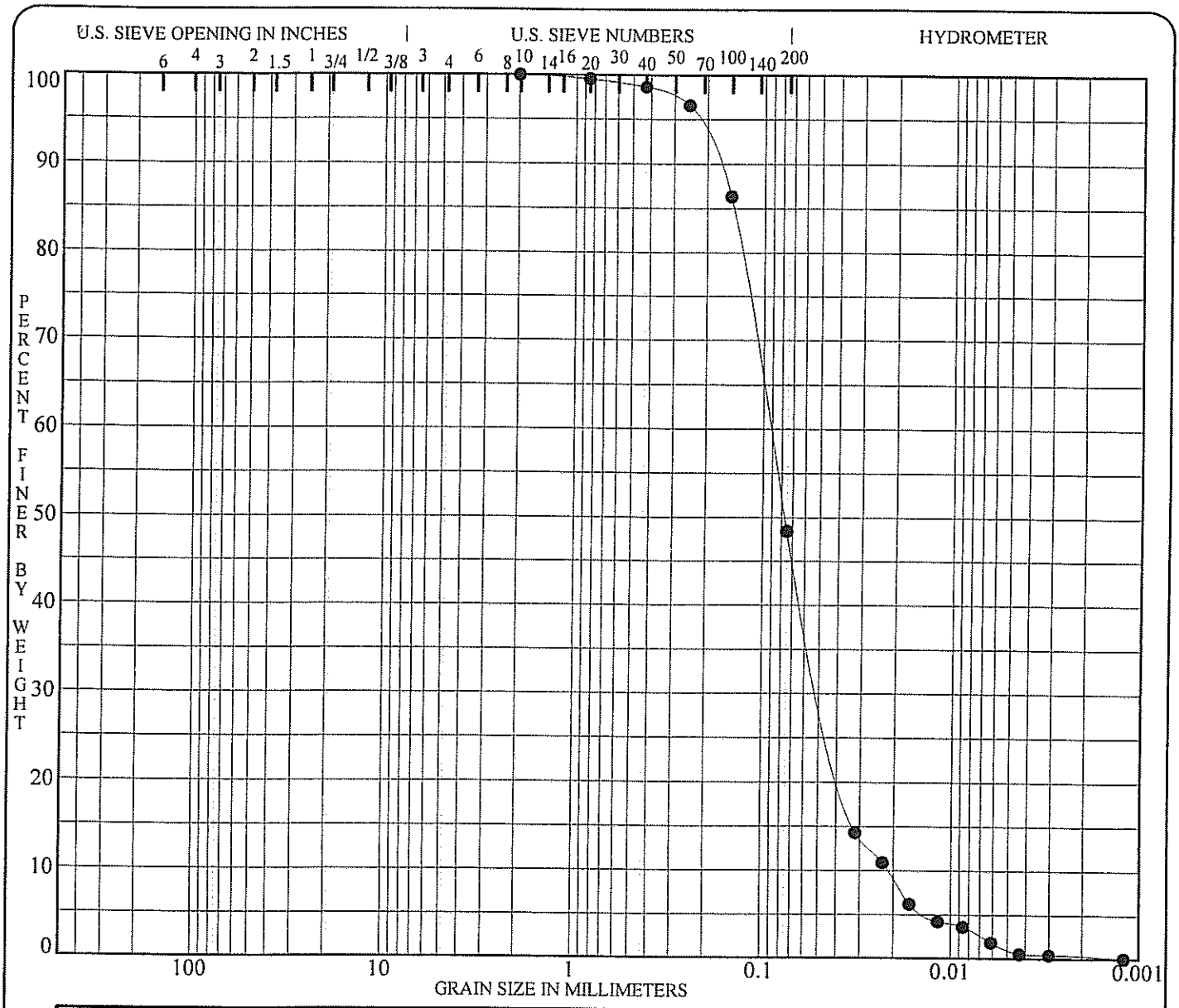
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PROJECT: 2007 Lab Testing

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 MLLR_ENG.GDT 2/1/07 14:36



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
● 11237-002(2011)						1.12	4.3
☒ LAB ID: SH2510							
▲							
★							
⊙							

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● 11237-002(2011)	2.00	0.09	0.047	0.0214	0.0	51.6	47.4	1.1
☒								
▲								
★								
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CLIENT : **Foth & Van Dyke**
PROJECT: **2007 Lab Testing**

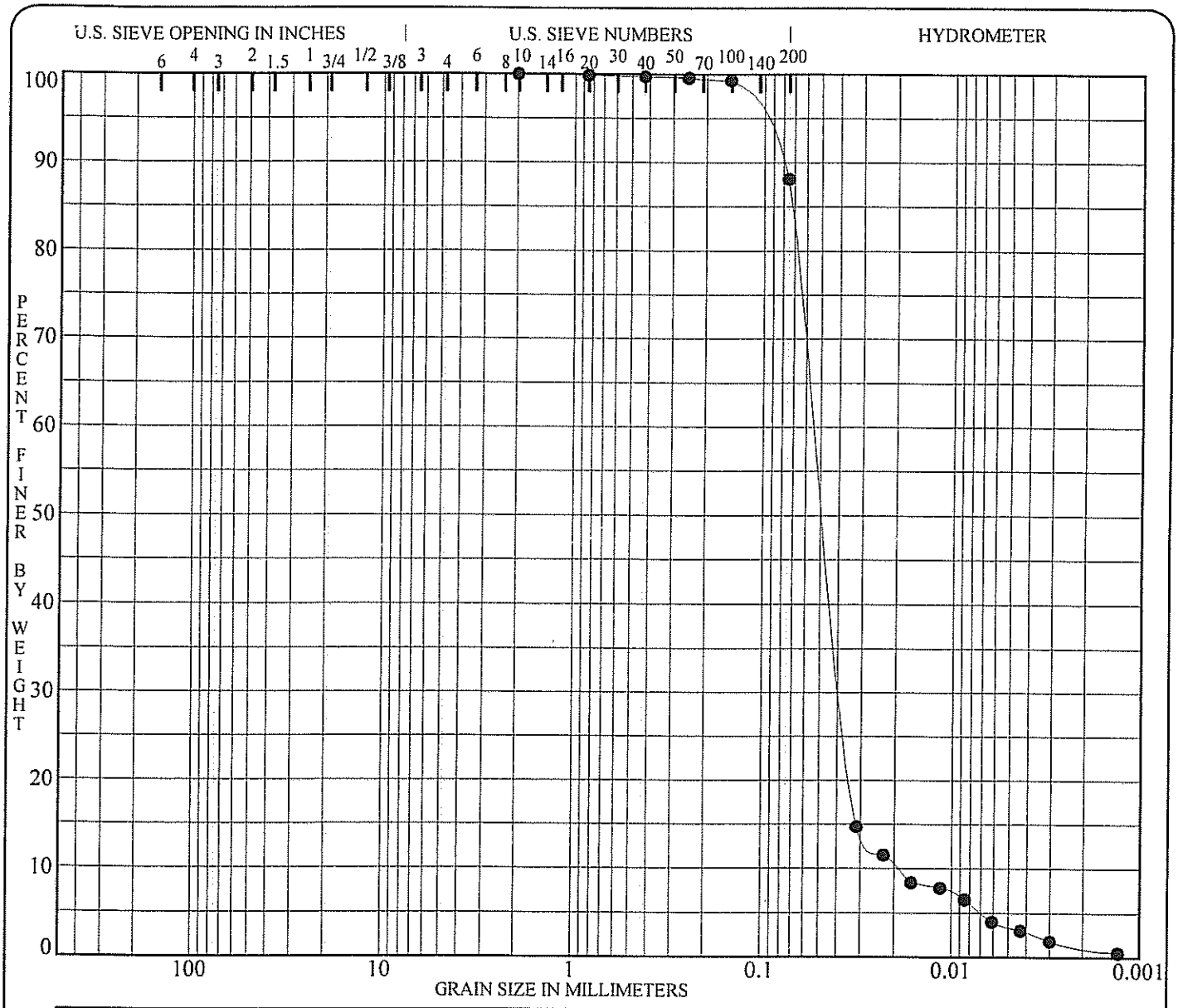
JOB NO.: **07-1-17422**
TEST DATE: **2/23/07**

MILLER ENGINEERS SCIENTISTS

GRAIN SIZE ANALYSIS
ASTM D422

SOURCE:
SAMPLED BY: **FOTH**
TESTED BY: **BJL**
REVIEWED BY: **RGM**

GRAFSIEV GINT 2007.GPJ MLLR_ENG.GDT 2/23/07 14:31



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
● 11237-002(2012)						1.37	2.8
☒ LAB ID: SH2511							
▲							
★							
⊙							

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● 11237-002(2012)	2.00	0.05	0.038	0.0193	0.0	11.9	84.7	3.4
☒								
▲								
★								
⊙								

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

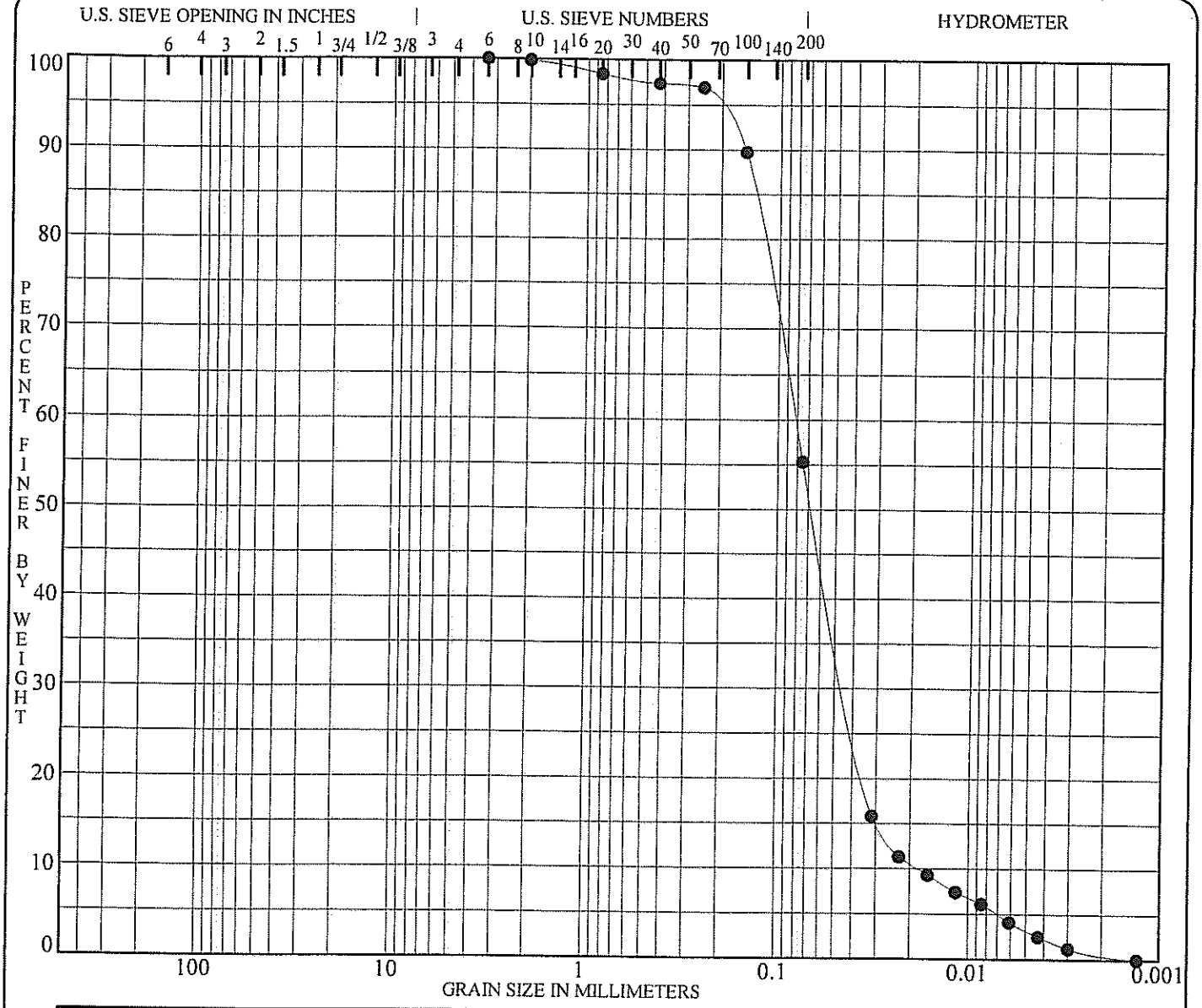
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TEST DATE: **2/23/07**

MILLER ENGINEERS SCIENTISTS

GRAIN SIZE ANALYSIS
ASTM D422

SOURCE:
SAMPLED BY: **FOTH**
TESTED BY: **BJL**
REVIEWED BY: **RGM**

GRAFSIEV GINT 2007.GPJ MLLR_ENG.GDT 2/23/07 14:31



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
● 11237-002(2013)						1.23	4.5
⧓ LAB ID: SH2512							
▲							
★							
⊙							

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● 11237-002(2013)	3.35	0.08	0.043	0.0182	0.0	44.7	52.1	3.2
⧓								
▲								
★								
⊙								

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

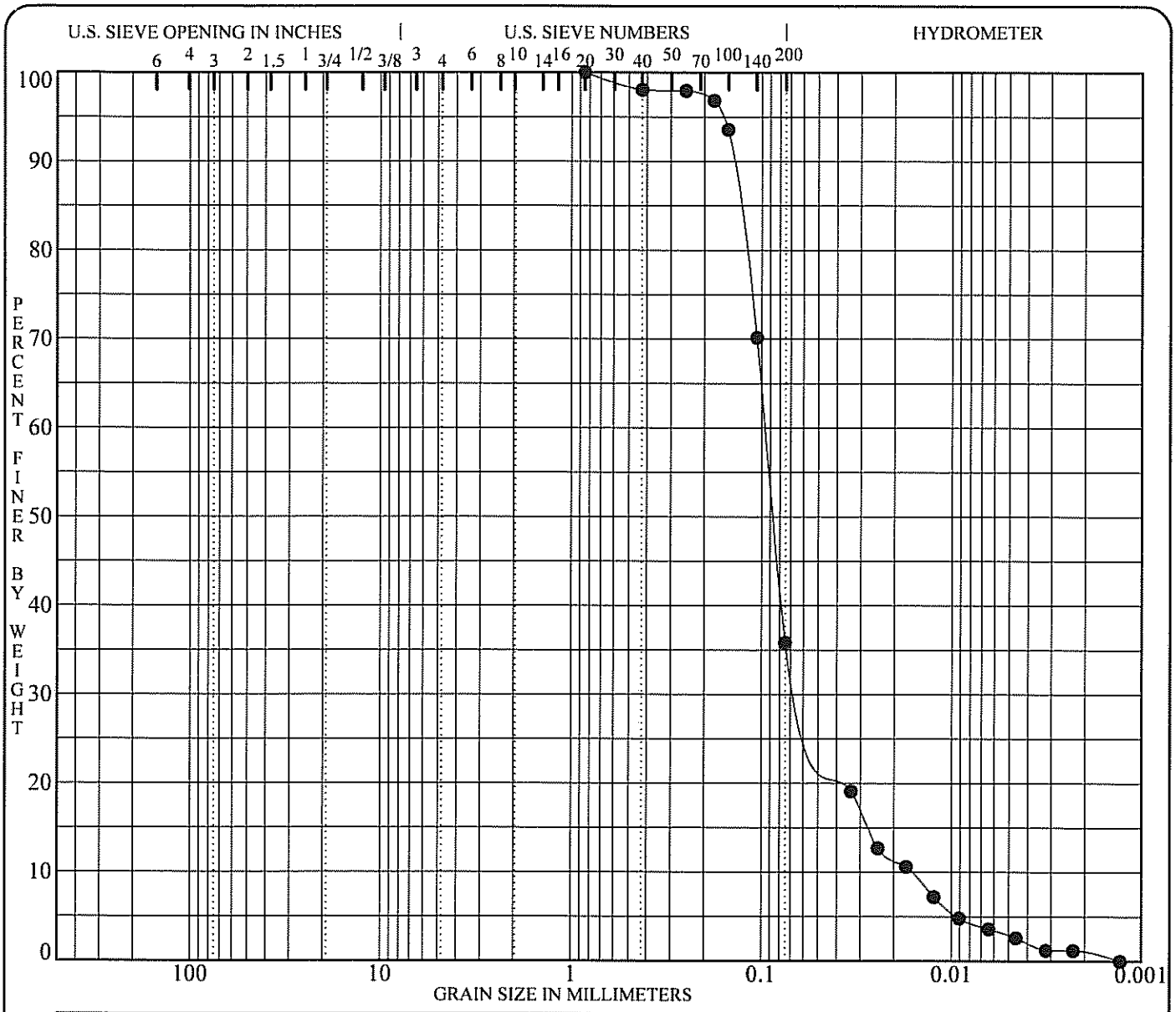
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TEST DATE: **2/23/07**

MILLER ENGINEERS SCIENTISTS

GRAIN SIZE ANALYSIS
ASTM D422

SOURCE:
SAMPLED BY: **Foth**
TESTED BY: **BJL**
REVIEWED BY: **RGM**

GRAFSIEV GINT 2007.GPJ MLLR_ENG.GDT 2/23/07 14:31



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

Appendix D

Hydrologic and Geochemical Mass Balance Model Report

Report

Kennecott
Eagle Minerals

Humboldt Tailings Disposal Facility Hydrologic and Geochemical Mass Balance Model Report

Project I.D.: 06W003

Kennecott Eagle Minerals Company

Marquette, Michigan

November 2007

Foth

Humboldt Tailings Disposal Facility
Hydrologic and Geochemical Mass Balance Model Report

Project ID: 06W003

Prepared for

Kennecott Eagle Minerals Company
ISO 14001:2004 Registered System

Prepared by

Foth Infrastructure & Environment, LLC

November 2007

Foth Infrastructure & Environment, LLC 2008
2737 South Ridge Road, Suite 600 • P.O. Box 12326 • Green Bay, WI 54307-2326 • (920) 497-2500 • Fax: (920) 497-8516

Addendum

This addendum addresses a minor change to an important attribute of the Humboldt Tailings Disposal Facility (HTDF). The watershed boundary described in Section 2.2 was adjusted to coincide with elevation contours developed from the same aerial survey. A revised estimate for the total HTDF basin area is 907,319 m^2 (224 Ac), an increase of 5.8% over the prior estimate. The estimated area of the HTDF water surface remained unchanged. The proportional drainage area to the northern HTDF decreased slightly from 14.4 percent to 14.3 percent of the total watershed. This change is insignificant. The revised estimate for the total watershed area is consistent with the boundaries and area table shown in Figure 2.

For purposes of water balance calculations and mass balance modeling presented here, the prior estimate for the watershed area (212 Ac) was applied. The revised area estimate was available only after extensive modeling had been completed and summarized. Several checks were made to show that, while the average annual outflow from the HTDF would increase by roughly 12 gpm as a result of applying the revised area estimate, the effect on the mass balance model results was negligible. For instance, changes to nickel concentrations at the expected HTDF outlet (and all main model compartments) were less than 0.1 ug/L for the 14 year period of simulation.

Humboldt Tailings Disposal Facility
Hydrologic and Geochemical Mass Balance Model Report

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Humboldt Tailings Disposal Facility
Hydrologic and Geochemical Mass Balance Model Report

Executive Summary

Kennecott Eagle Minerals Company (KEMC) is proposing to rehabilitate the existing Humboldt Mill facilities located in Humboldt Township, Marquette County, Michigan, for processing nickel and copper ore. The proposed milling operations are expected to produce tailings, and the proposed plan calls for the residual tailings to be placed in the Humboldt Tailings Disposal Facility (HTDF).

The HTDF is a former mine excavation adjacent to the mill, formed from iron mining and associated dewatering operations at the Humboldt Mine. The mine was developed in 1954, operated until about 1970, and then the excavation was allowed to fill with water to a water depth of approximately 350 ft (107 m). Tailings from on site milling of ore from the Ropes Gold Mine, operated by Callahan Mining Company and located 10 miles east of the Humboldt Mill, were placed in the HTDF from 1985 until 1989. The water depth decreased to roughly 190 ft (58 m). While the water quality is still impaired at depth within the HTDF, water quality has improved significantly since 1990. Monitoring data and the dynamics of the recovery of the water quality since the Ropes operation serve as a major data source for projecting the HTDF behavior upon additional loadings.

This report describes the proposed sub-aqueous placement of tailings, initial conditions in and surrounding the HTDF, and the expected response of the HTDF to the tailings discharge. The purpose of this report is to assess the water chemistry characteristics during active milling and tailings placement operations at the site and to assess post operations water chemistry and related post closure care needs. The report also provides a detailed description of the current state of water chemistry, bathymetry, climatology, and flows associated with the HTDF.

Recent field measurements indicate that the HTDF exhibits seasonal stratification with respect to temperature and, because stratification is very stable, complete mixing of the HTDF is not evident. Historical data shows that the original mine excavation pit was once completely oxygenated, but recent oxygen profiles show a persistent oxygen chemocline located at mid-depth in the HTDF, well beneath the thermocline. Diurnal oxygen measurements indicate essentially no primary productivity in the HTDF. The appearance of anoxic conditions in the bottom waters of the HTDF coincides with the placement of tailings from on site milling of ore from Ropes mine. Oxidation reduction potential measurements, as well as very low levels of organic carbon in the water column, strongly suggest that the existing sulfide tailings help to maintain anoxic conditions. The anoxia will be further enforced by the proposed placement of fresh sulfide tailings and slow rate of oxygen mass transfer to sediments, thus creating a persistent reducing environment near the tailings. Measured depth profiles of metals in the water of the HTDF show that, for most metals, highest concentrations occur in the bottom waters, and concentrations decrease, often to less than twenty percent of maximum concentrations, above the oxygen chemocline. This behavior is attributed to an ongoing iron cycle operating near the oxic-anoxic boundary, creating iron particles that scavenge other metals from the water column and deliver them to the bottom of the HTDF. Thus, extensive chemical characterization of the HTDF

reveals the presence of a system that prevents oxygen from reaching deep water, while also greatly limiting the transport of metals to surface waters.

Particular attention within the report is drawn to a detailed, multi-component, multi-compartment mass and heat balance model which was developed to prepare predictions of HTDF water quality and other conditions in the HTDF that are expected to change during and after the placement of tailings. The numerical model addresses heat and mass balances, density-dependent mixing between different strata or compartments of the HTDF, allowance for variable water storage to accommodate an even influent flow to the WWTP, and several key chemical processes. The tailings are planned to be delivered to the HTDF as a high density slurry at depth. The dynamics of heat and mass transfer at the point of discharge are included in the model. Modeled chemical processes include dissolved oxygen mass transfer and depletion, dynamics of oxygen-demanding chemicals, formation and settling of ferric hydroxide, scavenging of metals by ferric hydroxide, and alkalinity effects from the discharge and oxidation-reduction reactions. Various calibration measures were taken to provide reasonable estimates for seasonal runoff, ice conditions, temperature profiles within the HTDF, volume change and water elevation estimation, and outflows.

Given the complexity and scope of processes simulated by the model, this report also provides a detailed assessment of the water chemistry and hydrology of the HTDF as it relates to implications for tailings placement and subsequent changes in water chemistry. This includes an assessment of the range of potential water chemistry conditions during operations and after closure of the mill.

A key outcome of the multi-compartment mass balance model was that, during and after the period of the placement of mill tailings, the stratified behavior of the HTDF would likely be sustained. This is a particularly important and reasonable conclusion, but one which follows from the nature of the placement of the tailings, internal processes which tend to reinforce stability, and conditions regarding the natural flows and bathymetry of the HTDF.

The placement of tails at a high slurry density and the preservation of a stratified HTDF generally leads to low surface concentrations at the HTDF surface. Shallow surface water represents the source of water that will be pumped to the wastewater treatment facility during operations. Shallow surface water also represents the source of water at the outlet that will be allowed to naturally drain after closure of the mill. Modeling included simulation of a conservative tracer test, which showed that the HTDF outlet concentrations would peak at roughly 3% of the discharge concentration, but only after a long loading period of 7 years.

For metals that undergo complexation and precipitation reactions, such as nickel, copper, mercury, and other metals, the concentrations at the HTDF outlet and within the HTDF are expected to be greatly reduced due to complexation, precipitation, and scavenging by iron hydroxide. In addition, the levels for these constituents within the HTDF drop significantly after the period of tailings placement.

With current estimates of the Preliminary Effluent Limits (PELs) available for the constituents from the multi-component model, none of the modeled constituent concentrations for the HTDF outlet exceeded the PEL. For nickel, copper, mercury, and selenium, the outlet concentrations were all well beneath the PEL, and generally by an order of magnitude or greater. The main

conclusion of this report is that the mass balance model predicts that the HTDF will remain stratified during and after the proposed placement of mill tailings, and the constituent concentrations at the HTDF outlet are expected to never exceed the associated PEL.

A fully-mixed model was also developed to estimate maximum HTDF outflow concentrations. It is important to note that this model represents a highly unlikely scenario, given the known stratification of the HTDF, the nature of placement, and chemical processes, such as metals scavenging, that tend to remove metals from the water column in the HTDF. The washout mechanism inherent in the fully-mixed model was tested using historical measurements of nickel, and was found to greatly over-predict outflow concentrations. The level of over-prediction is expected to be higher for the period of tailings loadings, since the fully-mixed model also assumes that the pore water associated with the tailings would also be fully mixed within the HTDF. Nevertheless, the fully-mixed model predicted that water from the HTDF would require treatment to comply with standards for copper, mercury, and nickel, and possibly selenium. Under the fully mixed condition, treatment for these constituents would be required for at least seven years after mill production ceases.

Several recommendations are issued within the report. While the fully-mixed case is likely unrealistic, the model outcomes may be referenced as a worst-case for the proposed wastewater treatment plant (WWTP). Treatment should be provided to meet the expected wastewater treatment discharge limits for nickel, copper, and mercury. A management plan for the HTDF should provide routine monitoring of the mill tailings carriage water, the HTDF bathymetry, and water quality within the HTDF. Finally, with respect to contingency plans for the HTDF, it is recommended that the plans include options such as treatment with coagulants (such as ferric salt or alum) to remove suspended solids and metals within the HTDF by adsorption, coagulation, and flocculation. Although high concentrations are not unexpected, elevated HTDF concentrations of metals and other constituents from the tailings discharge could be effectively removed from the water column (within the HTDF) in order to meet and sustain constituent concentrations below discharge standards after closure.

This report has identified the use of the multi-compartment model, largely to provide estimates of the expected concentrations at the HTDF outlet. However, the model may also be used as a way to track the progress and state of the HTDF during loading. The modeling could be refined from regular calibration to observed conditions during loading, then used to refine projections for future performance.

ac	acre
ºC	Celsius
cm	centimeter
d	day
DEM	digital elevation model
DO	dissolved oxygen
E_H	Standard Hydrogen Potential
EQL	Estimated Quantitation Limits
ºF	Fahrenheit
ft	feet
Foth	Foth Infrastructure & Environment, LLC
GJ	giga-Joules
gpm	gallons per minute
hr	hour
HTDF	Humboldt Tailings Disposal Facility
in.	inches
J	Joules
ºK	Kelvin
KEMC	Kennecott Eagle Minerals Company
kg	kilograms
K_s	Solubility Product
L	liter
m	meters
m^2	square meters
m^3	cubic meters
MDL	Method Detection Limit
mg	milligrams
mm	millimeters
mV	millivolts
mol	mole
N	Nitrogen
NCDC	National Climatic Data Center
ng	nanogram
ORP	oxidation reduction potential
%	percent
pcf	pounds per cubic foot
pE	- Log [E]
PEL	Preliminary Effluent Limit
pH	- Log [H+]
s	second
TDS	total dissolved solids
tonnes	metric tonnes (1.102 tonnes per ton)
ug	microgram

V	volts
WWTP	wastewater treatment plant
yr	year

1 Purpose and Scope

The purpose of this report is to assess the water chemistry characteristics of the Humboldt Tailings Disposal Facility (HTDF) during proposed milling and tailings placement operations at the site and to assess post operations water chemistry and related post closure care needs. The scope of the report includes a summary of the hydrogeology of the HTDF and its sources of water and point where water exits the system to a regulated environment, and a water budget for the integrated operations of the mill and existing HTDF including its watershed and outlet.

A numerical model has been created to simulate the behavior of the HTDF during and after proposed tailings placement. The model addresses heat and mass balances, density-dependent mixing between different strata or compartments of the HTDF, allowance for variable water storage to accommodate an even influent flow to the wastewater treatment plant (WWTP), and several key chemical processes. The tailings are expected to be delivered to the HTDF as a high density slurry at depth. The dynamics of heat and mass transfer at the point of discharge are included in the model. Modeled chemical processes include dissolved oxygen (DO) mass transfer and depletion, dynamics of oxygen-demanding chemicals, formation and settling of ferric hydroxide, scavenging of metals by ferric hydroxide, and alkalinity effects from the discharge and oxidation-reduction reactions.

Given the complexity and scope of processes simulated by the model, this report also provides an assessment of the water chemistry and hydrology of the HTDF as it relates to implications for proposed tailings placement and subsequent changes in water chemistry. This includes an assessment of the range of potential water chemistry conditions during operations and after closure of the mill.

The proposed strategy for the HTDF includes several controls for water flow and quality. Prior to the placement of tailings, outflows for the HTDF are planned to be contained and controlled by a cut-off wall and surface water control structure (a berm). The berm will allow all HTDF outflows to be sent through a WWTP, from which water will be treated to meet applicable water quality standards prior to surface water discharge. The berm will also allow the build up of water levels within the HTDF, in order to accommodate peak flows during snow melt and storm events. Expected flows and water quality at the influent to the WWTP are addressed in this report.

2 Summary of HTDF Hydrology

The HTDF hydrology is discussed in terms of the monthly climate, watershed drainage subbasins, the lake bathymetry, and the hydrogeology.

2.1 Summary of Monthly Climate

A summary of monthly climate is presented in Table 1 and Figure 1. Climate data are drawn from Champion – Van Riper State Park (NCDC site 201439), a weather station close to the HTDF. Normal annual precipitation is 33.3 inches (846 mm), with extremes of 20.17 inches (low) and 46.94 inches (high). Annual evaporation (Marquette County, Station MI 5178) is estimated as 14.8 inches. Monthly mean temperatures range from 11.3 °F (-11.5 °C) in January to 64.3 °F (17.9 °C) in July. Mean annual snowfall is 132.8 inches, with snow depth highest in February and March (National Climatic Data Center; Natural Resources Conservation Service; Michigan Climatological Resources Program).

2.2 Watershed Drainage and Groundwater

Surface drainage into the HTDF is limited to a small bedrock highland watershed shown in Figure 2. Local relief in the vicinity of the pit is approximately 200 feet (ft). The subbasins and watershed boundary were generated using the watershed delineation tools within ArcGIS, and using a digital elevation model (DEM) based on the aerial survey. The aerial survey data were collected April 27, 2006 by Aero-Metric Engineering (Sheboygan, Wisconsin), and coordinates were reported with reference to the North American Vertical Datum of 1988 and horizontal datum based on NAD 83/96. The estimate for the total HTDF basin area is 857,628 m^2 (212 Ac), which included the lake area of 269,406 m^2 (67 Ac) for a water elevation of 468.8 m (1538 ft). The northern HTDF area is somewhat isolated from the main HTDF, and its area is 22,569 m^2 (5.6 Ac).

The expected discharge flow from the HTDF under normal hydrologic loading conditions was estimated from the simulated net monthly precipitation (adjusted for evaporation, snow storage, and melt) and the basin area. Details of the storage assumptions are shown in Figure 1. The net precipitation and expected monthly discharge from the HTDF under normal, existing conditions is shown in Figure 3. Discharge is limited to the period of March through November. Snow melt effects are most pronounced in April, leading to an average discharge in April of 578 gallons per minute (gpm) (3150 m^3/d). The average net annual surface inflow is estimated as 203 gpm (1107m^3/d). Groundwater inputs to the HTDF are estimated to be 43 gpm (234 m^3/d). The basis for the groundwater inflow estimate is discussed below. Assuming no change in storage in the HTDF (other than ice and snow storage), the average outflow is equal to the sum of net surface and groundwater inflow; average annual outflow from the HTDF is 246 gpm (1341 m^3/day).

The model can accommodate seasonal and monthly flow balances and estimate conditions under dry and wet years. However, for the purposes of mass balance modeling, there is sufficient dampening of flow irregularity by the large volume of the HTDF, and the effects of irregular, extended dry or wet periods, while they will affect outflows, are expected to be relatively small in terms of HTDF mass balance modeling. The HTDF volume is 8.0 million m^3, and at an average discharge rate of 246 gpm (1341 m^3/d), the fully-mixed hydraulic retention time is roughly 16 years.

Under existing conditions, the outflow is expected to be a combination of groundwater and surface water flow. Surface water migrates by flow through an earthen berm and expressed as seepage entering the wetland to the north. Traverse Engineering (1984) calculated a hydraulic conductivity for the outwash of 27 ft/d (0.0094 cm/s) and indicated that two discharge structures were constructed to regulate the flow out of the HTDF. However, only one of these features has been located. A detailed site survey of the HTDF conducted in April, 2007 by a Foth Infrastructure & Environment, LLC (Foth) geologist concluded there is no evidence of any other surface flow out of the HTDF.

It is important to establish the nature of the groundwater inflow and the combined surface water and groundwater outflow of the HTDF. The recent site survey and subsequent groundwater flow mapping confirmed that the outflow from the HTDF flows toward wetlands to the north of the HTDF (Foth, 2007). Generally, groundwater south of the HTDF flows south and away from the HTDF. However, mining of the original pit has created a cone of depression drawing groundwater from a localized area to the south. Almost all of the groundwater flowing into the HTDF at its southern end is from outside the drainage basin of the HTDF, as the perimeter of the drainage basin falls very close to the HTDF in this location (Figure 2). Therefore, this potential input would be distinct from, and in addition to, the rain input in the drainage basin. Thus, the recent groundwater monitoring strongly indicates that groundwater from a small area south of the HTDF flows into the HTDF, and that a small subsurface flow leaves the HTDF at its northern end.

Groundwater input on the southern end of the HTDF is estimated to average 43 gpm (234 m^3/d). The groundwater inflow at the southern end of the HTDF was estimated with Darcy's Law, using a hydraulic conductivity of 5.0 x 10^{-3} cm/s (14.2 ft/d), and a local hydraulic gradient of 0.12 across a rectangular cross-section of 800 ft (244 m) width by 5.0 ft (1.52 m) thickness. While the resulting flow rate from these inputs is 35 gpm, an investigation using varying input parameters indicated a mid-range estimate of 43 gpm is appropriate.

2.3 Geological Conditions

The Humboldt Pit was developed in a narrow valley, floored by iron-rich rocks, cutting through a ridge of silicified, dense, recrystallized sedimentary and mafic intrusive rocks. The east and west sides of the pit are poorly fractured bedrock overlain by a thin, patchy till, and provides very little observed subsurface inflow into the pit. The predominant groundwater flow into the pit is from the south, through sand and gravel outwash.

The stratigraphy in the vicinity of the HTDF consists of Negaunee Iron formation divided into a thin, upper hematite-rich oxide facies and a lower, thicker cherty silicate iron formation. Both units are generally even bedded, recrystallized and may display a strong foliation. The iron formation is overlain by the Goodrich quartzite, which, in the pit consists predominantly of thick lenses of basal conglomerate. Clasts in the conglomerate range from angular to subrounded iron formation and other sedimentary rocks, along with well rounded pebbles and cobbles of vein quartz. The matrix is completely silicified and is dominated by fine grained quartz with accessory muscovite, hematite and magnetite with little or no feldspar. Both have been intruded by a medium to coarse grained diabase that generally forms concordant masses. All of these rocks were then folded and metamorphosed, and contacts between the intrusive rocks and iron

formation were commonly sheared. The rocks are complexly folded, but generally form an anticline which plunges to the west.

The deformation and foliation of these rocks has served to produce a weakly jointed bedrock surface. Sheared and recrystallized contacts at depth would likely limit joint propagation. In addition, due to the interlocking recrystallized texture, storage would be limited to the joint network. Recrystallized formations without a well developed joint network are very poor groundwater producers. An inspection of the site during spring run off confirmed that this is the case at the HTDF.

The narrow valley represents a post-glacial stream channel that cut through the bedrock ridge. The bedrock is overlain by a complex sequence of till and outwash that is generally thinner over the ridge and thicker where it occurs in the valleys. The outwash on the north end of the pit is capped with a rock and earthen berm constructed by the original operator to regulate flow out of the HTDF.

2.4 HTDF Water Balance and Bathymetric Characteristics

The current estimate for the water balance to the HDTF is based on the net precipitation model expressed above and includes an out-of-basin groundwater input from the southern end. Outflows from the HTDF are expected to report fully as influent to a WWTP. The current, combined surface and groundwater seepage outflow along the northern end of the HTDF will be cut off by construction of a berm and slurry wall. Therefore, all flow out of the HTDF will pass through the WWTP.

The bathymetry and area-depth-volume relationships for the HTDF are shown in Figure 4 and are derived from the baseline hydrogeology study (Foth, 2007). The HTDF covers an area of 269,400 m^2 (67 Ac) at a normal elevation of 468.8 m (1538 ft), with a total volume of 7,997,000 m^3. Depths in the main HTDF area are over 20 m (66 ft) for roughly two-thirds of the main HTDF surface area, and are 58.5 m (192 ft) at the deepest point. Depths in the northern HTDF area are limited to less than 20 m, and less than 7 m at the confluence with the main HTDF area. These bathymetric characteristics influence decisions regarding the compartmentalization of the mass balance model.

3 HTDF and Mill Water Budget

This section provides details of the water balance for the HTDF under several loading conditions. HTDF water balances on an annual basis are detailed in Section 3.1. However, the mass balance model was designed for dynamic simulation in order to better understand the impacts of seasonal flows and a set mill tailings discharge schedule. This required an evaluation of hydrological flows on a monthly basis. Elements of the HTDF water balance to better support the mass balance model are detailed in Section 3.2. Details regarding the scheduling of proposed tailings loadings to the HTDF are presented in Section 3.3. Further details of the dynamic simulation of the water balance for the multi-compartment mass balance model are presented in Section 6.

3.1 HTDF Water Balance on Annual Basis

A summary of the HTDF water balance on an annual basis is presented below.

3.1.1 Estimated HTDF Outflows on Annual Basis without Proposed Mill Operation

Without flows associated with the proposed mill operation considered, the average annual flow into the HTDF is estimated as 246 gpm (1341 m^3/d). Of this, 43 gpm is from groundwater inflow and 203 gpm is from precipitation minus evaporation.

Maximum annual precipitation is roughly 1.4 times that of the normal annual precipitation of 33.3 in. (845 mm) and the maximum annual net precipitation (precipitation minus average evaporation) is 1.7 times that of normal (see Table 1).

Under maximum annual precipitation conditions and no mill operation, the average annual outflow is estimated as 395 gpm (2153 m^3/d). Dry conditions can be estimated from the minimum annual precipitation of 20.17 inches (Table 1) and normal evaporation of 14.8 inches. Under extremely dry conditions and negligible groundwater inflow, the average annual flow is expected to be only 24% of the normal average, or 59 gpm (323 m^3/d). Because the volume of the HTDF is expected to be conserved, the sum of outflows is expected to equal the sum of inflows.

3.1.2 Estimated HTDF Outflows on Annual Basis with Proposed Mill Operation

Under annual average precipitation conditions and during proposed mill and wastewater treatment operation, the sum of inflows to the HTDF is estimated as 640 gpm (3489 m^3/d), with the largest inflows from precipitation (365 gpm), groundwater (43 gpm), and the mill discharge of water (142 gpm) and solids (70 gpm). The HTDF outflows are expressed to the WWTP (362 gpm), as reclaim water back to the mill (116 gpm), and evaporation (162 gpm). Details of the flow balance are presented in Figure 5, and calculations used to support the estimate of the proposed mill discharge are discussed in Section 3.3. Under the same conditions, the outflows are equivalent to the inflows.

Under similar conditions but with maximum annual precipitation (see Figure 6), the sum of inflows to the HTDF is estimated as 789 gpm (4301 m^3/d). The increase in the sum of inflows is due only to the increase in precipitation (514 gpm versus 365 gpm for the average condition). Similarly, the increase in the sum of the inflow is matched by an equivalent increase in the outflow to the WWTP (511 gpm versus 362 gpm for the average condition).

Because a small portion of the HTDF outflow is recycled to the HTDF, the expected wastewater treatment effluent flow is only 352 gpm for the average annual precipitation case and 501 gpm for the maximum annual precipitation case.

3.2 HTDF Water Balance on Monthly Basis

The mass balance model was designed for dynamic simulation in order to better understand the impacts of seasonal flows and a set mill tailings discharge schedule. This required an evaluation of hydrological flows on a monthly basis. Storm flows with periods on the order of days or less will be handled by storage within the HTDF.

3.2.1 Estimated Monthly HTDF Outflows without Proposed Mill Operation

The highest average monthly surface inflow occurs in April at 578 gpm (3150 m^3/d). Details for this calculation are shown in Figure 3. With the normal groundwater inflow of 43 gpm, the inflow estimate for the April average increases to 621 gpm (3385 m^3/d). It is important to note that this flow estimate does not consider abnormally high winter snow pack and sudden melt conditions.

Two methods were used to estimate peak monthly flow. One method, based on a peaking factor of 1.5 times the normal April inflow of 621 gpm, yields a peak monthly flow of 932 gpm (5080 m^3/d). The other method is based on the same storage method shown in Figure 3, monthly precipitation that is 1.41 times the normal (maximum annual precipitation case), and a normal groundwater inflow of 43 gpm. This method yields a similar estimate for peak monthly flow of 953 gpm (5195 m^3/d).

It is important to note that these estimates for flows follow from the assumption of constant storage in the HTDF. In reality, heads are likely to build up in wet years and be drawn down in dry years. Head buildup of 0.305 m (1 ft) over the HTDF area yields additional storage of 82,000 m^3, enough for 22 days of storage to handle the a peak monthly rate (932 gpm) with an average outflow rate of 246 gpm. Greater storage is available and outflows are expected to be higher during the peak inflow periods. For example, an additional 1 ft of head buildup fully accommodates the necessary storage for the peak monthly inflow with the average outflow rate.

The HTDF water elevation may also rise during a storm event. The 100 year, 24-hr rainfall event for Marquette County is 4.50 inches. The expected change in elevation can be estimated from the precipitation magnitude, multiplied by the ratio of the area for the watershed over the area of the HTDF (see Section 2.2). Assuming rapid runoff, no evaporative losses and negligible outflow during the storm, the expected increase in HTDF water elevation is 1.21 ft (0.37 m).

3.2.2 Estimated Monthly HTDF Outflows with Proposed Mill Operation

During active tailings loadings of the HTDF at the design rate, the discharge of water and solids from the mill is expected to be 50.5 m^3/hr (1213 m^3/d or 223 gpm) with a return water flow of 26.7 m^3/h (641 m^3/d or 118 gpm). (Although Figure 5 shows the return water flow as 116 gpm, the calculated return flow is closer to 118 gpm; the difference is due to rounding of several, balanced flow values). The discharge flow includes a 60% solids discharge of tailings plus 2.3 m^3/hr (54.5 m^3/d or 10 gpm) of miscellaneous contact water and truck wash water. The net

discharge would be 572 m^3/d (105 gpm). Further details about the discharge are discussed below. With an annual average background flow of 246 gpm, the discharge raises the HTDF outlet flow to roughly 351 gpm (1912 m^3/d).

A conservative estimate for very wet conditions (without storage), based on the estimate for peak monthly flow without the proposed mill discharge (932 gpm), is 1037 gpm. As mentioned above, additional storage within the HTDF of a foot or more can greatly dampen peak outflows.

Flow rates are important for sizing of the wastewater treatment system, which will treat HTDF water prior to groundwater discharge. The treatment system design relies on storage within the HTDF to adequately handle storms and peak flow periods. The multi-compartment model was used to dynamically simulate the expected heads during normal and peak precipitation cases. Further details are presented in Section 6.

3.3 Scheduling of Tailings Loadings to HTDF

A schedule of tailings loadings to the HTDF, necessary as a model input, was created from available estimates of the total dry tons of tailings expected, nominal loading rates, and the expected period of loading of 7.1 years.

According to M3 Engineering, the design rate for the discharge of tailings is set by the expected milling rate for the ore, 1584 metric tons (tonnes) per day. Assuming an ore moisture content of 6.78% (or 6.35% water per wet weight) and 78.13% tailings produced from dry ore, the dry tailings processing rate is 1159 tonnes per day (48.3 tonnes/h). The total quantity of ore to be processed is expected to be 3,419,430 tonnes (wet). The total production of tailings by the proposed mill is expected to be 2,501,969 tonnes (dry).

The discharge of tailings would be taken from the thickener underflow at 60% solids. The basis for volumes and densities, unless otherwise specified, is for 25° C (standard conditions). The density of water (γ_w) at 25° C with zero salinity is 997.3 kg/m^3 (62.261 pcf). The main solids relationships describing the placement of the tailings are the volume, percent solids by weight, P (or gravimetric water content, w), and specific gravity, G_s. A common assumption is 100% saturation ($S_r = 1$). Key relationships are:

% solids *P* and moisture content *w*:
$$P = \frac{100\%}{1+w} \qquad (1)$$

Dry density:
$$\gamma_d = \frac{\gamma_w}{\frac{1}{G_s}+\frac{w}{S_r}} = \frac{997.3\ kg/m^3}{\frac{1}{G_s}+\frac{w}{(1)}} \qquad (2)$$

Bulk (wet) density:
$$\gamma = \frac{\gamma_w(1+w)}{\frac{1}{G_s}+\frac{w}{S_r}} = \gamma_d(1+w) = \frac{\gamma_d}{P/100\%} \qquad (3)$$

With a specific gravity of 3.03 and water density of 997.3 kg/m^3, the dry density of the tailings slurry is 1000.6 kg/m^3. Lab sheets for gradation and specific gravity measurements on representative mill tailings are presented in Appendix A. For the design dry processing rate of tailings at 1159.0 tonnes/d (dry) and 60% solids, the expected volumetric flow for the tailings slurry is 1158.3 m^3/d (212.5 gpm). Additional water discharges, from miscellaneous sources, are expected to add 10 gpm (54.5 m^3/d) to the flow, so the total discharge flow is expected to be 1212.8 m^3/d (222.5 gpm).

The water balance design for the proposed mill also includes a reclaim water stream from the HTDF back to the mill. This flow was provided by M3 Engineering as 118 gpm (640.5 m^3/d).

For the purposes of mass balance modeling, the proposed milling process is assumed to be continuous, with operation 24 hours per day, 7 days a week, 320 days a year, for approximately 7.1 years. The milling rates were matched to meet a schedule detailed in Table 2 and the total dry tonnes of tails and ore that are expected to be processed. Table 2 shows a reduced milling rate in the first calendar year, a constant mill processing rate of 1159 dry tonnes/d of tails in operating years 2 through 7, and a reduced rate in the last year of mill operation to yield a total project duration of 7.1 years.

As a simplifying measure, flows for the wastewater treatment operation were considered constant for the full period of simulation. However, there is ample opportunity for greater flexibility in the scheduling of flows at the wastewater treatment facility. The proposed wastewater treatment facility will have a treatment capacity to handle peak flow periods and may be shut down during winter months. Since the residence time of water in the HTDF is on the order of years and there is significant storage in the HTDF, shut-down periods of several months for the wastewater treatment facility can be handled by increasing flows during active operation, without significant implications to water quality or water levels within the HTDF. Similarly, wastewater treatment flows may be adjusted seasonally to handle the higher expected HTDF input flows in the spring and fall.

The volume change to the HTDF as a result of the proposed placement of tails was estimated from an assumption of the percent solids of the tails deposit after placement and consolidation. Further consolidation of the tails placed by the previous operator was assumed to be negligible. If the percent solids of the new tails deposit is estimated as 72% (w = 0.389) after placement and consolidation, the dry density is found (Eqn. 2) as 1387.3 kg/m^3 (86.6 pcf). For the processing rate of 1159.0 tonnes/d, the change in the HTDF volume from the proposed tails loading would be 835.5 m^3/d. For the purposes of mass balance modeling, the volume of HTDF water is reduced to adjust to the expected tails mass loading and density. The total proposed tailings loading is expected to reduce the volume of the HTDF by approximately 1.8 million m^3, or 22.5%.

Although the water balance diagram (Figure 5 and Figure 6) shows a 10 gpm flow of treatment solids from the proposed wastewater treatment facility to the HTDF, this stream was not incorporated to the mass balance model. When compared to the main HTDF input stream from the mill, the expected impacts from the treatment solids stream to flow, water quality, and solids loadings to the HTDF were considered negligible.

As mentioned above, the schedule of tailings loadings (shown in Table 2) will affect other processing rates. Loading and flow rates associated with the mass balance model were set by the expected schedule of dry tails loadings.

4 HTDF Physical and Chemical Limnology

4.1 Stratification of HTDF

The mass balance model for the HTDF was formed using ModelMaker™ (Version 4.0, Cherwell Scientific, 2000, Oxford, United Kingdom). The concept for the model was developed as a multi-compartment model, with variable volumes, loading rates, and flow rates. Flow rates vary to adjust to the dry tails loading schedule, mill downtime, and variations in the flows expected from the watershed.

Compartmentalization of the HTDF is based on measured stratification of temperature and water quality of the HTDF, as presented by Foth, 2007. In addition, compartmentalization of the northern HTDF area is supported by bathymetric characteristics.

4.1.1 HTDF Thermocline and Chemocline

A compartmentalization of water bodies occurs when a thermocline is created. As springtime air temperatures increase and the water body warms from the surface downward, the surface water will be warmer than the deep water. It is possible, due to specifics of thermal transfer in a particular water body, that the warm surface water becomes thermally separated from deep cold water, creating two stable compartments. The stability of the two compartments is a result of the density differences between the water in each compartment, with lower density warm water floating on top of denser cold water. The boundary between these compartments is known as the thermocline and is characterized by an extreme vertical temperature gradient relative to temperature gradients in each compartment. Mixing between compartments is reduced when a thermocline is present. However, as annual air temperatures cool, the thermocline may abruptly collapse and the two compartments can then mix vigorously, often greatly changing the chemistry in each compartment. The water body is said to "turnover" during this time.

The presence of a thermocline during a portion of the year does not imply that the water body will fully mix when the thermocline disappears. If sufficient turbulence is not present, a slowly mixing single compartment is briefly created and the possibility of large changes in chemistry is decreased. Also, as water has a maximum density at about 4° C, a stable surface compartment can reform as the water temperature in this compartment falls below this temperature.

A second important compartmentalization of a water body can occur when dissolved substances enter from sources located at either the surface or the bottom of the water body. A decreasing chemical concentration gradient away from the source will then be present. As with temperature, a single gradient may form, or a very sharp gradient may develop between two compartments, each with their own chemical gradient, and each with a unique concentration of the substance. When two chemically distinct compartments form, they are separated by a chemocline.

It is important to note that the presence of a thermocline, and the limited mixing that follows, will often be sufficient to create two chemically distinct compartments. Conversely, a chemocline may form in the absence of thermal stratification. Regardless of how they form, the presence of a thermocline and or a chemocline in a water body requires additional consideration of the water body structure, particularly with respect to mixing.

The presence or absence of any thermocline or chemocline must be known to construct an adequately detailed model of the HTDF. Such a model should have sufficient predictive capabilities to reliably predict outcomes from the dominant processes and inputs. To more adequately define the thermal and chemical structure of the HTDF, Foth conducted a water profiling regime with three-foot resolution at seven locations within the HTDF during May, 2007. Five sample locations are roughly equally spaced along a line parallel to the long axis of the HTDF (HPL-001 through HPL-005), with two more locations (HPL-006 and HPL-007) located on either side of HPL-003. The sample locations are shown in Figure 2. The profiling includes measurements of temperature, as well as DO, pH, and specific conductance. The results of this sampling are summarized below and are derived from the baseline hydrogeology study prepared by Foth (Foth, 2007).

4.1.2 HTDF Field Parameters May 2007

Temperature—Temperature measurements are presented as depth profiles in Figure 7. Temperature measurements vary somewhat in the surface water at each station, but all stations show a constant low temperature in deep water. A well-developed thermocline is clearly present at each station, and the shape of the thermocline does not vary among stations. Temperature stratification begins sharply at approximately 20 ft below the surface and is complete by the 50 foot depth.

Dissolved Oxygen—As shown in Figure 7, DO concentrations vary little among stations (mostly due to instrument noise) but change dramatically over the depth of the water column. The HTDF exhibits a very pronounced oxygen chemocline, with maximum concentration holding steady over the uppermost 80 ft of water, and then disappearing almost completely between 80 and 120 ft deep. The chemocline divides the HTDF into two distinct compartments: a well-oxygenated upper compartment and an anoxic lower compartment.

pH—Hydrogen ion concentration (pH) does not change greatly in the HTDF, remaining relatively constant both laterally and vertically, as seen in Figure 7. Vertical variation is greater than lateral variation, and there is a distinct vertical structure: maximum pH at the water surface, minimum values at approximately 100 ft deep, and intermediate pH values in the deep water.

Specific Conductance—Specific conductance (Figure 7) provides a general measurement of the concentration of dissolved ions in water. Values of this parameter very little among sampling locations, but the HTDF may be divided into two distinct vertical compartments based on specific conductance measurements. While not as extreme as temperature and oxygen, specific conductance (and thus, dissolved ions) changes rapidly from lower values in the upper waters to higher values in the bottom waters, with the change occurring at about 100 ft deep.

The various elements of the vertical structure present in the HTDF water column, suggested by the individual field parameter depth profiles, are more apparent when all four profiles are displayed in a single figure; Figure 8 shows this comparison. Because units and scaling differ among the profiles, each profile is plotted in Figure 8 relative to its maximum value. Thus, the temperature falls to about 40% (value of 0.4) of its maximum value deep in the HTDF, relative to its maximum surface temperature.

Figure 8 shows that the HTDF cannot be adequately modeled as a single compartment. Instead, an appropriate model consists of five contiguous compartments, with the boundaries of each compartment defined by the vertical structure of the individual field parameters, as well as the water surface and HTDF sediment floor. The necessary model compartments are

1) surface water	0-6 ft
2) start of the thermocline	6-24 ft
3) below the thermocline, above the oxygen chemocline	24-96 ft
4) below the oxygen chemocline	96-144 ft
5) deep water	144-192 ft

The actual boundaries are less important than the mid-depths of each compartment, and chemical data representative of each compartment was collected at the compartment mid-depth. Finally, it is important to note that three field parameters change abruptly at about 95 ft deep. This depth is at the mid-point of the major change in DO concentration and specific conductance, and the minimum pH occurs here. This result strongly suggests that the water chemistry is different in the top and bottom waters of the HTDF.

4.1.3 Seasonal Persistence of HTDF Thermocline

Temperature field measurements shown above (from May, 2007), as well as additional field and chemistry data from August and October, 2006, indicate the presence of a thermocline in the HTDF during these times of the year. As surface water temperatures cool in the late autumn, water temperatures (and densities) will momentarily become the same between top and bottom water, until surface water cools below 4° C and again becomes less dense than bottom water. During this time, the HTDF may theoretically mix completely. However, momentary loss of temperature (density) stratification alone will not bring about complete mixing; sufficient turbulence must also be present.

Thermal stability of a body of water may be quantified by the densimetric Froude number (Tchobanoglous and Schroeder, 1987), a dimensionless ratio comparing inertial and gravitational forces acting on the body of water:

$$N_{DF} = \frac{Q/(b \times d)}{\sqrt{(\Delta\rho/\rho) \times g \times d}} \qquad (4)$$

where

N_{DF} = Densimetric Froude Number
Q = Volume flow
b = Average width
d = Average depth
$\Delta\rho$ = Top and bottom water density difference
ρ = Depth-average water density
g = Gravity constant

Values of N_{DF} greater than one indicate that turbulent mixing prevents thermal stratification, while values less than one indicate that thermal stratification will remain despite small levels of mixing.

Representative values used to calculate N_{DF} for the HTDF were obtained from recently acquired data, as presented above. Direct measurement of aerial photography was used to estimate the length to width ratio for the facility (3.33:1). This ratio was then used with the known surface area to determine the average width of the facility.

From equation 4, the HTDF has a $N_{DF} = 0.0000054$ and is very strongly stratified. Moreover, because of the very small flow out of the facility compared to the cross-sectional area, the difference in density between the upper and lower zones must be less than about 10^{-14} before the Froude number approaches unity. This suggests that it is unlikely that the HTDF will mix completely.

4.2 HTDF Depth Profiles of Dissolved Constituents

As presented in Foth, 2007, measurements of the chemical concentrations of many dissolved constituents in the HTDF have been completed. These measurements are fundamental inputs for any model describing the evolution of the HTDF as new mine tailings are added to the facility.

Water samples were collected from five depths defined by the vertical structure of the HTDF, as discussed above. These depths are 3, 15, 60, 120, and 175 ft deep. Sampling at each depth was done at two locations (HPL-003 and HPL-004) to assess horizontal variability in the HTDF. The data from a given depth varied little between these two locations, and results presented here are from HPL-003, located in the center of the HTDF.

All water samples were analyzed for a suite of chemicals. Twenty-two chemicals (including related parameters such as hardness, turbidity and alkalinity) were successfully quantified (reported values were greater than the Estimated Quantitation Limit [EQL], also know as the Limit of Quantitation) at all five depths at each sampling station. In addition, ammonia was quantified at the two deepest depths (120 and 175 ft). To facilitate comparisons among the chemicals, and to examine the vertical structure displayed by each chemical (if any), data presented here are in the form of depth profiles for each chemical. Representative results for four metals found in the HTDF are shown in Figure 9.

The constituents measured in HTDF water vary in concentration over five orders of magnitude. Despite this range, three general patterns with respect to depth are observed in the data. Some constituents, for example nickel, are present at low concentrations in surface water, but increase to high levels with increasing depth; other constituents, like copper, increase from intermediate to high values with increasing depth; finally, another set of constituents, represented here by calcium, are nearly constant with depth.

The fourth depth profile shown in Figure 9 displays measured concentrations of iron. The shape of this profile is unique and points to the importance of iron in the HTDF as a mediator of surface concentrations of a number of metals. The mechanism involves the reduction-oxidation coupling of Fe^{+2} and Fe^{+3} below and above the oxygen chemocline, and formation of iron precipitates in the upper regions of the HTDF. A complete model of HTDF mixing will include this aspect of HTDF chemistry.

The patterns present in the individual depth profiles are compared in Figure 10 by plotting all profiles together using relative values, as was done above with field parameters. Three of these field parameters are also included in Figure 10.

Although Figure 10 is complex, several general patterns are present. Almost all of the chemical constituents in the HTDF are present at highest concentration at the very bottom of the HTDF. This result strongly suggests that the sediments (old tailings) are the predominant source of these constituents. As noted above, almost all of these chemicals then decrease to varying degree at shallower depths. The greatest decrease occurs for nickel, manganese, molybdenum, cobalt, and antimony; all of these fall to less than 20% of their maximum concentrations. Potassium, sodium, chloride, copper, and boron also decrease, but by only about one-half their maximum levels. Finally, magnesium and calcium change very little with depth, suggesting that the rock that forms the HTDF is the source of these cations. The rock forming the HTDF contains large amounts of iron, so the fact that iron does not behave like calcium and magnesium strongly suggests that iron participates in reactions within the HTDF. And, it is likely that the decrease in other metal concentrations is due to iron chemistry in the HTDF.

4.3 HTDF Chemical Limnology

Understanding the complexity present in Figure 10 requires a more thorough examination of the chemical limnology of the HTDF. While the transport of chemical species from the deep water to the surface water of the HTDF will be primarily controlled by mixing within the facility, mixing alone cannot explain the variation among the relative depth profiles displayed in Figure 10. If the transport was only due to mixing, all relative profiles would be identical and appear as a single profile, because bulk mixing would affect all chemical species equally. The variation observed in relative surface concentrations implies that chemical species are affected to varying degree by chemical processes within the sediments and water column of the HTDF.

4.3.1 Background

All surface water bodies share many common chemical characteristics because of a common bulk solvent (water), and because almost all exist under an atmosphere rich in oxygen with a small, but relatively constant amount of carbon dioxide. Also, a small set of twelve elements, present at relatively high concentrations, dominate the chemistry of surface waters. These major aquatic elements are boron, carbon, nitrogen, oxygen, sodium, magnesium, aluminum, silicon, sulfur, chlorine, potassium and calcium. All of the other elements, while essential in many cases for biochemical reactions and life, are referred to as minor aquatic elements based on their relatively low concentrations.

The chemistry of surface waters is regulated by four types of reactions: acid-base, oxidation-reduction (redox), complexation, and precipitation. The state of a particular body of water with respect to these four types of reactions is assessed with intensity parameters; pH (acid-base reactions) and pE (redox reactions; equal to the negative logarithm of the theoretical electron activity) are common intensity parameters. The chemical state of a body of water, as described by intensity parameters, determines which chemical reactions are most prevalent. The extent of a particular type of reaction required to move a body of water to a new chemical state is quantified by capacity parameters. Alkalinity is the capacity parameter associated with acid-base reactions; similar capacity parameters exist for the other three reaction types, though they are more difficult to quantify.

4.3.1.1 Acid-Base and Redox Chemistry

The most prevalent major aquatic elements (and chemical species formed from these elements) within a body of water control the acid-base and redox chemistry within that body of water, and the intensity and extent of these two types of reactions then regulate the concentration and speciation of both the major and minor elements in the body of water.

In many surface bodies of water, acid-base chemistry (and, therefore, pH) is dominated by the carbonate system, comprised of atmospheric carbon dioxide and calcium carbonate. In bodies of water in contact with calcareous rock, the fixed atmospheric concentration of carbon dioxide and solubility of calcium carbonate set the pH at about eight.

At the air-water interface of a body of water, the redox chemistry (and, therefore, pE) is most influenced by atmospheric oxygen. Oxygen is one of the most potent oxidants, and conditions near the air-water interface are generally very oxidizing. However, the extent to which oxygen influences redox conditions in deeper waters varies greatly, and is affected by both physical and biological processes.

Surface concentrations of oxygen are set, in part, by its solubility in water, which varies inversely with water temperature (oxygen saturation is about 8-9 mg/L at 20° C and increases to 12-13 mg/L at 5° C). Also, oxygen concentrations at increasing depths are affected by the relatively slow diffusion of oxygen downward from the surface. Given the constant atmospheric supply, diffusion of oxygen to deep water is continuous. However, depletion of oxygen with increasing water depth is often observed in bodies of water, as internal chemical processes consume oxygen more rapidly than diffusion can replace it.

The presence of life capable of photosynthesis (predominantly algal cells, and referred to as primary production) near the air-water interface will also affect oxygen concentrations, as well as acid-base (pH) and redox (pE) chemistry in these waters. During daylight hours, ongoing photosynthesis will produce oxygen and consume carbon dioxide, increasing DO, pH, and pE. Conversely, algal respiration during dark hours will consume oxygen and release carbon dioxide, and so, often lower pH and pE.

As noted above, oxygen concentrations in deep waters (greater than about thirty ft) depend on the rate at which oxygen is consumed by various chemical processes. In waters with high primary productivity (eutrophic waters), most oxygen in waters below the surface is rapidly consumed by the decomposition of settling detritus resulting from primary productivity. Although the detrital material may consist of a number of compounds, it is predominantly organic, or reduced, carbon. Often in eutrophic systems, the amount of organic carbon produced greatly exceeds that needed to remove essentially all oxygen from deep waters. In these systems, an oxygen chemocline will develop, the bottom waters will become anoxic, and the excess organic carbon will accumulate in bottom sediments.

Organic carbon is a potent reductant, and in a system like that described above, a redox gradient will be present, with oxidizing conditions in surface waters and reducing conditions in deep water. In fact, the system represented by oxygen reduction and organic carbon oxidation sets the possible redox (pE) range for most bodies of water. With acidic surface water, pE values in

these systems range between almost 20 at the water surface to -10 at (or just under) the sediment surface.

If primary production is very low in a body of water (oligotrophic waters), the extent to which oxygen is depleted in deep water will depend on the amount of reductants present from sources other than the settling detritus of primary production. These may still include organic carbon which enters the water body from outside (allochthonous carbon), but also include reduced nitrogen, manganese, iron, and, importantly, sulfur.

In water bodies where organic carbon is in limited supply, sulfur compounds may become the dominant reductants in sediments. Sulfur compounds are common in most natural systems, and are particularly prevalent in those systems in contact with sulfide minerals.

4.3.1.2 Complexation and Precipitation Chemistry

Once the large-scale chemistry of a water body is established by the major aquatic elements through acid-base and redox reactions, the fate of the minor aquatic elements is largely determined by those complexation and precipitation reactions that are possible under prevailing pH and pE conditions. Minor elements are most often removed from the water column through complexation reactions with the surface of aquatic particles, and subsequent sedimentation of these particles.

Settling particles with suitable complexation sites for minor element binding may come from a variety of sources, including allochthonous organic matter, clay particles, and iron, aluminum and manganese oxide particles. In some water bodies, autochthonous (formed within the water body) colloids form from precipitation of major and minor elements within the water column. The colloid surfaces often contain a large number of complexation sites and are in close proximity to dissolved metal ions in the water body. This combination results in very effective scavenging of the dissolved metals by the colloids. Subsequent coagulation of these colloids produces settling particles. This completely internal mechanism effectively reduces surface concentrations of a number of metals by transporting them to deep waters.

4.3.2 Major and Minor Chemical Species in the HTDF

Table 3 lists the concentrations of all quantified chemical species in each of the five compartments of the HTDF, as well as the volume-weighted average for each species. As described previously, only chemical species at concentrations above EQL are considered in detail in this report, as other species were reported to be either below the EQL or below EQL and Method Detection Limit (MDL). Four elements within this unquantifiable group of chemicals are mentioned here, because while they could not be quantified, they were often observed above the MDL, and so must be considered present in the HTDF. The four elements are arsenic, lead, zinc, and mercury, and EQLs for these elements are (ug/L) 1, 1, 10, and (ng/L) 0.5, respectively. These elements are present in the HTDF at levels below their respective EQL. Arsenic and mercury were observed in all five compartments, zinc was present in the bottom three compartments, and lead was only observed in the bottom compartment. In addition, mercury was quantified at levels just above its EQL at two depths at station HPL-004 (15 ft, 0.63 ng/L; 60 ft, 0.55 ng/L). Measurements at these depths at station HPL-003 were below EQL. Therefore, given that eight out of ten (two stations, five depths) mercury measurements were below EQL, mercury is best described as present in the HTDF at levels below its EQL.

Concentrations of quantified species in Table 3 are reported in common units of mass per volume (ug/L). To assess the chemistry that can occur within the group of chemical species shown in Table 3, it is necessary to convert all concentrations to a mole per liter (molar, M) basis so that direct comparisons of amounts are possible, and so that possible stoichiometric relationships are apparent. Molar concentrations of major aquatic species are displayed on the graph in Figure 11. Concentrations of minor aquatic species are shown in Figure 12.

Nine of the twelve major aquatic elements described above are found in the HTDF as major chemical species, and are shown in Figure 11 (oxygen is shown in the table below the graph). Boron is present but at reduced concentration (shown on the top graph in Figure 12); aluminum was sought as an analyte but was never detected above its MDL; and silicon was not an analyte.

Figure 11 shows that sulfur, in the form of sulfate, is the most abundant species measured in the HTDF. Concentrations of sulfate decrease with distance from the bottom, suggesting that sediments (tailings) are the source of the sulfur in the sulfate.

Calcium and magnesium are also abundant and present, particularly in the bottom two compartments, in roughly equal proportions. This is most likely due to the presence of dolomite in the previously placed tails. This possibility is confirmed by an earlier analysis (Cyanamid, 1986, Appendix B) of the tailings generated by the Ropes Mine, which stated that ferroan dolomite, as well as calcite and talc, were common in the tailings from this mine.

Ammonium and nitrate concentrations are inversely related in the bottom two compartments. Ammonium decreases while nitrate increases with distance from the bottom, such that concentrations are approximately equal in compartment four. This oxidative transformation of nitrogen away from the bottom shows that waters are most reducing near the sediments.

A summary table listing average compartment values of pH, pE, ionic strength, DO and temperature in the HTDF is also shown in Figure 11. Values in the table summarize a second field sampling effort conducted in July, 2007 (Foth, 2007). The values for these parameters, measured in July, confirm earlier observations from May (discussed above; redox potential was not measured in May). Redox potentials (pE) and DO are discussed later in this report.

As in May, pH is relatively constant in the HTDF. Maximum pH (8.30) occurs at the surface of the HTDF, and a minimum (7.28) is found in the fourth compartment. Overall, the pH profile is consistent with a system buffered by a carbonate system, with a small acidic influence deep in the water column.

Water column temperatures are similar to those in May, although surface temperatures are higher. As before, a sharply defined thermocline is present.

Ionic strength, a parameter describing the change in aquatic chemistry due to the presence of charged species, is shown for each HTDF compartment, and a volume weighted average is also provided. Ionic strength values are relatively low (about eighty times lower than seawater, for example) in each compartment.

Molar concentrations of the minor aquatic species measured in the HTDF are shown in two graphs in Figure 12. It is apparent from these two graphs that, despite over two orders of magnitude difference in concentrations, the behavior of many of the minor species is very similar. Manganese, nickel, antimony, cobalt, and molybdenum are all present at much higher concentrations in the deep water relative to the surface water of the HTDF.

4.3.2.1 Alkalinity and Carbon Chemistry

A second table in Figure 11 shows the calculation of total alkalinity in the HTDF, based on a carbonate dominated system. Bicarbonate is by far the dominant inorganic carbon species at pH values found in the HTDF, and measured values are comparable to those for sulfate, calcium and magnesium (see graph, Figure 11). Based on measured values of bicarbonate, there are over 900 tonnes ($CaCO_3$ equivalent) of alkalinity in the water column of the HTDF. Also, given that carbonates are present (Cyanamid, 1986; Appendix B) in the almost 2 million tons of tailings from the Ropes mine (Montgomery Watson, 1993, Appendix C), a significant reserve of alkalinity is present in the sediments of the HTDF.

Historical measurements (Traverse Engineering, 1984) indicate that sources of alkalinity other than Ropes tailings contribute alkalinity to the HTDF. Alkalinity was measured at 90 mg/L in both surface water and at 200 ft below the surface in October, 1984. These values are less than current values by about 20% and do not show the increase with depth apparent in the current values. This information indicates that both allochthonous sources and Ropes tailings contribute to the alkalinity in the HTDF.

Organic carbon measurements were obtained as a part of the May, 2007 field sampling (Foth, 2007). Samples were analyzed both for total and dissolved organic carbon (MDL 1.4 mg/L, EQL 2.0 mg/L for both sample types). In total, twenty samples were analyzed for organic carbon (two sampling stations, dissolved and total samples, at five depths). Of these, four were less than MDL, and seven were less than, and two equal to, EQL. The seven quantified samples have an average value of 2.39 mg/L and standard deviation of 0.28 mg/L. The measurements did not agree well between the two stations and no consistent trends were observed with depth or type of sample.

Dissolved organic carbon is much more prevalent than particulate organic carbon in surface bodies of water, often accounting for more than 90% of total organic carbon. Total organic carbon ranges between about 0.7 mg/L (ground water) and 33 mg/L (bog water), with oligotrophic waters averaging 2.2 mg/L and eutrophic waters at about 12 mg/L (Wetzel, 2001). Based on total organic carbon, the HTDF would be classified as, at most, an oligotrophic system. This may be misleading, however, as the number of values below the 2.0 mg/L EQL and the lack of structure suggest that even less organic carbon is autochthonous than in an oligotrophic system. It is likely that the small amount of organic carbon present in the HTDF is predominantly allochthonous.

4.3.3 Dissolved Oxygen and Primary Productivity

Graph A in Figure 13 displays measurements of DO measured in the HTDF during July, 2007. The values are displayed as a depth profile and are very similar to those shown in Figure 7, based on sampling done in May 2007. Oxygen was measured using a different methodology in May and July. May measurements were made using a colorimetric method, whereas measurements in

July used an electronic probe with approximately ten times the resolution of the colorimetric method. Despite this difference, the two profiles are essentially identical, with the exception of the top of the profiles. While both profiles show DO values of about 8 mg/L from the surface to a depth of about twenty feet, the July measurements capture an increase in DO that occurs between twenty feet and about forty feet. At this depth, oxygen reaches a maximum of about 10.5 mg/L. The increase is due to the greater solubility of oxygen in cold water, and the oxygen trend mirrors the water temperature profile shown in Graph B, Figure 13.

The oxygen chemocline observed in the May profile is clearly present in the July profile. The loss of oxygen occurs at the same depths in both profiles, with anoxic water below 100 ft in both cases. Thus, oxygen dynamics are very stable over at least months of time, and show no seasonality between spring and summer.

Also shown in Graph A, Figure 13 is a depth profile of measurements of DO collected in 1984 in the Humboldt Pit (now known as the HTDF) (Traverse Engineering, 1984). In 1984, before Ropes mine tailings were placed, the pit was about 300 ft deep, and the historical measurements show that the entire water column was oxygenated, with DO concentrations at the bottom equal to about 75% of surface values.

Comparison of the historical and contemporary oxygen profiles shows that, in the surface waters of the HTDF, little has changed with oxygen dynamics over about twenty three years. The profiles show very similar surface concentrations, and each profile captures the increased oxygen due to decreasing water temperature.

However, below about 75 ft the two profiles are very different. In 1984, the entire pit was oxygenated, whereas currently the HTDF is anoxic below about 100 ft. Given that atmospheric oxygen levels and rates of oxygen diffusion through water have not changed over the past twenty years, the difference in bottom water oxygen over this time is most likely due to an increase in oxygen demand, that is, an increase in chemical reductants, in the bottom of the HTDF during this time.

An increase in reductants at the bottom of a body of water most often occurs as a result of increased primary productivity in the surface waters. Also, an increase in input of allochthonous carbon might occur. In either case, more organic (reduced) carbon would reach the sediments, leading to an increase in oxygen consumption, and oxygen depletion in bottom waters.

Aerial photography shows that land usage has not changed greatly around the HTDF in the last several decades, so allochthonous carbon loading to the HTDF has likely been relatively constant during this time. Also, dissolved organic carbon levels are typical of a system with low primary productivity. The extent of primary production may also be assessed by examining DO.

Two sets of DO measurements are shown in Graph B, Figure 13. These measurements were taken on the same July day as the measurements shown in Graph A, but at different times. The first set shown in Graph B was obtained at about 5:00 AM, while the second set was measured at about 4:00 PM. As explained above, photosynthesizing algal cells would release a pulse of oxygen during the day and consume oxygen at night, resulting in very different DO levels early and late in the day. The fact that the oxygen profiles in Graph B are almost identical strongly

indicates that photosynthesis, and therefore, primary production, is essentially not occurring in the HTDF.

Measurements of organic carbon and DO show no evidence of high levels of organic carbon production in the water column of the HTDF, and so, little organic carbon is expected in the sediments. The depletion of oxygen in the bottom waters must then be due, at least in part, to the presence of other reductants capable of consuming oxygen.

The change in oxygen dynamics between 1984 and present, visible in Graph A, Figure 13, and the fact that the Ropes tailings were placed during this interval suggests that the tails are helping to maintain anoxic conditions in the HTDF. In this scenario, oxygen continually diffuses into the waters of the HTDF, past depths where primary production would otherwise begin to consume it. At deeper depths, oxygen encounters in situ reductants, including small amounts of predominantly allochthonous organic carbon, and is at least partially consumed by these reductants. Any oxygen that remains at deeper depths eventually reacts with reduced sulfur from mine tailings. Thus, the large mass of sulfidic mine tailings is self-stabilizing, in that variations in amounts of other reductants, principally organic carbon, cannot lead to a build up of oxygen near the tailings.

4.3.4 HTDF Oxidation-Reduction Chemistry

The chemistry of the HTDF was further investigated by measuring the oxidation-reduction potential (ORP [oxidation reduction potential], or redox potential) in July, 2007.

Measurements were taken at three foot intervals using a platinum electrode and an Ag/AgCl reference electrode. These measurements were then converted to Standard Hydrogen Potentials (E_H) using a ZoBell calibration measurement obtained in the field (+231 mV) and the standard conversion equation (American Public Health Association, 1998b)

$$E_{H,System} = E_{Observed} + E_{H,ZoBell-\mathrm{Re}\,ference} - E_{H,ZoBell-Observed} \quad (5)$$

where

$E_{H,System}$ = E_H of the sample
$E_{Observed}$ = measured field value
$E_{H,ZoBell-Reference}$ = reference value of ZoBell's solution and Ag/AgCl electrode = +428 mV
$E_{H,ZoBell-Observed}$ = field calibration value of ZoBell's solution

Field measurements were also converted to pE values to facilitate comparison with literature values,

$$pE = E_H \times \frac{F}{2.3 \times R \times T} \quad (6)$$

where

pE = -log{e}; e represents electron
F = Faraday constant = 96,485 Coulombs/mol
R = Gas Constant = 8.314 V Coulombs/mol ºK
T = Absolute temperature (298 K, 25° C reference temperature)

The redox potential profile for the HTDF, expressed as E_H and pE is shown, along with temperature and DO, in Figure 14.

The redox potential profile is useful for evaluating the redox conditions within a body of water, as indicated by the associated intensity parameter, pE. Evaluation of a redox profile is based on comparisons with laboratory measurements of ideal systems consisting of well-defined chemical solutions, often containing only one redox couple (a single element present in both oxidized and reduced form, as in an electrochemical cell). Actual environmental systems (bodies of water) are complex, contain many chemical species and several redox couples. Because of this, redox profiles should be interpreted with caution and cannot be expected to predict individual chemistries. However, field measurements are very useful in understanding relative conditions within a body of water, and may provide chemical information when compared to literature values of redox potentials.

It is also important, when interpreting redox profiles, to recognize that the presence of a spatial gradient implies that the system is not at equilibrium, much as an electrical battery is far from equilibrium until it is completely discharged. Thus, kinetics is as important as thermodynamics in determining the type and amount of chemical species present at any given time.

Redox information describing a body of water may also be obtained if it is possible to simultaneously measure the concentrations of both species in a redox couple. The observed concentrations, as well as the standard potential for the redox couple, are combined with the Nernst equation to calculate the redox potential of the aquatic system containing the couple. The Nernst equation, in pE units, is

$$pE = pE° + \frac{1}{n}\log\frac{\prod_i \{ox\}^{n_i}}{\prod_j \{red\}^{n_j}} \qquad (7)$$

where

pE° = standard potential as pE
n = number of electrons transferred
ox = activities of oxidized species
red = activities of reduced species

Ammonium and nitrate were both present and quantified at depths of 120 and 175 ft in the HTDF. This redox couple is related by the reduction half-reaction and associated standard pE value, pE° (the value of pE when the reaction occurs under standard conditions) shown below:

$$\frac{1}{8}NO_3^- + \frac{5}{4}H^+ + e = \frac{1}{8}NH_4^+ + \frac{3}{8}H_2O \qquad pE° = 14.90 \qquad (8)$$

Because of low ionic strength and the single charge on each species, measured concentrations may be used to approximate activities in the Nernst equation. Inserting these values, and pH at each depth (175 ft, pH=7.4; 120 ft, pH=7.2), the pE at 140 and 175 ft in the HTDF is calculated as 5.89 and 5.59, respectively. These values are shown on the graph in Figure 14. The

calculated values are in good agreement with the measured profile, suggesting relatively stable chemistry at these depths.

As with most bodies of water, the redox profile for the HTDF displays a reduction gradient with increasing water depth; waters are most oxidizing at the surface and are most reducing in the bottom waters. The profile is erratic in the oxygenated top waters, but much more stable in the anoxic bottom waters.

Although a gradient is present, the range of pE values is small, varying between about 7 at the surface and 5.5 near the bottom; as mentioned previously, bodies of water may vary by as much as +20 at the surface and -10 at bottom sediments. The first value in the redox profile is at a depth of three feet below the surface. It is likely that water just below the surface would have higher pE values, perhaps approaching the theoretical maximum for oxygen of 13.75 at pH=7.

Common redox reactions are shown in Figure 14. Each reaction has a pE°(W) value. This is the standard pE° when pH=7. These values allow direct comparison of redox half-reactions under conditions similar to those often found in aquatic environments. The reactions are in order of decreasing pE°(W). It is thermodynamically possible for the oxidant in a reaction with a higher pE°(W) to oxidize a reductant at a lower pE°(W). Whether or not this occurs depends on the concentration of each species in the reaction.

While specific chemistries cannot be known based on the redox profile alone, several inferences can be made. A simple linear gradient connects the top two pE values with values below 100 ft. This indicates that oxygen (the most potent oxidant in the reactions show in Figure 14) is controlling the redox conditions in the water above about 100 ft but is encountering several reductants at various depths in the top waters. These reductants are oxidized by the oxygen and pull pE values lower until they are consumed. Narrow bands where this occurs are referred to as redox boundaries, and several major and minor boundaries are visible in the profile.

One of the reductants present in the top waters of the HTDF is organic carbon, particularly from allochthonous sources. The carbon redox couple is shown as the last reaction listed in Figure 14 (the six-carbon sugar glucose is a model organic carbon). The large difference in pE°(W) values between the oxygen and carbon redox reactions implies that oxidation of reduced carbon by oxygen will essentially go to completion, such that the reactant present in excess will completely consume the other reactant. As mention previously, in eutrophic systems excess carbon eventually consumes all oxygen deep in the water column and accumulates in bottom sediments. If this were the case in the HTDF, the bottom waters would be expected to have a lower pE than that observed in the profile, given the negative pE°(W) associated with the carbon couple.

Other possible oxygen-consuming reductants are shown in the reactions listed in Figure 14. Thus, oxidation of nitrogen compounds, and the formation of oxidized solid phases of manganese and iron from their reduced, dissolved metal ions can all contribute to oxygen consumption within the HTDF.

4.3.4.1 Sulfide Mineral Chemistry

As is the case with many other minerals, the elemental constituents of sulfide minerals enter aquatic solutions through dissolution reactions (a dissolution reaction may be viewed as the opposite of precipitation), as shown in reaction 9, where Me represents a metal ion:

$$MeS(s) = Me^{2+} + S^{2-} \quad (9)$$

Univalent metals will produce two moles of ions for every mole of sulfur.

Sulfide ions (S^{2-}) are very basic and react strongly with hydrogen ions to produce bisulfide (HS^-) and, at lower pH (less than about seven), hydrogen sulfide

$$S^{2-} + H^+ = HS^- \quad (10)$$
$$HS^- + H^+ = H_2S(g) \quad (11)$$

Reactions 10 and 11 are common in water bodies with anoxic bottom waters, particularly within sediments and at the sediment-water interface. Both of these reactions may lead to the production of more oxidized forms of sulfur, including elemental sulfur (S_8), thiosulfate ($S_2O_3^{2-}$) and sulfate (SO_4^{2-}). Oxidation of sulfide can follow a number of pathways and can be a complex process (Morin, 1993). However, it is likely that the high concentration in the HTDF of sulfate is due to sulfide oxidation via several pathways.

Because of the very basic nature of sulfide, a more representative dissolution reaction for a metal sulfide under environmental conditions is given by the sum of Reactions 9 and 10

$$MeS(s) + H^+ = Me^{2+} + HS^- \quad (12)$$

The solubility of a metal sulfide can be defined as equal to the metal concentration on the right side of Reaction 12 when the reaction has reached equilibrium. The solubilities of metal sulfides can be quantified by determining the equilibrium constant for Reaction 12; this value is referred to as a conditional solubility product, ${}^*K_s$, for metal sulfides (conditional because of its dependence on hydrogen ion concentration).

Tabulated values of ${}^*K_s$ are available (Stumm and Morgan, 1996). Metal sulfide solubilities vary greatly, depending on the specific metal and the mineral phase. Qualitatively, with the exception of manganese sulfide, metal sulfides have low to extremely low solubilities, with log ${}^*K_s$ values ranging between about -3 and -40.

Solubilities of iron sulfides are variable and relatively high to intermediate, with log ${}^*K_s$ values such as -2.95 (amorphous), -5.1 (pyrrhotite) and -16.4 (pyrite). Sulfides of nickel and cobalt have intermediate solubilities, with log ${}^*K_s$ ranging between about -6 and -13. Mercury sulfides are among the least soluble of the metal sulfides; log ${}^*K_s$ values are almost -40.

Concentrations of several metals have been measured in the bottom water of the HTDF (Figure 12), and a qualitative ranking of these concentrations is similar to a ranking of the observed ${}^*K_s$ values discussed above. It is likely that a limited dissolution of sulfide tailings helps to maintain

the low metal concentrations observed in the bottom water of the HTDF. This process will also increase the concentration of reduced sulfur, present as bisulfide, in the tailings porewater and near the sediment-water interface.

Given the high sulfur content of the in-place tailings, and the prevalence of sulfate, another relevant reaction is the oxidation of reduced carbon by sulfate. This reaction is not uncommon in bodies of water. The reaction thermodynamics may be estimated by summing the sulfur reaction shown in Figure 14 with the carbon couple reaction shown below (a simple carbohydrate is used as a model of reduced carbon). The sum is performed by reversing the carbon reaction (carbon is being oxidized) and subtracting the pE°(W) of the oxidized couple from that of the reduced couple.

$$\frac{1}{4}CO_2(g) + H^+ + e = \frac{1}{4}CH_2O + \frac{1}{4}H_2O \qquad pE°(W) = -8.20 \qquad (13)$$

$$\frac{1}{8}SO_4^{2-} + \frac{1}{4}CH_2O + \frac{1}{8}H^+ = \frac{1}{8}HS^- + \frac{1}{4}CO_2(g) + \frac{1}{4}H_2O \qquad pE°(W) = 4.45 \qquad (14)$$

The positive pE°(W) value associated with Reaction 14 indicates that, under standard conditions of unit concentrations and pH=7, the reaction will go to the right.

In the HTDF, sulfate concentrations are high, particularly in the bottom waters, and pH is about 7. Thus, under existing conditions, Reaction 14 may go to the right and consume any remaining organic carbon present at the bottom of the HTDF. In the process, bisulfide is produced. Bisulfide is also a product of any dissolution of metal sulfide tailings. Production of bisulfide by oxidation of organic carbon would therefore be expected to limit dissolution of tailings and as the case with DO, the sulfide tailings would be self-stabilizing under the redox conditions in the HTDF.

As with oxygen at the surface, the presence of bisulfide at or just in the sediments (tailings) suggests that the actual pE at the very bottom of the HTDF is lower than measured values indicate, and may approach the theoretical maximum for sulfur of around -3 at pH=7. Thus, the actual shape of the redox profile may be sigmoid, with a central linear portion resembling the measured profile and long tails at each end very near the air-water and water-sediment interfaces.

In summary, a profile of redox measurements in the HTDF shows that reducing conditions increase with depth, but only by a small amount in the water column. The range of observed pE values suggests that sulfur may be more important than organic carbon with respect to establishing the redox range. If oxygen and sulfur redox couples are assumed to be the end members of the redox profile, the actual range will be larger than that suggested by the measured profile. Reductants other than reduced carbon are available to consume oxygen. And, the large excess of sulfate, due in part to limited dissolution of sulfide tailings, may ultimately limit this process through oxidation of small amounts of residual organic carbon.

4.3.5 Iron Cycling and Metal Scavenging

As discussed above, major aquatic elements establish the fundamental chemical conditions within the water column of the HTDF. Specifically, carbon in the form of carbon dioxide and

calcium carbonate maintain the pH near 8. Oxygen and sulfur, with some carbon, allow the pE to range between values somewhat greater than 7 and somewhat less than 5 in most of the water column, but approach values nearer to 13 at the air-water interface and nearer to -3 at the water-sediment interface. Redox reactions in the HTDF also involve the major element nitrogen, as well as the minor elements iron and manganese. With dominant chemistry established, it is possible to consider complexation and precipitation in the HTDF, and how these reaction types control the fate of the minor aquatic elements.

Complexation refers to the formation of complexes and complex ions, that is, species that result when complexants form coordination bonds with metal atoms or ions in solution. Once formed, coordination bonds are no different than covalent bonds. Unlike covalent bonds (formed when each of two atoms donates one electron to form a bond), coordination bonds form using an electron pair from one atom and an open orbital on the other atom. The electron pair comes from the complexant and the open orbital is present around the metal atom or ion. If the resulting species (consisting of the central metal atom and bonded complexants, referred to as ligands) carries no charge, it is a complex; if charged, it is a complex ion. Coordination chemistry, named for the bonds that form complexes and complex ions, is the dominant chemistry of metals, and greatly affects the fate and transport of metals in the environment.

Precipitation reactions occur when several dissolved chemical species that are capable of reacting to form solids are present in solution at concentrations that exceed solubility limits. The dissolved constituents may then combine to form new molecules. If present in sufficient quantity, the molecules will coalesce into a solid phase, often initially as colloids. If conditions of pH and pE are favorable, the colloids will coagulate to form particles of sufficient mass such that settling may occur. Precipitation reactions affect the fate of minor aquatic elements because the surfaces of precipitated particles often contain very high numbers of molecular sites that act as complexants in the presence of metal ions. The resulting complexes, consisting of metal ions and surface sites on settling particles, represent a very effective mechanism for scavenging dissolved metals from the water column and transporting them to the bottom of the water body.

There are many possible aquatic complexants, and they may be grouped into three types (Buffle and De Vitre, 1994):

- Small ligands, including hydroxide, chloride, carbonate and amino acids
- Macromolecules, such as proteins, polysaccharides, fulvic and humic acids
- Colloids and particles like iron and manganese oxides, and clay particles

Any and all of these complexants may be present in the HTDF and affect the fate of the minor elements shown in Figure 12. Many of these complexants are capable of scavenging the minor elements from the HTDF. This report will focus on one representative, and very common scavenging mechanism in bodies of water: the reduced-oxidized iron cycle, or simply, the iron cycle. Scavenging by this system is a component of the multi-compartment model of the HTDF.

The iron cycle has long been recognized as an important mechanism in water bodies for the regulation of a number of species, for example, bioavailable phosphorus and other trace nutrients. The essential aspects of the mediation of these species by the iron cycle are identical to the mechanism by which minor elements are scavenged from the water column.

The relationship between reduced and oxidized iron is of primary importance in the iron cycle, as is the fact that iron changes oxidation state when transported between oxic and anoxic portions of the water column. The main chemical reaction describing this relationship is shown below

$$Fe^{2+} + \frac{1}{4}O_2 + \frac{5}{2}H_2O = Fe(OH)_3(amorph,s) + 2H^+ \qquad \text{Iron Oxidation} \qquad (15)$$

It is important to note that Reaction 15 affects alkalinity. In oxic waters, iron is oxidized and hydrogen ions are released, thereby reducing alkalinity.

The above reaction is a redox reaction and involves release of hydrogen ions. Therefore, the direction of the reaction not only depends on the presence of oxygen, but also on pE and pH. Also, iron undergoes a phase change from reduced dissolved to oxidized solid. Several other reactions involving the iron couple in water, and various dissolved and solid phases, are possible. To understand the iron cycle, and if and when it may occur in a water body, it is necessary to describe these various states of iron and to know which state will be dominant under different pE and pH conditions. A useful tool for this type of analysis is the pE-pH diagram.

The construction of a pE-pH diagram for any species begins by creating functional relationships between pE, pH and all possible species for the chemical components under consideration. The iron diagram might begin with the reduction of oxidized iron

$$Fe^{3+} + e = Fe^{2+} \qquad pE° = 13 \qquad (16)$$

combining this reaction with the Nernst equation

$$pE = 13 + \log\frac{\{Fe^{3+}\}}{\{Fe^{2+}\}} \qquad (17)$$

At the boundary between conditions of pE where the dominant form of dissolved iron changes between oxidized and reduced, the concentrations of both species will be equal, and the functional relationship describing this boundary reduces to

$$pE = 13 \qquad (18)$$

By considering all other possible reactions between water and reduced and oxidized iron, as well as equilibrium constants like pE° for each reaction, functional relationships can be developed that predict the dominant species for any pE and pH value. Some of these relationships will also depend on total dissolved iron concentrations, so each pE-pH diagram will be unique to a specific concentration of total iron.

A pE-pH diagram has been constructed for the HTDF and is shown at the top of Figure 15. This diagram includes bicarbonate as a component, so it is a pE-pH diagram for the Iron-Carbon Dioxide-Water system in the HTDF, and the associated concentrations of total dissolved iron and bicarbonate are listed at the top of the diagram.

The diagram displays regions bounded by lines within which a particular form of iron is the dominant species. The axes show the values of pE and pH so that for any set of pE-pH values, the dominant species can be found. Note that the example functional relationship presented above appears as the short horizontal line in the upper left of the diagram, and separates dissolved reduced iron from dissolved oxidized iron. The other lines are representations of the other functional relationships for each of the species in this system. The red dashed lines on the diagram indicate the stability zone for water.

The dominant iron species in the HTDF can be found by reading the diagram. pH in the HTDF ranges between 7 and 8, and pE values over the entire water column, including estimates near the air and sediment interfaces, range between -3 and about 12. By examining the area on the diagram enclosed by these pE-pH ranges, it is found that amorphous iron (III) hydroxide solid and dissolved iron (II) are the dominant iron species in the HTDF. These two iron species form the iron cycle in water bodies, so it is very likely that this cycle is operating in the HTDF.

The iron cycle is displayed in the lower diagram in Figure 15. Dissolved iron (II) enters the water column by diffusion upward from the sediments. This is common in water bodies with anoxic bottom waters, and very likely in the HTDF, given the iron pyrite tailings (Cyanamid, 1986) that form the sediments. As the upward diffusing iron (II) encounters oxygen diffusing downward from above, the iron is oxidized, producing amorphous solid iron (III) oxide, initially as colloids. The colloid surfaces provide many complexation sites, and various dissolved minor aquatic metals react with these sites to form surface-bound complex ions (this process is also known as adsorption). As the oxidized iron oxide colloids and associated metals coagulate, larger particles form and begin to settle back to low pE, anoxic conditions. Some of the particles begin to undergo reductive dissolution, while other, larger particles deposit in the sediments. As the cycle continues, some of the iron (III) oxides on the sediment surface are reductively dissolved. This provides more iron (II) for the cycle, while also releasing minor metals. The released metals may diffuse upward, but they are prevented from moving beyond the bottom waters by the iron cycle. In this way, high concentrations of dissolved minor metals may appear in the deep waters, but these metals cannot reach the surface water.

The cycle is strengthened by allochthonous iron entering from above and settling toward the bottom, adding to the pool of available iron. Ground water near the south end of the HTDF has high dissolved iron (Foth, 2007). Additional iron, both reduced and oxidized may enter the HTDF at the south end and help sustain the iron cycle, and so help retain dissolved metals deep in the HTDF.

The unusual relative depth profile for iron (Figure 10), compared to the depth profiles for other chemical species in the HTDF, may now be explained as a consequence of the iron cycle within the HTDF, and inflowing iron at the surface of the HTDF. Iron concentrations are elevated in the surface waters due to allochthonous iron input at the surface. Iron concentrations decrease below the oxygen chemocline as oxidized iron particles settle rapidly from this depth. And, iron concentrations increase near the sediments as settling iron oxides undergo reductive dissolution.

5 Complete Mixing Model of the HTDF

The previous discussion has established that the HTDF has a well defined vertical structure with respect to field parameters and chemical constituents and reactions. An appropriate model of this system will consist of five discrete compartments. However, it is important to examine the HTDF under the assumption that all vertical structure decays and the HTDF becomes completely mixed. A fully mixed model was developed and run during and after a simulated mill operation to estimate HTDF effluent concentrations during these periods.

A fully mixed system will have much higher surface water concentrations of many constituents, compared to the stratified HTDF, and, as such, represents a "worst-case" scenario under the planned loading conditions with respect to the concentrations of chemical constituents in the water that enters the WWTP. The model is presented here to aid in the design of the WWTP. In addition, because analytical solutions are available for the fully mixed case, the simulations can be easily checked.

Model parameterization of the fully mixed HTDF was done by calculating daily loadings for all constituents quantified in bench scale process water. Laboratory reports describing the process water testing are included as Appendix D. Measured concentrations from three tests were averaged to create a solution representing mill effluent into the HTDF, and daily loadings were calculated by multiplying these concentrations by the daily volume of carriage water necessary to convey a slurry containing 60% mine tailings by weight. The masses of metals and other constituents calculated in this way were added to the previous daily totals in the HTDF. The total mass of each constituent was then divided by the total volume of the HTDF water (decreased daily by the volume occupied by the tailings as a 72% weight percent sediment) to calculate the daily concentration of each constituent in the HTDF.

Each day, a mass of each constituent was removed by flow out of the HTDF, equal to the annual flow divided by 365 days, plus the water displaced that day by the tailings, and the difference between water from, and back to, the mill. The actual mass removed was equal to the product of the concentration from the previous day and the daily flow. Initial conditions in the HTDF were set by calculating the mass of all constituents in the HTDF, based on measured concentrations in each of the five identified model compartments. These masses were divided by the initial volume of water in the HTDF to determine initial concentrations of constituents in the HTDF under the assumption of complete mixing. The iterative process of adding the current day loadings to the current mass in the HTDF, dividing by the current HTDF water volume, and exporting mass proportional to concentrations from the previous day was run for 2555 days, equivalent to seven years of mill operation. Then, the loading term was removed, and the model was run for an additional 2555 days. Under these conditions, the volume of the HTDF remains constant at that reached on day 2555, no new loading occurs, and a daily mass of chemical constituents is exported (just as during the loading phase). Thus, the concentrations of chemical constituents decrease over this second 2555 day period, simulating ongoing washout of the HTDF after loading ceases.

Input concentrations in each of the five HTDF compartments, calculated initial concentrations, and concentrations of chemical species in the mill effluent are shown in Table 3. Model predictions of HTDF concentrations under fully mixed conditions at the end of years one, three, seven, ten and fourteen are shown in Table 4; preliminary effluent limits (PEL, see Appendix E)

are also provided. Note that mill effluent contains several constituents not currently found in the HTDF, but antimony, boron, and lithium are currently in the HTDF (Figure 12) but not in the mill effluent.

Concentrations of constituents that are greater in the mill effluent than initially in the HTDF increase in HTDF water over time (for example, copper, iron and nickel), while those that are initially elevated in HTDF water relative to mill effluent decrease over time as washout removes more than is added (for example, manganese and nitrate). After loading, concentrations decrease as chemical constituents wash out of the HTDF. Thus, all values decrease in years ten and fourteen, relative to maximum values in year seven.

The fully mixed model predicts several metals will enter the WWTP at concentrations that will require treatment to meet regulatory limits. These metals include copper, mercury, nickel, and possibly selenium.

5.1 Fully-Mixed Model Predictions and Historical Washout

The HTDF has been used previously as a tailings disposal facility for tailings from the Ropes mine. This resulted in elevated concentrations of some metals in the HTDF after closure of the Ropes mine, and subsequent monitoring of some metal concentrations. One historical depth profile is available describing nickel concentrations at five depths similar to those used here to describe the five compartments of the HTDF (Montgomery Watson, 1995). Using these historical data and current nickel concentrations (Table 3), it is possible to test the assumption that a simple washout mechanism controls nickel concentrations over time in the HTDF.

The specific calculation used to test this assumption, as well as the results of the calculation, are shown in Figure 16. The washout calculation depends on the volume and the retention time of water in the HTDF. The upper curve on the graph shows how nickel concentrations decrease over time if nickel is only removed by washout. The predicted nickel concentration in 2007, beginning with 1994 concentrations, is about three times higher than that actually measured in 2007. The lower curve on the graph is fitted to the data points, and predicts that flow from the HTDF would have to be almost three times greater (such that retention time is almost three times lower) to remove enough nickel to decrease concentrations from 1994 levels to those measured in 2007.

There is no evidence that flows from the HTDF have changed significantly between 1994 and 2007. Thus, a simple washout model like that presented above for the fully-mixed HTDF will greatly over-predict future metal concentrations in water flowing from the HTDF. And, the over-prediction of future concentrations indicates that mechanisms in addition to mixing (such as particle scavenging) must be actively reducing outflow concentrations from the HTDF. More accurate predictions require a multi-compartment model that includes compartmentalization and chemical reactions within the HTDF.

6 Multi-Compartment Model of the HTDF

The concept for the model was developed with a multi-compartment network, with variable volumes, loading rates, and flow rates. Flow rates vary to adjust to the dry tails loading schedule, mill downtime, and expected variations in the flows from the watershed.

The multi-compartment model of the HTDF addresses dynamic simulation of the following processes:

- Dynamic Loading and Seasonality
  - Mill tailings loading according to schedule
  - Uses average monthly climate and hydrology

- Variable Volumes
  - Variable surface water elevation
  - Accounting for mill tailings loading and associated pore volume
  - Dynamic updating of compartment volumes

- Flow Balance
  - Seasonal surface precipitation minus evaporation in watershed
  - Steady groundwater flow input
  - Steady water outflow from surface compartments to WWTP
  - Mill discharge and reclaim water recycle stream
  - Intercompartment flows balanced to inputs and volume changes

- Density-Driven Mixing and Plume Distribution
  - Density calculated from temperature and total dissolved solids
  - Intercompartment mixing affected by density differences
  - Distribution of mill discharge plume affected by density of compartments and plume

- Heat Balance
  - Surface heating from solar and atmospheric radiation
  - Surface heat exchange from back radiation, conduction, convection, evaporation
  - Predictions of ice formation and melting
  - Heating from mill discharge of tailings
  - Accounting of all compartment inflows and outflows
  - Heat transfer from tailings bed
  - Temperatures of discharge plume and all compartments tracked

- Mass Balances
  - Background concentrations in runoff
  - Initial concentrations from profile sampling of HTDF
  - Estimated loading from mill tailings porewater
  - Total dissolved solids modeled as conservative component.
  - Chemically active components include DO, oxygen demand, oxidized iron, alkalinity, and metals.
  - DO dynamics from surface water exchange and reaction with oxygen demand
  - Oxygen reaction rates and saturation affected by temperature

- Oxidized iron formation from conversion of oxygen demand
- Alkalinity effects from oxidation-reduction chemistry
- Metals scavenging from complexation and settling of oxidized iron
- Alkalinity dependence on settling of oxidized iron
- Bed diffusion from tailings bed porewater

The model is carried out using seven parallel components, each having the same general flow and mixing dynamics for inputs, outputs, and between compartments. These main components and their interdependencies within the model are shown in Figure 17. The mass balance model for the HTDF was fully implemented using ModelMaker™ (Version 4.0, Cherwell Scientific, 2000, Oxford, United Kingdom). Further details regarding the motivation and methods for modeling are presented below. A model definition and parameter listing is presented in Appendix F.

6.1 Motivation for HTDF Multi-compartment Model

The need for a multi-compartment model for the HTDF was to allow the simulation of stratification identified as five vertical compartments, while also allowing the disruption of the natural stratification by continuous, inter-compartmental mixing. Since the proposed mill discharge will be placed at depth, and the influent to the water treatment facility will be drawn from the HTDF near the surface, assessing stratification of the HTDF during mill operation is necessary.

The stability of stratified compartments is established by the trend of increasing water density with depth. If this general trend in water density is maintained during and after proposed loading, the compartments should remain stratified. Conversely, if the density of a lower compartment decreases relative to the adjacent upper column, the instability can be modeled as a relatively high inter-compartment flow. If the instability is maintained over time, the two compartments will mix to a high degree, effectively destroying the stratification. Stratification is affected by surface heating and cooling, as well as dissolved solids in the water. Stratification in the upper layers is also affected by wind-generated currents.

It is important to note that the model is based on the assumption that the individual compartments are completely mixed, a generally conservative assumption. A water parcel from the discharge, entering the lower compartment, may quickly come into contact with the interface of the next compartment. Once regular flow and inter-compartment mixing flow brings that parcel into the above compartment, a portion of that parcel is immediately available to flow to the next compartment.

Another reason for a multi-compartment model was to simulate tailings loading to the bed. As intended, the mill discharge is to be more dense and thermally stable relative to the bottom HTDF compartment, and the discharged tailings slurry should be delivered at a relatively high percent solids to the bed and the lower compartment. A large portion of the discharged pore water from the slurry would be delivered to the freshly placed sediment bed, although bed compression and diffusion would lead to a steady bed flux of the chemical constituents to the lower compartment. This placement strategy for the mill tailings is preferred, because it reduces HTDF mixing and will lead to lower metals loadings to the upper HTDF compartments.

Conversely, if the mill discharge water is less dense than the surrounding water or placed with a high rate of flow, the slurry would mix more completely at the point of discharge and a significant portion of the fluid flow may be expected to rise to the surface. Negative chemical consequences would compound the other disadvantages of a high-rate or low-density mill discharge. Although the tailings would settle to an anoxic sediment bed, metals and other compounds from the mill discharge pore water would mix with water from the upper compartments. DO from the HTDF surface waters, mixed into the upper compartments, would react quickly with the reduced sulfur species and reduced iron in the discharged water, producing sulfate, oxidized iron, a loss of alkalinity, and higher dissolved metals concentrations. For these reasons, the placement of mill tailings in the HTDF at high rate and low density is to be avoided.

Chemical processes internal to the HDTF are expected to remove metals and other chemical constituents from the water column. Under suitable pH and alkalinity conditions, oxidized iron will form ferric hydroxide and other iron precipitates, which will complex with dissolved metals and settle to the lower compartments. Removal of metals by complexation and settling of ferric hydroxide is referred to as metals scavenging. The chemistry of other metal precipitates, such as metal hydroxides, manganese carbonate, and calcium carbonates, are not modeled directly. The multi-compartment model tracks oxygen demand, DO, oxidized iron, alkalinity, and provides simulation of metals scavenging.

Since the tailings loading will significantly reduce the volume of the HTDF, the multi-compartment model must accommodate compression of the compartments. Volume changes in the upper HTDF compartments will also vary with seasonal surface water runoff from the HTDF watershed and a steady outflow to the water treatment facility.

6.2 Compartmentalization of the HTDF Model

Compartmentalization of the HTDF was based on measured stratification of temperature and water quality of the HTDF, as determined from Foth surveys in Fall 2006 through Summer 2007. In addition, compartmentalization of the northern HTDF area was suggested by bathymetric characteristics.

The multi-compartment model was developed as is shown in Figure 17. For the stratified HTDF, Compartment 1 corresponds to the surface samples, compartment 2 corresponds to samples immediately above the thermocline, compartment 3 corresponds to the region between the thermocline and the chemocline, compartment 4 corresponds to the regions immediately below the chemocline, and compartment 5 corresponds to the near-bed region. The top 2 compartments (1 and 2) are assumed to be relatively fixed in volume, changing only with changes in the surface elevation. Compartment 1 represents the normal water depth interval of 0-6 ft (0-1.83 m), and compartment 2 represents the water depth interval of 6 – 24 ft (1.83 – 7.32 m). The bottom elevation of compartment 2 is assumed fixed, at 1514 ft (461.5 m), and the volume fraction of compartment 1 ($VF_1 = Vol_1/(Vol_1+Vol_2)$) is held fixed at 0.26. The lower compartments (3-5) are initially assumed to cover the water depth intervals of 24-96 ft, 96-144 ft, and 144 – 192 ft, respectively. Expected volumes and depth range information for the compartments are shown in Figure 18.

6.2.1 Upper HTDF Volume Changes Due to Storage

A polynomial regression model of bathymetric data provided the following relationships between the volume of the HTDF and the surface water elevation. The upper storage volume in main HTDF is presented as:

$$V_{US} = V_1 + V_2 = V_M\{elev\} - V_M\{1514\,ft\} \quad (19)$$

where $V_M\{elev\}$ is the main HTDF volume prior to new tailings loadings, but subject to changes in surface elevation and $V_M\{1514\ ft\}$is a reference volume of 6,094,897 m^3 for the elevation of 1514 ft (461.467 m). Fitting bathymetric data over the elevation range of 461-470 m leads to the following relationship:

$$V_M\{elev\} = a_M(elev)^2 + b_M(elev) + c_M \quad (20)$$

where a_M = 2098.946 m, b_M = -1,717,071 m^2, and c_M = 352.131 x10^6 m^3. A similar fitting process was used develop equations with the same form for the northern HTDF and the full HTDF volume. For the northern HTDF, a_N = 809.614 m, b_N = -735809 m^2, and c_N = 167.216 x10^6 m^3. For the full HTDF, a_F = 2905.56 m, b_F = -2,452,880 m^2, and c_F = 519.347 x10^6 m^3.

Changes in the volumes can be related to changes in elevation, by differentiation. For the main HTDF (and upper storage volume), the change in volume is

$$\dot{V}_{US} = \dot{V}_M = (2a_M(elev) + b_M)\frac{\partial elev}{\partial t} \quad (21)$$

Similarly, the change in the full HTDF volume is

$$\dot{V}_F = (2a_F(elev) + b_F)\frac{\partial elev}{\partial t} \quad (22)$$

From the flow balance, the change in volume in the full HTDF is also

$$\dot{V}_F = Q_D - Q_R + Q_{nat} + Q_{gw2} - Q_{T,out} \quad (23)$$

Where Q_D is the total discharge flow (mill to HTDF), Q_R is the reclaim flow (HTDF to mill), Q_{nat} is the net natural surface flows to the HTDF (see Figure 3), Q_{gw2} is the groundwater inflow (43 gpm, delivered to compartment 2), and $Q_{T,out}$ is the total outflow that is set by the WWTP design. Setting the last two equations equal yields the following model equation for rate of the change in the elevation (elevRate):

$$\frac{\partial elev}{\partial t} = \frac{Q_D - Q_R + Q_{nat} + Q_{gw2} - Q_{T,out}}{2a_F(elev) + b_F} \quad (24)$$

Using a starting elevation of 1538 ft (468.782 m), the model keeps track of the flows and integrates this equation to provide the surface elevation at all times. With the elevation, the elevation rate, and fixed volume fractions of compartments 1 and 2 known, the change in the volumes of these two compartments can be expressed. For compartment 1, the expression for the volume rate (VolRate1), is

$$\dot{V}_1 = VF_1 \dot{V}_{US} = 0.26(2a_M(elev) + b_M)\frac{\partial elev}{\partial t} \quad (25)$$

The expression for the rate of change in the compartment 2 volume has the same form, but the volume fraction VF_2 is 0.74. For the northern HTDF, the coefficients a_N and b_N (presented above) are used, and the volume fraction is 1.0.

6.2.2 Lower HTDF Volume Changes Due to Tailings Loadings

As the lower HTDF volume is occupied by the discharged mill tailings, the volume associated with these compartments decreases. The volumes of the compartments 3-5 were adjusted so that they represented the same proportional volume to the total remaining volume in the lower HTDF (sum of water volumes above placed tails, or sum of Vol_3, Vol_4, and Vol_5). If VRL is the volume remaining in the lower HTDF (sum of volumes 3-5), Vol_3 was adjusted to 0.60 times VRL, Vol_4 was adjusted to 0.24 times VRL, and Vol_5 was adjusted to 0.16 times VRL. Bathymetric relationships (shown in Figure 4) were used to estimate available water depth after uniform placement of tails.

The volume rate of tails loading (VolRateTails) is found from the dry tailings loading rate and the expected dry density

$$\text{VolRateTails} = \dot{V}_{TB} = \frac{\dot{M}_{DT}}{\gamma_d} \quad (26)$$

At 72% solids, the dry density of the new tails deposit is 1387.3 kg/m^3 (86.6 pcf). For the dry tails processing rate of 1159.0 tonnes/d, VolRateTails would be 835.5 m^3/d. The decrease in the volume remaining in the lower HTDF is VolRateTails. Therefore, the changes in the lower compartment volumes are found as:

$$\dot{V}_3 = -0.60\,\dot{V}_{TB} \quad (27)$$

$$\dot{V}_4 = -0.24\,\dot{V}_{TB} \quad (28)$$

$$\dot{V}_5 = -0.16\,\dot{V}_{TB} \quad (29)$$

Volume change information for the compartments is needed for establishing compartmental mass and heat balances, as well as to establish inter-compartmental flows.

6.2.3 General Approach for Mass, Heat and Flow Balances

The mathematical approach for mass, heat, and flow balances is based on completely-mixed compartments that may have a variable volume. As an example, consider one compartment with a known inflow Q_{in}, a known volume change, and an unknown outflow Q_{out}. The flow balance would be written as:

$$Q_{out} = Q_{in} - \dot{V} \quad (30)$$

If the volume change is negative (compartment compresses), the outflow would have to be higher than the inflow for the flow balance to be satisfied. If the concentration in the compartment is C and the input concentration is C_{in}, the mass balance would be constructed as:

$$\frac{d(VC)}{dt} = \dot{V}C + V\frac{dC}{dt} = C_{in}Q_{in} - CQ_{out} \qquad (31)$$

For a well-mixed compartment, the concentration of the outflow has to be equal to C, the concentration within the compartment. Rearranging, the expression for the change in concentration is:

$$\frac{dC}{dt} = \frac{C_{in}Q_{in} - C(Q_{out} + \dot{V})}{V} \qquad (32)$$

Similarly, the heat balance would be

$$\frac{dT}{dt} = \frac{T_{in}Q_{in}\rho_w C_p + \dot{H}_{in} - T(Q_{out} + \dot{V})\rho_w C_p}{V\rho_w C_p} \qquad (33)$$

where T is the temperature, $\dot{H}_{in}$ is the net heat input into the compartment (other than from fluid flow), ρ_w is the water density, and C_p is the heat capacity.

6.2.4 Diffusion from Active Bed Tailings and Burial of Inactive Tails

The model allows diffusion and heat transfer from active bed tailings to compartment 5. Heat and mass balances for the active bed tailings compartment are tracked normally, although there is some additional complexity regarding the pore volume and combined heat capacity of tailings and porewater. In particular, the model keeps track of the tailings bed area for all loadings. Details are provided in the model definition and parameter files presented in Appendix F.

All simulations discussed in this report were run with an active bed tailings layer thickness of 0.50 m (1.64 ft), a diffusion mass transfer coefficient of 4.0 $x10^{-4}$ m/d, and a bed heat transfer coefficient of 0.05 GJ/m^2-d. Because the active bed is assumed to be completely mixed, the effective bed diffusion and heat transfer rates should be considered to be conservative (favoring mass and heat flows back to compartment 5).

Once the tailings bed thickness exceeds the active bed thickness of 0.5 m, the mass and heat associated with the overflow volume is reported to a buried tails compartment. Once buried, there are no mechanisms within the model for mass or heat return to the HTDF. However, the heat and mass delivered to the buried tails are tracked for purposes of checking model mass and heat balances.

6.3 Flows in Multi-compartment Model

The flow balance for the HTDF mass balance model is presented in Figure 19. The compartments are set up in a straightforward network, with introduction of tails at compartment 5, upward flow at the discharge flow rate through compartment 4 to compartment 3, return flow to the mill at compartment 3, and the remainder of the forward flow through compartment 2 to

the surface compartment 1. In the upper compartments, there are additional flow inputs from groundwater at compartment 2 and to the surface from the watershed. Forward flow exits from compartment 1 and from the northern HTDF to the influent of the WWTP. Under this conceptualization, the northern HTDF is the expected to be somewhat segmented from the main processes of the HTDF, since only a very limited portion of the discharge will enter it and normal surface flows will continually flush out this compartment.

6.3.1 Formation of Discharge Plume

The model considers the discharge from the mill to first form a discharge "plume" at a mixing point. This concept is shown in Figure 20, along with the relevant mass and heat balances. Discharge solids (mill tailings) and water are delivered to a plume mixing point, where compartment 5 water is also brought in and the inputs are completely mixed. All the tailings solids are delivered to the tails bed, and the porewater associated with the expected bed porosity is also drawn to the bed. The heat and chemical mass associated with tailings can diffuse back to compartment 5, but the model assumes no additional flow from further compression of the tails.

The resulting flow to the plume comes from a simple flow balance. Commonly, for 40 units of water in the discharge over a set time period, 26.2 units of compartment 5 water is also brought into the mixing point, 23.3 units is delivered to the tails bed porewater, and 42.9 units is brought into the plume.

6.3.2 Distribution of Discharge Plume and Density-Dependent Mixing

Details regarding the distribution of flows from the discharge plume are presented in Figure 19. However, the complexity of the concept requires additional discussion. The flow distribution of the discharge plume is driven by density differences. If the plume is significantly less dense than water in the lower compartments, a greater portion of the discharge plume would be delivered to the upper compartments.

A physical analogy for density-dependent fluid mixing is expressed in Figure 21. While the physical analogy is presented for intercompartment mixing, the same general form is used for the distribution of the plume flow. The physical analogy is a simple pulley system of two weights, where a lighter mass on the bottom M2 will move up and the heavier mass M1 will move down. If the initial potential energy is converted to kinetic energy at the midpoint elevation, this midpoint velocity can be derived. Converting the system to address parcels of water moving across a liquid interface, the physical analogy shows that the velocity should be proportional to the square root of the differences in the densities over the sum of the densities. The mixing function is considered at a maximum flow (simulating complete mixing) if the bottom water is less dense and the density difference is maintained at roughly a 0.08% difference. The formulation allows for some inter-compartment mixing, even if the lower water is denser than the upper water.

For the plume distribution (detailed in Figure 19), the comparison of densities is between the discharge plume and the compartment. The flow is assigned sequentially, from compartment 5, then to compartment 4, then to compartment 3, and so on.

For compartment 5, the mixing function applies to whole discharge plume flow (less what reports to the tails bed). If the density of the plume is greater than that of compartment 5, the

plume is considered stable and 99% of the discharge plume flow is delivered to compartment 5. The remaining 1% of the flow is distributed to the upper compartments, with 0.99% of the discharge plume flow likely to compartment 4.

If the density of the plume is less than that of compartment 5, then the plume is considered unstable and the mixing function is evaluated. To simplify an example, let us assume that the density of compartment 5 water is 1000 kg/m^3 and the density of the discharge plume is 999.6 kg/m^3. Under the current mixing function settings (MF_{min} = 0.03, MF_{max} = 0.99, DF = 0.02), the plot shown on Figure 21 applies, and the mix function would be approximately 0.72. In this case, 72% of the discharge plume flow would report to the upper compartments and only 28% of the discharge plume flow would report to compartment 5. If the density of compartment 4 was also 1000 kg/m^3, 28% of the remaining flow or 20.2% of the discharge plume would report to compartment 4 (0.28 x 0.72 = 0.202). If the density of compartment 3 was also 1000 kg/m3, 28% of the remaining flow or 14.5% of the discharge plume would report to compartment 3 (0.28 x 0.72 x 0.72). If the density of compartment 2 was lower than the discharge plume, 99% of the remaining discharge flow or 37.0% of the discharge plume would be delivered to compartment 2 (0.99 x 0.72 x 0.72 x 0.72 = 0.370). The remaining 0.3% of the discharge flow would be delivered to compartment 1.

If the discharge plume is considerably less dense than water in compartments 2 through 5, more than 96% of the discharge plume could report to compartment 1. The model is therefore sensitive to discharges that are less dense than the lower compartments. In the case of a low-density discharge, a greater portion of the plume flow would simply rise to the surface, effectively bypassing the lower compartments.

It is important to note that the formation of the discharge plume (as shown in Figure 20) is still affected by the temperature and composition of the water from compartment 5. This water is used to exchange some heat and porewater with the incoming tailings before the tails bed is formed. There is some dilution and cooling of the discharge prior to the formation of the discharge plume. Because of heat transfer and chemical diffusion back from the tails bed to compartment 5, the placement of tailings is expected to raise the concentration and heat stored in compartment 5. An increase to total dissolved solids will increase the density of compartment 5, and an increase in temperature will decrease it. The multi-compartment model tracks expected changes to compartment density, and assigns an inter-compartment mixing rate that increases significantly if a lower compartment has a lower density than the compartment above it. Details are discussed below.

6.3.3 Density-Dependent Mixing and Inter-compartmental Flows

Reverse flows in the compartments 1 through 5 are used to provide inter-compartment mixing. Details are described in Figure 19. In this model, this is handled simply as an equal flow (up and down) from adjoining compartments. If the flow rate Q_{21} represents the normal forward flow from compartment 2 to 1 and a backward flow Q_{12} is added to simulate greater mixing, Q_{12} is added to Q_{21} to achieve the same net forward flow. The upper zone mixing flow variable Q_{12} is influenced by a wind-generated mixing flow of 2000 m^3/d during the ice-free season and the normal density-driven mixing flow. Density-driven mixing flows can be as high as 15,000 m^3/d, or roughly 11 times the average natural flow. Typical values for Q_{12} are seasonal, ranging from

2000 m^3/d to 7300 m^3/d over the ice-free season, but may be only 500 m^3/d during the mid winter.

The mixing flow Q_{23} between compartments 2 and 3 is set to the normal density-driven mixing flow, plus one-tenth of the mixing flow Q_{12}. The idea is that forces that mix the upper 20 ft will still have some influence at the next compartmental interface. Typical values for Q_{23} are also seasonal, ranging from 700-1200 m^3/d during the ice-free season and 500 m^3/d for other periods.

Inter-compartment mixing Q_{1N} between the northern HTDF compartment and compartment 1 is set to a minimum mixing flow of 50 m^3/d or 50% of the natural flow to the northern HTDF. Since the natural flow is seasonal, the mixing flow is also, ranging from 50 to 220 m^3/d. Flow from both compartments 1 and N are drawn in to form the wastewater influent flow $Q_{T,out}$.

Unless the discharge heats the lower compartments significantly, the inter-compartment mixing in the lower compartments is limited to 500 m^3/d. Other factors, such as the compression of compartments, circulation effects of the discharge to compartment 5 and the reclaim water from compartment 3, add additional mixing to the system.

6.4 Parallel Model Components and Simulation of HTDF Chemistry

A range of chemical constituents and heat flow are modeled in parallel, using the same general mixing model to determine inter-compartmental transfers. These parallel components are shown in a diagram in Figure 17. The mill discharge plume and the HTDF are expected to consist of a dissolved metal (C), total alkalinity (Alk), DO, compounds carrying oxygen demand (P), and total dissolved solids (S). In addition, temperatures (T) are tracked and oxidized iron (OxFe) (which is used to track the oxidation of compounds carrying oxygen demand) are also tracked with compartments and inter-compartment flows.

Surface and groundwater flows may carry background concentrations of the constituents and there may be additional fluxes of DO and surface heat at the water surface, without flow. As initial chemical profile data are available, they are used as initial concentrations in the model. Some estimation was required for the constituents P and OxFe.

6.4.1 Surface Heat Flows

Chemical kinetics, DO transfer, ice formation, and water density are sensitive to temperature, and a surface heat balance was considered necessary to properly estimate surface temperatures. Temperature (T) in water is related to heat (H) through the volume, density (ρ_w) and heat capacity (C_p):

$$T = \frac{H}{V \rho_w C_p} \qquad (34)$$

While the product of the density and heat capacity does vary with temperature, it ranges from 4.21 x10^6 J/m^3 °C at 0 °C to 4.15 x10^6 J/m^3 °C at 35 °C. For the purposes of HTDF model, the product of the density and heat capacity was referred to as a constant heat factor (HF_w), set at 0.00419 GJ/ m^3 °C, where GJ refers to giga-Joules (x10^9 J). The heat capacity of the dry tailings was set to a value used for common brick, 840 J/kg °C or 0.00084 GJ/ tonne °C.

Chapra (1997) describes the surface heat balance from net absorbed solar and atmospheric radiation, losses by longwave back-radiation and evaporation, changes from conduction and convection, and input/exports from flows. A simplified expression for atmospheric longwave radiation flux was:

$$J_{an} = \left(4.75 \frac{mJ}{m^2 d\, K^4}\right)(T_{air} + 273)^4 \left(0.6 + 0.31\sqrt{e_{air}}\right) \quad (35)$$

where T_{air} is the air temperature (°C) and e_{air} is the vapor pressure (mm Hg) that is related to the relative humidity Rh and saturated vapor pressure (e_{sat}):

$$e_{air} = \frac{Rh}{100\%}\, e_{sat} \quad and \quad e_{sat} \approx 4.596 \exp\left(\frac{17.27 T_{air}}{237.3 + T}\right) \quad (36)$$

Using monthly normal tabulated values for relative humidity and air temperature at the Champion-Van Riper station, the surface atmospheric radiation flux could be determined. The longwave back-radiation was estimated as:

$$J_{br} = \left(4.75 \frac{mJ}{m^2 d\, K^4}\right)(T_1 + 273)^4 \quad (37)$$

Where T_1 is the temperature of compartment 1. With assumption of an average wind speed of 7 mph (3.1 m/s), the flux due to conduction/convection was estimated as:

$$J_c = \left(0.55\, x10^6 \ \frac{J}{m^2 d\, °C}\right)(T_1 - T_{air}) \quad (38)$$

The flux due to evaporation was estimated as:

$$J_e = \left(1.17\, x10^6 \ \frac{J}{m^2 d\ mmHg}\right)(e_{sat} - e_{air}) \quad (39)$$

Monthly solar radiation data from the Eagle Project site was presented by Golder (2005). The monthly values starting with June 2004 were 273, 225, 213, 174, 89, 43, 26, 39, 72, 144, 215, and 224 W/m^2. The values were reduced 10% for losses due to reflection and shading, and converted to units of J/m^2-d.

6.4.1.1 Considerations for Ice Formation and Melting

When the water temperature was predicted to drop below 0 °C, ice was formed from the surface heat imbalance. The surface heat flux was negative, and the balance of other heat flows between the compartments had to be balanced by the formation of ice with a latent heat of 0.334 GJ/tonne and assumed density of 0.916 tonnes/m^3. With the surface area known and the total tonnage of ice formed, the thickness of the ice could be estimated.

Without correction to the surface heat fluxes during the ice period, ice formation was very large (3m or more) and the ice period was too long, melting in July. Because the ice and snow cover were expected to provide insulation to the water, the surface heat losses were reduced by a factor that varied exponentially with the ice thickness, and boundary temperature at the air-ice interface

was also adjusted to retain more heat in the system. The simulation led to steady seasonal ice formation and melting, forming in late October or early November, forming a peak ice thickness of approximately 80 cm in mid-February, and melting by mid-April.

6.4.1.2 Considerations of Surface and Groundwater Flows

The water temperature of surface water inputs, including miscellaneous contact water, was assumed to be at the air temperature. Groundwater temperature was assigned a temperature of 15 °C.

6.4.2 Considerations of Heating from Mill Discharge

The temperature of the tailings discharge was modeled as a variable, assuming a constant rate of heat input from dry tailings, use of recycle water at the temperature of compartment 3, and other factors, such as the inclusion of miscellaneous contact water in the discharge. Although an expected discharge temperature of 10 °C has been provided by M3 Engineering, the temperatures modeled for the discharge range from 10.5 °C to 12.6 °C during discharge, with the peak temperature occurring during the summer months.

No additional heating from the tails, such as from exothermic reactions, is expected, since DO and other reactants needed for the exothermic reactions will likely be absent, or at low concentrations.

The heat balance associated with the formation of the discharge plume (see Figure 20) demonstrates that there is some cooling of the discharge prior to full formation of the discharge plume. Some excess heat is stored in the tails bed, but may transfer back to compartment 5. The remaining excess heat is discharged to the compartments. The discharge plume temperatures are expected to be roughly 1.4 °C less than the discharge temperature, or roughly in the range of 9.1 °C to 11.1 °C.

The dynamics of temperature expected in the HTDF during and after loading are shown in Figure 22. The temperature of the bottom HTDF water is initially in the range of 5.0 – 5.6 °C, and the introduction of warmer tails will heat the system over time. The temperature of compartment 5 is expected to increase from 5.6 to 8.2 °C after 7.1 years of loading, declining slowly afterwards. Compartment 4 temperatures are expected to increase from 5.1 to 7.3 °C, without significantly declining after the tails loading. And, compartment 3 temperatures are expected to increase from 5.1 to 6.7 °C during loading, and continue to increase to 7.3 °C seven years after tailings loading ends.

It is important to note that water density was estimated from fitting standard density-temperature tables as well as density-salinity relationships. As an illustration, temperature and density profiles are shown in Figure 23. Temperatures increase during loading from compartments 3 to 5. If the salinity was the same, the higher temperatures at the bottom would be associated with lower densities, and there would be greater mixing. However, the higher salinity (or TDS) in the lower compartments counteracts the temperature effect and density increases with depth. Several years after loading, the temperature profile is relatively flat, but the trend of increasing density with depth appears stable.

Long-term simulations, run for a total of 27 years, showed that the water temperature for the lower HTDF is relatively constant, with compartment 3 showing a slight increase to roughly 8.0 °C at 27 years, and compartments 4 and 5 rising slightly to 7.8 °C at 27 years. No significant changes in the upper HTDF temperatures are expected over the long-term, as compartment 1 and compartment 2 temperatures are controlled by normal seasonal conditions. However, the effect of year-to-year variations in surface heating conditions are not modeled, since the same, normal record for annual climate was used for the simulations.

6.5 Flow and Water Level Dynamics

The record of flows simulated from the model is shown in Figure 22. The irregular natural inflow follows directly from the monthly net precipitation and melt record that is fed into the model. The flow record shows the flows from the mill discharge and the return (reclaim water) flow. The net precipitation to the main HTDF is the same for every year, but the outlet flow (to WWTP) is held constant at 1816 m^3/d (333 gpm) during the period of mill discharge and 1340 m^3/d (246 gpm) after the tailings loading is completed. Water levels during the loading period range from 468.5 m (1537.2 ft) to 469.1 m (1539.1 ft). This range in elevations is maintained for periods after loading. An alternate model simulation was run, using the net precipitation time-series from the maximum annual precipitation case (see Section 3.2) and an outlet flow to the WWTP at 2627 m^3/d (482 gpm) based on a 320 day operating period for the mill. For this simulation, the elevations ranged from 468.5 m (1537.1 ft) to 469.4 m (1540.0 ft). The proposed berm elevation along the northern edge of the HTDF is 470.3 m (1543 ft). Since a 100-yr, 24-hr storm event is expected to raise the water elevation 1.2 ft (see Section 3.2), the maximum HTDF water level should always be less than 470.0 m (1542.0 ft). Since the HTDF volume is large relative to the flows, the hydraulic retention time is also large. The effects of seasonal and year-to-year variations on the mass balance are dampened significantly by the large volume.

As is mentioned in Section 3, flows at the proposed WWTP may be adjusted to handle seasonal variations in flow. Given the significant available storage with the HTDF and low flows during winter months, wastewater treatment operations may be focused during warm weather periods without significant impacts to HTDF water quality and elevations. Based on upon the flow dynamics discussed above and in Section 3.1.2 a WWTP capacity of 510 gpm is appropriate for a mill operations.

6.6 Dissolved Oxygen and Iron Chemistry Dynamics

DO and dissolved components expressing an oxygen demand are modeled to better understand the risks of the oxidation of the placed tailings. The concept for placement of tailings in the HTDF provides two main elements that should greatly limit oxidation:

- Deep placement of tailings
- High slurry density

Reducing exposures of the slurry to the overlying water and reducing the amount of water discharged should greatly reduce exposure of the tailings to DO during loading and over the long term.

DO dynamics are modeled by considering aeration of the surface water (compartments 1 and N) during the ice-free season, consumption of oxygen by oxygen depleting chemicals, complete

mixing within compartments, and mass transfer from fluid flow between compartments. Oxygen saturation levels and the rates for reaeration and oxygen depletion are temperature-dependent. Adjustments to oxygen saturation for salinity (as estimated from TDS) were also made. An eight-term polynomial equation was used to relate DO saturation to temperature and salinity (American Public Health Association 1998a, Chapra 1997).

The DO of the background water (from net precipitation, melt, and groundwater input) was modeled to be 3 mg/L below oxygen saturation. However, the surface waters (compartments 1 and N) were well aerated. The Wanninkhof, et al. (1991, as cited by Chapra 1997) estimation for lake reaeration coefficient was used. Although a typical wind speed is 7 mph, a 10 mph wind speed was selected as a conservative measure (more aeration), and the reaeration mass transfer coefficient was estimated as 1.15 m/d. Using a mean depth of compartment 1 of 1.83 m (6 ft) and the surface area, the aeration coefficient at 20 °C was estimated as 156,000 m^3/d for compartment 1 and 26,000 m^3/d for compartment N. Both rate coefficients were subject to temperature corrections of the form:

$$k_a(T) = k_{a(20^\circ C)}\ \theta^{T-20} \qquad (40)$$

where θ was selected as 1.024. No aeration was allowed during ice seasons.

The interdependencies related to DO dynamics are described in Figure 17 and Figure 24. DO is depleted by oxygen depleting chemicals (P), and the oxidation of P also leads to the formation of oxidized iron (OxFe) and a reduction of alkalinity (Alk). DO, which is abundant at the surface, may be brought into contact with water in the lower layers, from a downward mixing flow, internal recycling associated with the discharge and reclaim streams, or water flow from the lower compartments into the upper compartments. In addition, oxygen depleting chemicals (P) may flow up into compartments with higher levels of DO, and oxidized iron (OxFe) may reduce to form P in compartments with low DO.

The basic rate coefficient for oxygen depletion (k_d) is set to 0.1 m/d. This rate coefficient is corrected by temperature (see Figure 24). The oxygen demand P is assumed to be completely from dissolved ferrous iron. In order to address a model instability at low DO, the oxygen depletion rate is made first-order with respect to DO at DO levels below 1 ppm. This allows fairly rapid numerical integration and a somewhat rapid depletion of DO.

Reduction of oxidized iron (OxFe) to oxygen demand (P) is assumed to occur when the DO is less than 0.5 mg/L. The presence of additional reductants, primarily bisulfide, at low DO levels is expected to convert oxidized iron to reduced iron (or P). However, the reaction rate is first-order with respect to the OxFe concentration and the rate coefficient is assumed to be only 1.5% of k_d, the rate coefficient for oxygen depletion. These settings led to reasonable iron and DO levels for the unloaded model run condition, which was the primary method used for selection of these settings. Expected profiles of DO during and after loading are shown in Figure 23.

6.6.1 Alkalinity Effects

The consumption of DO by oxygen demand (P) is expected to coincide with a decrease in the alkalinity of the water. The oxidation of ferrous iron to ferric iron by DO, followed by the formation of ferric hydroxide, is expected to reduce alkalinity by 12.5 mg as $CaCO_3$ for 1 mg of

DO consumed. The slower reaction of the reduction of oxidized iron to P is expected to increase alkalinity by 1.68 mg as $CaCO_3$ for each 1 mg of iron reduced.

While pH is not modeled directly, large decreases in alkalinity would generally indicate more acidic conditions and opportunity for greater leaching from the tailings. There are two main attributes of the loading that provide a significant level of protection against acidic conditions:

- Discharge is expected to have high alkalinity (900 mg/L as $CaCO_3$).
- Deep placement at high percent solids will limit exposure of tailings and chemicals carrying oxygen demand to DO.

In the model, the discharge alkalinity was assigned a value of 860 mg/L as $CaCO_3$. Using this input and the expected mixing and reaction dynamics of the model, the expected alkalinity profiles for the HTDF during and after loading are shown in Figure 23.

Alkalinity is also expected to affect the settling of ferric hydroxide (see Figure 24). Settling should be more favorable under conditions of higher alkalinity. An empirical alkalinity pivot function was used to scale the settling rate. If the alkalinity of the water was less than 100 mg/L as $CaCO_3$, the settling rate would be roughly one-tenth of the full rate (8 cm/d) or less. If the alkalinity was 200 mg/L, the settling rate would be roughly one-half the full rate, or 4 cm/d. An alkalinity of 450 mg/L as $CaCO_3$ would lead to settling at roughly nine-tenths of the full rate.

6.6.2 Metal Scavenging by Iron Hydroxides

Metals, such as nickel, copper and mercury, are expected to complex with ferric hydroxide to form mixed metal complexes. An empirical relationship, shown in Figure 24, was used to simulate the level of complexation, which is sensitive to the level of oxidized iron (OxFe) and adjusted by a complexation coefficient, $K_{complex}$. Under the formulation, a higher value of the parameter $K_{complex}$ leads to less complexation. Once complexed, the removal of the metal by iron scavenging depends on the settling rate. Therefore, effective removal through scavenging requires favorable complexation and availability of oxidized iron, as well as favorable settling to the lower compartment. As mentioned above, effective settling of iron hydroxides requires that the alkalinity is suitable. For compartment water with a low alkalinity, complexation may be favorable, but losses to scavenging may be small because of the greatly reduced settling rate.

Determining the iron scavenging dynamics of the HTDF is complicated. Fortunately, chemical profile data from 1994 for nickel and copper were available (Montgomery Watson, 1995). The empirical iron scavenging algorithm could be calibrated to fit current (2007) conditions using the earlier 1995 dataset as the initial condition. As shown in Figure 16, the nickel concentration in the HTDF has decreased more than would be predicted from complete mixing and simple washout. Under stratified conditions, the removal from washout is expected to be much less, so internal metals scavenging should be considered to be an important removal mechanism.

A set of nickel scavenging model runs were carried out, using the 1994 initial conditions and without any tailings loading. The initial alkalinity profile was assumed to be 100, 100, 100, 165, and 185 mg/L as $CaCO_3$, for compartments 1 through 5, respectively. The initial nickel concentrations, estimated from the reported values at 10 m depth intervals (Montgomery Watson 1995), were 520, 510, 910, 990, and 1000 ug/L, respectively (see table, presented in Figure 16).

To be conservative, nickel concentrations in the background were held to 0.0 ug/L. A favorable fit was found with a value for $K_{complex}$ of 0.01. Whereas current (2007) measurements show that the nickel concentration profile is 14, 13, 17, 210, and 280 ug/L for compartments 1 through 5, the modeled concentrations were 13, 27, 113, 174, and 363 ug/L. Since the calibration generally led to higher concentrations than were measured in the 2007 profile, the calibration is considered conservative. In addition, normal model runs conservatively assumed a background concentration for nickel of 5 ug/L, while the calibration case assumed no background.

A similar process was used to find the complexation parameter $K_{complex}$ for copper . The initial copper concentrations, estimated from the reported values at 10 m depth intervals (Montgomery Watson, 1995), were 13, 12, 32, 57, and 70 ug/L, respectively. The background concentration for copper was set to 2.0 ug/L. A favorable fit was found with a value for $K_{complex}$ of 0.05. Whereas current (2007) measurements show that the copper concentration profile is 1.9, 1.8, 1.8, 2.7, and 3.3 ug/L for compartments 1 through 5, the modeled concentrations were 1.5, 2.4, 7.2, 10.8, and 23.8 ug/L.

6.7 HTDF Simulation Results for Complexed Metals

HTDF simulation results for the selected metals of nickel, copper, mercury, and selenium are shown in Figure 25. Trend plots for nickel, copper, and mercury for all major compartments are shown in Figure 26. Model results for concentrations expected at the HTDF outlet, to the WWTP, are presented in Table 5.

6.7.1 Nickel

The concentration of nickel discharge was set to 2230 ug/L. However, with internal mixing and scavenging processes, the simulated peak concentrations in the lower HTDF were always less than 400 ug/L. Even during loading, nickel concentrations increase only slightly or drop significantly because the rate of mass removal due to scavenging is greater than the rate of loading. Scavenging in the lower compartments is particularly strong. The increased alkalinity of the lower compartments (from the discharge) tends to favor more rapid settling. Surface nickel concentrations continue to decrease from the initial value of 14 ug/L to values less than 10 ug/L. At year 10, the surface concentration is expected to be less than 2 ug/L. Due to the assumption of sustained background loadings, the surface concentrations are expected to be stable for a long period after loading, while the concentrations in the lower HTDF compartments 2, 3, and 4 will continue to decline. Because of diffusion from the active bed tailings, the concentration of compartment 5 is relatively constant after year 10 (see Figure 26).

6.7.2 Copper

The concentration of copper discharge was set to 2760 ug/L, with much lower concentrations initially in the HTDF. However, with internal mixing and scavenging processes, the simulated peak concentrations in the lower HTDF were always less than 400 ug/L. During loading, copper concentrations increase significantly in the lower compartments, rising from 3.3 ug/L to roughly 300 ug/L in the first two years of loading, then decreasing to roughly 140 ug/L at the end of loading. Because of stratification and a general delay in the arrival of mass released from the bottom discharge, the surface copper concentrations drop slightly from 1.8 ug/L over the first year of loading, then increase to a peak of roughly 2.6 ug/L at the end of loading. After loading, scavenging is expected to further reduce concentrations throughout the HTDF. At year 10, the

surface concentration is expected to be less than 1 ug/L. Due to the assumption of sustained background loadings, surface concentrations are expected to decline to a level of 0.5 ug/L at year 14, with a much slower rate of decline for periods after year 14. For the 7 year period after loading, copper concentrations in the lower HTDF are expected to decline to 10 ug/L or less. However, diffusion from the active tailings bed porewater will likely lead to copper concentrations in the range of 5 to 10 ug/L to be sustained in compartment 5 for a long period (see Figure 26).

6.7.3 Mercury

Mercury concentrations in the HTDF initially are non-detect, but relatively large in the expected tailings discharge. With a discharge concentration of 200 ng/L, the lower HTDF concentrations increase significantly during loading, from less than 1 ng/L to a peak of roughly 21 ng/L in compartment 5 at the end of the second year of loading. Due to internal scavenging ($K_{complex}$ = 0.01) and some internal mixing of the discharge, the lower HTDF mercury concentrations are expected to decline to roughly 11 ng/L at the end of loading (year 7). After loading is complete, mercury concentrations in the lower HTDF are expected to decrease to less than 1 ng/L.

Even during loading, the surface mercury concentrations continue to decline from the initial setting of 0.5 ng/L. Background concentrations for mercury were set to 0.5 ng/L. However, higher background concentrations of mercury would likely control surface concentrations.

The assumption for assignment of the complexation coefficient of 0.01 is supported by the general chemical behavior of mercury relative to nickel. Mercury is expected to form complexes with iron and other compounds (such as bisulfide) with a higher affinity.

6.7.4 Other Complexed Metals

The model was carried out for several other metals that were expected to be scavenged by complexation and settling with iron hydroxide. Initial concentrations were drawn from Table 3. Background concentrations, estimated from the initial concentrations, are summarized in Table 5.

The set of other metals expected to have iron scavenging complexation coefficients similar to nickel ($k_{complex}$ = 0.01) include aluminum, arsenic, cadmium, chromium, lead, strontium, and zinc. Aluminum, arsenic, chromium, strontium and zinc were not detected above the EQL in the initial profile, but are expected in the mill discharge. For the purposes of modeling, the assumed background and initial concentrations for this set were set to 0.001 ug/L. Of this set, aluminum is expected to have the highest discharge concentration, at 686 ug/L. For the aluminum simulation, the peak concentration in compartment 5 was less than 60 ug/L, and the peak HTDF effluent concentration was less than 0.4 ug/L. It follows that all other metals of this set are expected to have lower concentrations in the profile and at the HTDF outlet.

An additional consideration was made for arsenic. Arsenic would likely be present as the arsenate ion, subject to redox reactions, iron scavenging, and potentially more labile under basic conditions. However, the more complex fate of arsenic species was not modeled. Arsenic was detected in each of the 5 compartments, but reported values were below the EQL of 1 ug/L. Assuming a background concentration of 0.5 ug/L and an upper-bound initial concentration of 1 ug/L in each compartment, the expected arsenic concentration in the HTDF outlet at was 0.5

ug/L at 1 year and drops steadily to roughly 0.2 ug/L at the end of 7 years. At 10 and 14 years, the arsenic concentration at the HTDF outlet is within the range of 0.1-0.2 ug/L. Decreasing the background concentration to 0.1 ug/L resulted in arsenic concentrations at the HTDF outlet of less than 0.1 ug/L after 7 years.

Cobalt, manganese, and molybdenum were modeled with a complexation coefficient of 0.05, the same setting as for copper. Background concentrations were set to match the initial concentrations of the upper compartments. These compounds are expected to be scavenged by iron hydroxides, but not as completely as the other scavenged metals. Although manganese oxides may also participate in metal scavenging and are important in redox reactions, modeled reactions were limited to scavenging with iron.

6.8 HTDF Simulation Results for Non-Complexed Species

The HTDF model was run for a set of compounds not expected to participate in iron complexation. This set included barium, calcium, chloride, fluoride, lithium, nitrate, potassium, selenium, sodium, sulfate, and total dissolved solids (TDS). Although scavenging may be effective for antimony, antimony was also modeled without iron complexation. For each case, the value of $K_{complex}$ was set to 100,000, in order to minimize iron scavenging. Expected concentrations at the HTDF outlet to the WWTP are summarized in Table 5.

6.8.1 Tracer Simulation

An additional HTDF model run was made to simulate a nonreactive tracer. The discharge concentration was set to 1000 ug/L and the initial and background concentrations were set to zero. This run case serves as a useful reference case. For this case, the simulation time was extended to roughly 27 years. A trend plot of the concentrations of the tracer is shown in Figure 27. Concentrations in compartment 5 increase steadily from roughly 110 ug/L after 1 year of loading to a peak of 530 ug/L at the end of loading. After loading the concentration drops steadily to roughly 200 ug/L at year 27. At the HTDF outlet to the WWTP, the concentrations for the same times are 0.0, 0.7, 15.3, 23.0, and 33.3 ug/L. This demonstrates that the peak concentration does not occur at the end of loading, but after loading. During loading the outlet concentrations are generally less than 1.5% of the discharge concentration, and increase to roughly 3% of the discharge at 14 years. After 14 years, there is little decay of the tracer in the HTDF outlet (WWTP influent), due to the inventory in the lower compartments and no scavenging of the tracer within the HTDF.

6.8.2 Selenium

Expected concentration profiles for selenium are presented in Figure 25. Unlike nickel, copper, and mercury, the model was run without any scavenging of selenium by iron hydroxide complexation and settling. The expected discharge concentration was 21 ug/L and the initial and background concentrations were nondetect. The continued loading is expected to lead to a steady increase in the lower HTDF concentrations during loading, increasing the selenium concentration of compartment 5 to approximately 11 ug/L. At year 14, the selenium concentration in the lower HTDF is still somewhat elevated at roughly 7 ug/L. At the surface, the selenium concentration increases to 0.3 ug/L at the end of loading, and continues to increase to roughly 0.7 ug/L at year 14.

6.8.3 Nitrate and Ammonia Nitrogen

The initial concentration profile of nitrate was modeled as the combination of ammonia and nitrate/nitrite nitrogen, with the conservative assumption that the ammonia would eventually convert to nitrate. The initial ammonia nitrogen concentration was 3.0 mg N/L in compartment 4 and 4.5 mg N/L in compartment 5. These levels were added to the measured, initial nitrate levels to yield a modeled, initial nitrate concentration of 5.6 mg N/L in compartment 4 and 6.0 mg N/L in compartment 5. The discharge was expected contain 0.237 mg N/L as nitrate. Using these initial and loading conditions, the model was run without any internal nitrogen reactions. Nitrate concentrations in the HTDF outlet to the WWTP are expected to be only slightly higher than the implied background concentration of 2.0 mg N/L.

Reactions with ammonia nitrogen were not modeled directly. Ammonia may participate in metal complexation in the lower HTDF, leading to elevated dissolved metal concentrations. Ammonia may also be complexed with solid phases, such as with iron hydroxide. Ammonia may also participate in the expression of oxygen demand, provided there are nitrifying organisms active in the HTDF. At the surface, ammonia is currently absent. If detected, the near neutral pH would dictate that it would be in the form of ammonium ion, not as free ammonia. However, the current version of the model did not consider ammonia reactions, other than to adjust the initial profile for modeled nitrate concentrations. While the upper HTDF is well aerated and DO levels remain high during and after loading, it is uncertain whether ammonia in the lower HTDF will migrate to the point of HTDF discharge at trace levels that may require treatment.

In order to address this uncertainty, an upper-bound estimate of ammonia concentration was modeled for the HTDF outlet to the WWTP. The initial profile of ammonia was set to 3 mg N/L at compartment 4 and 4.5 mg N/L in compartment 5, and a washout simulation was performed. This run of the model ignored any other sources of ammonia and no reactive conversion of ammonia. Under this conservative scenario, the ammonia levels in the HTDF outlet increase from zero to roughly 0.4 mg N/L at the end of year 7, with a slow decline to 0.3 mg N/L at the end of year 14. As mentioned above, the ammonia would likely be present as ammonium ion, rather than free ammonia. Since some complexation of ammonium with suspended solids in the lower HTDF is expected, and since conversion of ammonia to nitrate would be expected with the aerobic conditions in the upper HTDF, these modeled ammonia levels conservatively represent an upper bound.

A Preliminary Effluent Limit (PEL) for ammonia was not available (see Table 5). Typically, ammonia levels below 1.0 mg N/L are considered safe to aquatic life for receiving waters with a pH less than 8. Because these conditions are expected to be met prior to wastewater treatment for the HTDF, ammonia is not expected to be present at levels of concern.

6.9 Further Discussion of HTDF Simulation Results

While the level of complexity of the loading condition and chemical trends within the HTDF are relatively high, the HTDF mass and heat balance model has been developed to capture a wide range of processes. Focus was given to what were considered dominant processes, particularly the variable mixing conditions, the heat balance, displacements from the tailings loading on an irregular schedule, oxygen mass transfer and reactions, iron dynamics, and metals scavenging.

While there remains some uncertainty regarding loading conditions and internal chemical processes, the modeling is based on reasonable, empirical measures, fundamental quantities, best estimates for initial and input conditions, and explicit numerical strategies.

An important conclusion of the set of modeling simulations is that the HTDF is expected to remain stratified during and after the period of loading. This is expected for several reasons.

1. The current system is stratified and there are internal chemical mechanisms reinforcing that stratification. Previous tailings loadings, which were more disruptive because tailings were discharged to the surface, were followed by a period of significant restoration of the overall water quality and the stratified conditions that are observed presently.
2. The tailing discharge is expected at a high slurry density, so the level of exchange with the pore water is expected to be minor and a large portion of the inventory is expected to be stored in the tailings bed porewater.
3. Care will be taken to place the mill tailings at the bottom of the HTDF, to minimize exposure with water in the upper compartments of the HTDF.
4. The tailings will be placed at a moderate temperature, to minimize the likelihood of the formation of an unstable, thermal plume that may emerge at the HTDF surface.

The tracer simulations provide a useful mathematical reference for tracking the effects of the discharge on surface concentrations. The tracer simulations showed that, with no initial or background concentration near the HTDF, roughly 3% of the discharge concentration of a non-complexed compound would reach the HTDF outlet to the WWTP. If 1000 ug/L was discharged, the peak concentration occurred at roughly 14 years after loading and was roughly 30 ug/L. Because of the significant mass inventory within the lower HTDF and without any other mechanism to reduce concentrations in the HTDF, this outlet concentration of this ideal compound is expected to be at 20 ug/L at 27 years. Further washout is likely to be slow.

For most of the heavy metals brought in from the mill as tailings are placed in the HTDF, there is good evidence that internal chemical processes, particularly metals scavenging by settling iron hydroxide, will greatly reduce concentrations within the HTDF and at the HTDF outlet. For instance, while nickel is expected to be discharged at a concentration of 2203 ug/L, the concentration at the HTDF outlet is expected to be less than 2 ug/L after 10 years (less than 0.1% of the discharge concentration). Because scavenging causes a reduction of the metals inventory within the HTDF, the concentrations at the HTDF outlet are expected to continue to decline over time.

The model expectation of significant scavenging was supported by an evaluation that compared nickel and copper concentrations in the HTDF profile as measured in 1994 to more detailed measurements from 2007. Simple washout, even with complete mixing, could not explain the significant reductions in the HTDF metals concentrations. Using conservative settings for metals complexation coefficients, the scavenging portion of the model was fit to reproduce the measured decrease in nickel and copper concentrations.

Other chemical processes within the system reinforce the removal of metals and stability of the HTDF system. There is a continuous flow of DO from the surface into the HTDF, and mixing will bring some DO into contact with the lower HTDF compartments. Similarly, there is a

counter-acting flux of oxygen depleting chemicals from the base of the HTDF – and these oxygen depleting chemicals (such as reduced iron and bisulfide) are expected to counterbalance the downward flux of DO. Because the system is adequately buffered with considerable alkalinity from the discharge, the acids produced from the oxidation reactions should be effectively neutralized for a long period. This attribute of the system is particularly important for the sustained scavenging of metals by iron hydroxide within the HTDF.

In Table 5, the HTDF outlet concentrations predicted from the model are compared to PEL for discharge (PEL calculations are provided in Appendix E). None of the modeled outlet concentrations exceed the PEL, and in most cases the concentrations are more than an order of magnitude lower than the PEL.

The range of modeled chemical processes are based on the current understanding of bathymetry, climate, HTDF chemistry, and the estimated properties of the tailings as they are expected to be placed in the HTDF. However, the model may also be used as a way to track the progress and state of the HTDF during loading. At regular intervals during the loading, the modeling could be calibrated to observed conditions before and during loading, then used to refine projections for future performance. This may be particularly valuable during the period of loading, to refine predictions of long-term performance and to better understand loading conditions that tend to reduce long-term impacts.

7 Conclusions

This report presented a detailed assessment of the water chemistry characteristics of the HTDF. The assessment included an evaluation of the drainage basin, the HTDF bathymetry, climate, recent and current water chemistry, detailed evaluations of the thermal stability and stratification of the HTDF, and a detailed mass balance model used to estimate the water chemistry and flows that would be expected at the HTDF outlet to a WWTP.

Field measurements indicated that the HTDF exhibits stratification with respect to temperature, DO concentrations, and almost all dissolved chemical constituents; this is discussed extensively in this report.

An extensive effort was placed on the development and testing of a multi-compartment, heat and mass balance model, which was used to estimate the expected water chemistry and flows at the HTDF outlet to the proposed WWTP. The model included a large set of processes, including dynamic and seasonal loading conditions, variable volumes, density and vertical stability of the discharge plume and HTDF compartments, and a variety of chemical mass balance modeling processes.

Important model outcomes include a predicted average outflow from the proposed WWTP of about 350 gpm during mill operation, with a maximum outflow of about 500 gpm. Volume predictions indicate that the tailings from the proposed mill will occupy about 22.5% of the current HTDF volume, and that water depth after the tailings are placed will be over one hundred feet. With proper control over tailings placement, the bottom waters of the HTDF will remain anoxic, and will continue to be anoxic after placement ceases, and a reserve of alkalinity will be present during and after mill operation

A key outcome of the multi-compartment mass balance model was that, during and after the period of the placement of mill tailings, the stratified behavior of the HTDF would likely be sustained. This is a particularly important and reasonable conclusion, but one which follows from the nature of the placement of the tailings, internal processes which tend to reinforce stability, and conditions regarding the natural flows and bathymetry of the HTDF.

The placement of tails at a high slurry density and the preservation of a stratified HTDF generally leads to low surface concentrations at the HTDF outlet to a WWTP. Modeling included a conservative tracer test, which showed that the HTDF outlet concentrations would peak at roughly 3% of the discharge concentration, and only after a long loading period of 7 years. However, without internal processes to reduce the concentrations within the HTDF, several decades of washout may be needed to further reduce the concentrations of compounds that behave conservatively in the water column (compounds that are not complexed and not scavenged).

For a set of complexed metals, such as nickel, copper, mercury, and other metals, the concentrations at the HTDF outlet and within the HTDF are expected to be greatly reduced from metals complexation, precipitation, and scavenging by iron hydroxide. In addition, the levels for these constituents within the HTDF drop significantly after the period of tailings placement.

With current estimates of the PEL available for the constituents from the multi-component model, none of the modeled constituent concentrations for the HTDF outlet exceeded the PEL.

For nickel, copper, mercury, and selenium, the outlet concentrations were all well beneath the PEL.

A fully-mixed model was also developed to estimate maximum HTDF outflow concentrations. It is important to note that the fully-mixed case is a highly unlikely scenario, given the known stratification of the HTDF, the nature of placement, and chemical processes, such as metals scavenging, that tend to remove metals from the water column in the HTDF. The washout mechanism inherent in the fully-mixed model was tested using historical measurements of nickel, and was found to greatly over-predict outflow concentrations. The level of over-prediction is expected to be higher for the period of tailings loadings, since the model also assumes that the pore water associated with the tailings would also be fully mixed within the HTDF.

Nevertheless, the fully-mixed model predicted that nickel, copper and mercury will exceed discharge limits in almost all years of mill operation and for at least seven years after mill production ceases. Nickel, copper and mercury concentrations at the HTDF outlet exceeded the PEL, and selenium levels were near the PEL. However, these compounds would be removed by the proposed WWTP.

The dynamic, multi-compartment model was used to evaluate expected changes in HTDF water elevation with a steady flow rate through the proposed wastewater treatment facility. Modeling showed that normal annual variations and peak annual flows can be handled without large variations in the expected water elevation. Simulated water levels for average flow years were always less than 469.1 m (1539.1 ft). An alternative simulation of peak annual flows and steady outflow resulted in simulated water elevations less than 469.4 m (1540.0 ft). Although a 100-yr, 24-hr storm event is expected to raise the water elevation 1.21 ft, the maximum HTDF water level should always be significantly less than proposed berm height of 470.3 m (1543 ft).

Since the capacity of the proposed WWTP will be sized generously, even greater control of water elevations will be available. Periods of high natural inflow during the spring melt or heavier fall rains can be balanced by higher rates of wastewater treatment. In addition, WWTP operations may be scaled back or shut down during winter months, without significant reductions in the expected water quality of the wastewater treatment influent or to the available storage.

7.1 Recommendations

The main conclusion of this report is that the HTDF is expected to remain stratified during and after the proposed placement of mill tailings, and the constituent concentrations at the HTDF outlet are expected to never exceed the associated PEL. The following recommendations are made:

1. Provide wastewater treatment for the outflow of the HTDF in order to handle the metals concentrations under the fully-mixed case. While the fully-mixed case is likely unrealistic, the model outcomes may be referenced as a worst-case for the proposed placement plan. Treatment should be provided to meet the expected wastewater treatment discharge limits for nickel, copper and mercury, in particular. To accommodate maximum annual precipitation conditions, it is recommended that the WWTP be designed for a capacity of 510 gpm.

2. Provide routine monitoring of the mill tailings carriage water, the HTDF bathymetry, and water quality within the HTDF. It is important to note that, due to the large scale of the HTDF and expected continuation of stratification, the time-scale of a response from the point of tailings placement to the proposed wastewater treatment influent is on the order of years. The following basic elements of monitoring plan are recommended:

    a. Indicators of the composition and density of mill tailings carriage water (such as conductivity and selected metals concentrations) should be sampled routinely, and there should be continuous monitoring of temperature near the point of mill tailings discharge. The sampling frequency for the carriage water composition can be developed according to expected variations in mill operation and ore quality. The main purpose of this monitoring is to develop a controls strategy, which may include regulated placement of mill tailings and associated pore water at or above set densities. Discharges of mill tailings or pore water with densities significantly below the density of the lower HTDF water should be avoided.
    b. During the period of tailings loading to the HTDF, water quality monitoring should occur at two horizontal locations, with field parameters collected at 5 ft intervals beginning at the surface. Vertical sampling intervals for selected chemical parameters should be set to capture the water composition at the surface, above and below the thermocline and above and below the chemocline. The main purpose of water quality monitoring within the HTDF is to track trends in water quality and to refine projections of expected water quality at the proposed wastewater treatment influent. The frequency of chemical monitoring should be more frequent over the first two years, but may be reduced upon effective demonstration of water quality projections.
    c. Outflow and water level information within the HTDF should be monitored to support planning for seasonal flows, particularly for the management of spring melt conditions. Basic climatological information such as snow pack, ice thickness, precipitation, and air temperature can be drawn from direct measurements at the HTDF site as well as from the Champion-Van Riper weather station. The frequency of site monitoring may be monthly during the first several years of operation, but may be reduced upon effective demonstration of water level and flow balance predictions.

3. Within contingency plans for the HTDF, include options such as treatment with coagulants (such as ferric salt or alum) to remove suspended solids and metals within the HTDF by adsorption, coagulation, and flocculation. Effective removal of the chemical constituents from the water column may be a cost-effective approach to meeting and sustaining constituent concentrations below discharge standards. Steps such as these are likely to reduce the time required to operate a WWTP for the period following the active placement of mill tailings.

This report has identified the use of the multi-compartment model, largely to provide estimates of the expected concentrations at the HTDF outlet. However, the model may also be used as a way to track the progress and state of the HTDF during loading. The modeling could be refined from regular calibration to observed conditions during loading, then used to refine projections for future performance.

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Tables

Table 1

Expected Climate at Humboldt Mill

Month	Precipitation				Temperature Normals [1]		
	Normal [1] (in.)	High [2] (in.)	Low [2] (in.)	Evaporation [3] (in.)	max. (°F)	min. (°F)	mean (°F)
Jan	1.82	4.74	0.48	0.15	22.4	0.2	11.3
Feb	1.32	3.53	0.24	0.30	28.2	2.1	15.2
Mar	2.32	4.43	0.52	0.89	38.2	11	24.6
Apr	2.42	7.42	0.76	1.33	51.9	23.4	37.7
May	3.10	6.77	0.17	1.63	67.1	35.3	51.2
Jun	3.35	8.54	1.00	2.07	74.6	44.3	59.5
Jul	3.80	7.50	0.90	2.81	78.8	49.7	64.3
Aug	3.74	8.92	0.48	2.66	76.6	48.4	62.5
Sep	3.88	9.89	0.75	1.77	67.1	41.2	54.2
Oct	3.29	6.41	0.77	0.74	55.1	31.8	43.5
Nov	2.44	5.61	0.71	0.30	38.3	20.5	29.4
Dec	1.82	3.38	0.28	0.15	26.3	7.4	16.9
Annual	33.3	46.94	20.17	14.78	52.1	26.3	39.2

Prepared by: GRE
Checked by: CED1

Notes:

1. Precipitation and temperature 1971-2000 NCDC Normals for Station 201439, Champion - Van Riper Park, Michigan. Obtained from Midwest Regional Climate Center.
2. Monthly precipitation extremes, 1949-2001 NCDC Precipitation Extremes for Station 201439, Champion - Van Riper Park, Michigan. Obtained from Midwest Regional Climate Center.
3. From average monthly pan evaporation data for Marquette County, Michigan, National Resources Conservation Service. Multiplied by 0.77 to obtain estimate for actual evaporation.

Table 2

Expected Mill Tailings Production Schedule

for Purposes of HTDF Mass Balance Model

Year	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Totals
Total Tails (dry)	tonnes	154,000	370,880	370,880	370,880	370,880	370,880	370,880	122,689	2,501,969
Expected Rate	tonnes/d	700	1159	1159	1159	1159	1159	1159	900	
Expected Timing	days	220	320	320	320	320	320	320	136.3	2276.3
	years	0.60	1	1	1	1	1	1	0.37	7.0
Discharge flow	m^3/d	754.1	1213	1213	1213	1213	1213	1213	953.9	
	gpm	138.3	222.5	222.5	222.5	222.5	222.5	222.5	175.0	
Reclaim flow	m^3/d	386.8	640.5	640.5	640.5	640.5	640.5	640.5	497.4	
	gpm	71.0	117.5	117.5	117.5	117.5	117.5	117.5	91.2	

Prepared by: GRE
Checked by: JBM

Notes:

1. Total ore production is expected to be 3,419,430 tonnes (wet). Total dry tonnes tails is expected from 6.78% moisture content and tailings content in ore of 78.13% (dry basis).
2. Discharge flow of mill tailings estimated from 60% solids, specific gravity of solids of 3.03, and assumption of complete saturation. Additional mill discharges (added to 60% solids stream) include truck wash and miscellaneous contact water at a flow of 10 gpm. Minor water or solids discharges from WWTP to HTDF were not considered in mass balance model.
3. Reclaim flow is water reclaimed from HTDF, a recycle stream brought back to mill for ore processing.

Table 3

Initial and Weighted Average Concentrations of Chemical Constituents in HTDF and Expected Mill Discharge

Analyte	HTDF Initial Conditions (ug/L)						Mill Discharge[1] (ug/L)
	Compartment					Weighted Average	
	1	2	3	4	5		
Aluminum							686
Antimony	8	8	9	35	42	17	-
Arsenic							11
Barium	8	8	8	9	11	9	15
Bicarbonate (CaCO3)	100,000	100,000	100,000	140,000	160,000	114,156	11,000
Boron	85	82	87	130	150	101	-
Cadmium							1
Calcium	47,000	46,000	48,000	49,000	49,000	47,905	114,000
Carbonate (CaCO3)							851,000
Chloride	12,000	12,000	12,000	22,000	26,000	15,432	50,667
Chromium							18
Cobalt	4	4	4	16	21	8	68
Copper	2	2	2	3	3	2	2,760
Fluorine							120
Iron	420	450	390	190	240	347	13,020
Lead							53
Lithium	3	4	3	4	4	3	-
Magnesium	24,000	23,000	24,000	28,000	29,000	25,141	10,010
Manganese	250	250	280	1,300	2,100	665	80
Mercury							0.2
Molybdenum	10	10	11	45	61	23	31
Nickel	14	13	17	210	280	82	2,203
Nitrogen, Ammonia				2,800	4,500		-
Nitrogen, Nitrate (N)	2,000	2,000	2,200	2,600	1,500	2,157	237
Nitrogen, Nitrite (N)							80
Potassium	8,100	7,800	8,200	17,000	20,000	11,091	15,333
Selenium							21
Silicon							18,567
Sodium	13,000	13,000	14,000	27,000	32,000	18,212	542,000
Strontium							96
Sulfate	130,000	130,000	140,000	170,000	180,000	147,803	81,667
Total Alkalinity (CaCO3)	100,000	100,000	100,000	140,000	160,000	114,156	900,000
Total Dissolved Solids	330,000	330,000	340,000	430,000	460,000	367,965	1,146,667
Total Suspended Solids							374,333
Zinc							70

Prepared by: JBM
Checked by: GRE

1. Drawn from testing of bench scale process water, see Appendix D.

Table 4

Expected Concentrations of Chemical Constituents in HTDF Outlet After 1, 3, 7, 10 and 14 Years of Operation, with Complete Mixing

Analytes	HTDF Concentration at End of Year (ug/L)					Preliminary Effluent Limit (ug/L)
	1	3	7	10	14	
Aluminum	20.2	59.9	135.4	106.8	77.9	NA
Antimony	16.4	14.8	11.9	9.4	6.8	130
Arsenic	0.3	0.9	2.1	1.6	1.2	150
Barium	8.6	8.7	8.8	7.0	5.1	1012
Bicarbonate (CaCO3)	109,501	99,728	81,156	64,040	46,700	NA
Boron	96.7	87.5	70.0	55.2	40.3	1900
Cadmium	0.03	0.09	0.19	0.15	0.11	8.4
Calcium	49,053	51,297	55,560	43,842	31,971	NA
Carbonate (CaCO3)	25,104	74,374	167,995	132,564	96,670	NA
Chloride	16,282	17,805	20,700	16,334	11,912	NA
Chromium	0.5	1.6	3.6	2.9	2.1	212
Cobalt	9.7	12.9	19.0	15.0	10.9	100
Copper	83.5	243.1	546.3	431.1	314.4	26
Fluoride	3.5	10.5	23.7	18.7	13.6	NA
Iron	715	1437	2809	2217	1617	NA
Lead	1.6	4.6	10.5	8.3	6.0	108
Lithium	3.3	3.0	2.4	1.9	1.4	96
Magnesium	24,306	22,596	19,347	15,266	11,133	NA
Manganese	646	590	482	380	277	3857
Mercury	0.01	0.02	0.04	0.03	0.02	0.0013
Molybdenum	22.8	22.5	22.0	17.4	12.7	3200
Nickel	144	264	492	388	283	111
Nitrogen, Nitrate (N)	2,056	1,874	1,529	1,207	880	NA
Nitrogen, Nitrite (N)	2.4	7.0	15.8	12.5	9.1	NA
Potassium	11,090	10,964	10,723	8,462	6,170	NA
Selenium	0.6	1.9	4.2	3.3	2.4	5
Silicon	548	1,623	3,665	2,892	2,109	NA
Sodium	33,438	63,154	119,619	94,391	68,833	NA
Strontium	2.8	8.4	18.9	14.9	10.9	8300
Sulfate	143,466	134,744	118,171	93,248	68,000	NA
Total Alkalinity (CaCO3)	135,726	177,423	256,653	202,523	147,687	NA
Total Dissolved Solids	385,241	418,121	480,597	379,236	276,552	NA
Total Suspended Solids	11,043	32,715	73,897	58,311	42,523	NA
Zinc	2.1	6.2	13.9	11.0	8.0	484

Prepared by: JBM
Checked by: GRE

Notes:
1. PEL calculations are provided in Appendix E

Table 5

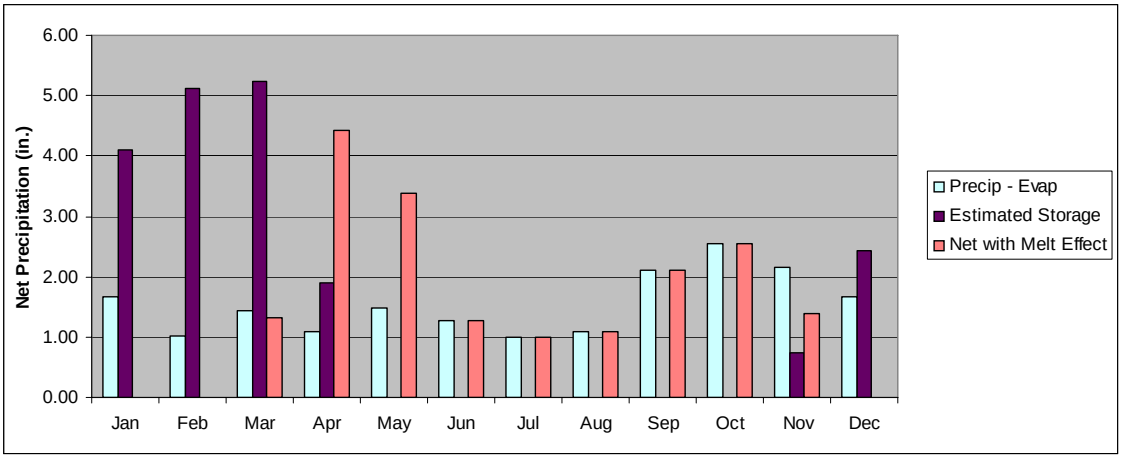
Expected Concentrations of Chemical Constituents in HTDF Outlet After 1, 3, 7, 10 and 14 Years of Operation, with Multi-Compartment Model

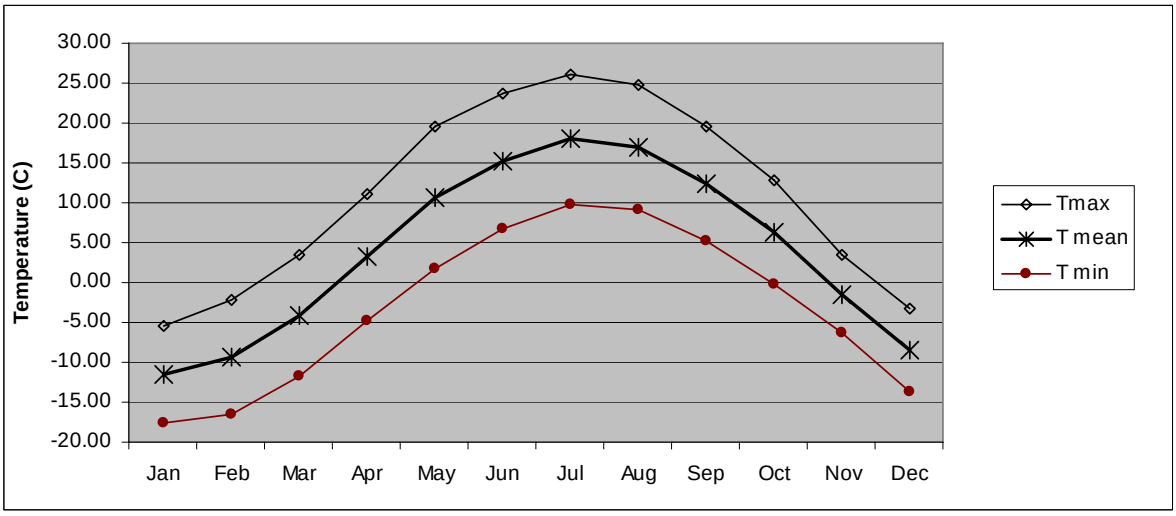
Analytes	Background Concentration	Expected Concentration in HTDF Outlet and Wastewater Treatment Influent at End of Year (ug/L)					Preliminary Effluent Limit
	(ug/L)	1	3	7	10	14	(ug/L)
Aluminum	<0.1	<0.1	0.2	0.2	<0.1	<0.1	NA
Ammonia (as N)	<10	<10	<100	<350	<320	<320	NA
Antimony	<0.1	7.7	8.5	10.4	10.0	9.9	130
Arsenic	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	150
Barium	8	8.0	8.1	8.4	8.5	8.6	1012
Boron	80	83	84	87	86	85	1900
Cadmium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8.4
Calcium	47,000	46,700	47,200	48,900	49,700	50,700	NA
Chloride	12,000	12,000	12,400	13,900	14,100	14,600	NA
Chromium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	212
Cobalt	3	2.1	1.8	1.2	1.0	0.7	100
Copper	2.0	1.2	1.5	1.7	0.8	0.5	26
Fluoride	<0.1	<0.1	0.1	1.8	2.8	4.0	NA
Iron	450	390	500	410	290	270	NA
Lead	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	108
Lithium	3.5	3.5	3.5	3.5	3.5	3.5	96
Magnesium	24,000	23,600	24,000	24,400	24,500	24,500	NA
Manganese	250	155	139	92	79	58	3857
Mercury	0.0005	0.0003	0.0003	0.0002	0.0002	0.0001	0.0013
Molybdenum	10	6.2	5.4	3.6	3.2	2.3	3200
Nickel	5.0	6.6	6.5	5.6	1.8	1.1	111
Nitrogen, Nitrate (N)	2000	2000	2200	2400	2400	2400	NA
Potassium	8100	8020	8390	9310	9320	9460	NA
Selenium	<0.1	<0.1	<0.1	0.3	0.48	0.70	5
Sodium	13,000	13,100	14,100	23,100	27,000	32,500	NA
Strontium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	8300
Sulfate	130,000	131,000	134,000	137,000	137,000	137,000	NA
Total Alkalinity (CaCO3)	100	100	101	117	124	131	NA
Total Dissolved Solids	200	294	278	288	281	282	NA
Zinc	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	484

Prepared by: GRE
Checked by: JBM

Notes:
1. PEL calculations are provided in Appendix E

Figures





Month	Precip. (in.)	Evap. (in.)	Precip-Evap (in.)	Percent Storage	Storage (in.)	Net (in.)	Net (mm)
Jan	1.82	0.15	1.67	100%	4.09	0	0
Feb	1.32	0.30	1.02	100%	5.12	0	0
Mar	2.32	0.89	1.43	80%	5.24	1.31	33.3
Apr	2.42	1.33	1.09	30%	1.90	4.43	112.6
May	3.10	1.63	1.47	0%	0.00	3.37	85.7
Jun	3.35	2.07	1.28	0%	0	1.28	32.5
Jul	3.80	2.81	0.99	0%	0	0.99	25.2
Aug	3.74	2.66	1.08	---	0	1.08	27.4
Sep	3.88	1.77	2.11	0%	0	2.11	53.5
Oct	3.29	0.74	2.55	0%	0	2.55	64.8
Nov	2.44	0.30	2.14	35%	0.75	1.39	35.4
Dec	1.82	0.15	1.67	100%	2.42	0	0
Annual	33.3	14.78	18.52			18.52	470.3

Simulated net precipitation from 1971-2000 NCDC monthly normal precipitation at Champion - Van Riper Park, Michigan and NRCS monthly normal evaporation data from Marquette Co., Michigan. Ice and snowpack storage is estimated based on temperatures and typical seasonal snowpack. Sublimation ignored.

Net water in any month (W) is found by :

$W_i = (1-F_i) \times (P_i-E_i+S_{i-1})$

where F is the percent storage by snow or ice,
P is the precipitation, E is the evaporation, and S_{i-1} is the storage from the prior month.

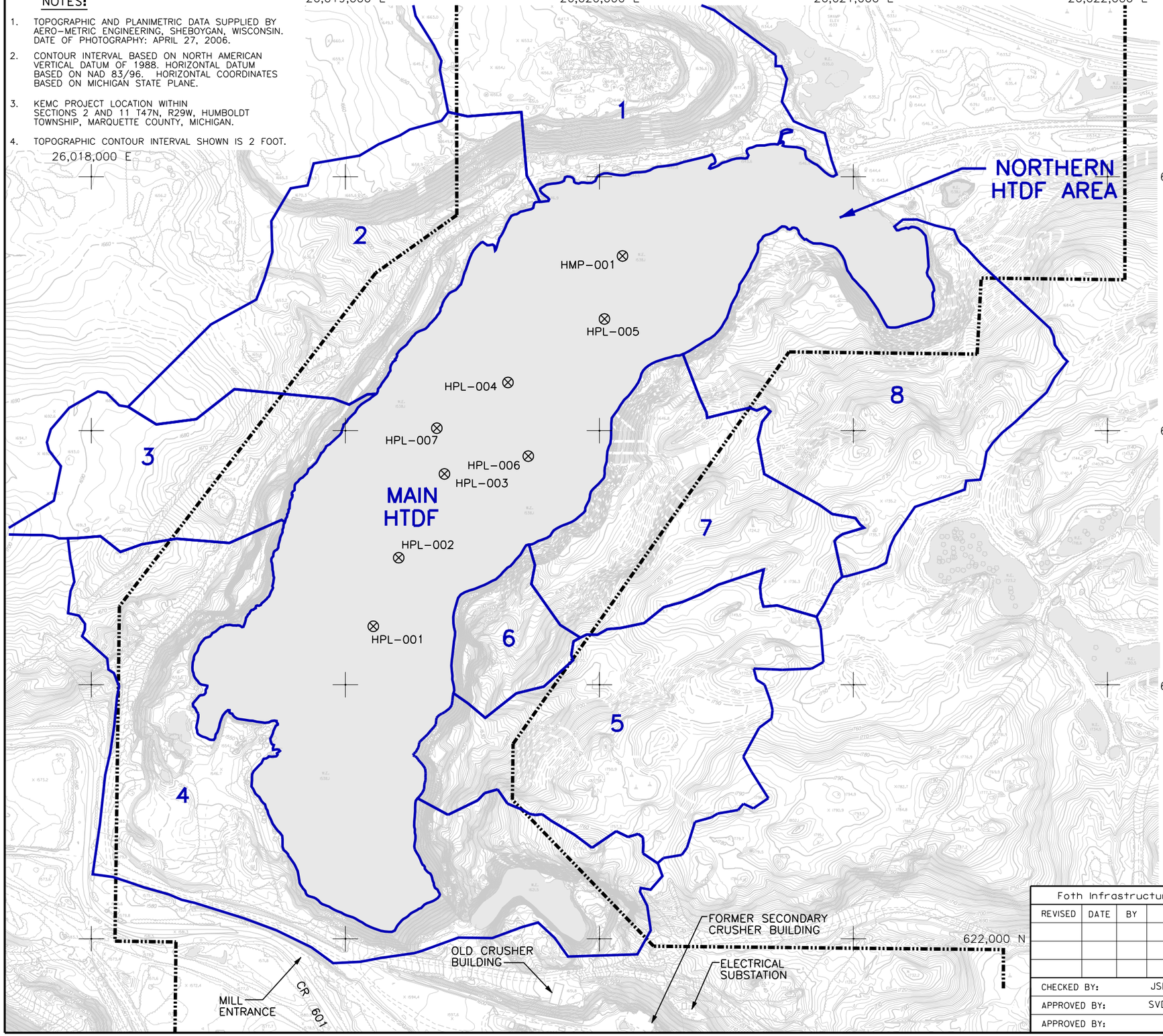
Foth Infrastructure & Environment, LLC				Kennecott Eagle Minerals	
REVISED		BY	DESCRIPTION	FIGURE 1	
				NORMAL MONTHLY CLIMATE FOR HTDF	
CHECKED BY: JBM			DATE: OCT '07	Scale: NA	Date: OCTOBER 2007
APPROVED BY: JBM			DATE: OCT '07	Prepared by: GRE	Project No: 06W003
APPROVED BY:			DATE:		

Foth Infrastructure & Environment, LLC

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NOTES:

1. TOPOGRAPHIC AND PLANIMETRIC DATA SUPPLIED BY AERO-METRIC ENGINEERING, SHEBOYGAN, WISCONSIN. DATE OF PHOTOGRAPHY: APRIL 27, 2006.
2. CONTOUR INTERVAL BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988. HORIZONTAL DATUM BASED ON NAD 83/96. HORIZONTAL COORDINATES BASED ON MICHIGAN STATE PLANE.
3. KEMC PROJECT LOCATION WITHIN SECTIONS 2 AND 11 T47N, R29W, HUMBOLDT TOWNSHIP, MARQUETTE COUNTY, MICHIGAN.
4. TOPOGRAPHIC CONTOUR INTERVAL SHOWN IS 2 FOOT.



LEGEND

- BUILDING
- PAVED ROAD
- UNPAVED ROAD
- STREAM/LAKE
- SURFACE WATER
- KEMC PROJECT LOCATION
- WATERSHED BOUNDARY
- ⊗ HPL-006 — SURFACE WATER SAMPLE NUMBER AND LOCATION

NOTES:

1. WATERSHED DELINEATION WAS PREPARED WITH ARCGIS, USING DEM FROM AERIAL SURVEY. WATERSHED BOUNDARIES WERE THEN ADJUSTED MANUALLY TO COINCIDE WITH TOPOGRAPHIC CONTOURS PREPARED FROM THE SAME SURVEY.
2. SUBBASINS WERE NUMBERED ARBITRARILY. AREA PORTIONS OF SUBBASINS 1 AND 8 DRAINING TO NORTHERN HTDF AREA WERE ESTIMATED FROM SUBBASIN TOPOGRAPHY.
3. VALUES IN TABLE (BELOW) ARE REVISED FROM THOSE PRESENTED IN THE TEXT SECTION 2.2. SEE ADDENDUM OF THIS REPORT.

SUBBASIN	AREA			
	(SQ. FT.)	(SQ. M.)	(%)	
1	958238	89023	14.0	9.8
2	915913	85091	13.3	9.4
3	558593	51895	8.1	5.7
4	1408000	130807	20.5	14.4
5	966815	89820	14.1	9.9
6	195722	18183	2.9	2.0
7	761993	70791	11.1	7.8
8	1101164	102301	16.0	11.3
SUBTOTAL	6866438	637913	100.0	70.3
	(157.63 AC)	(63.79 HA)		
MAIN HTDF AREA	2656929	246837	91.6	27.2
NORTHERN HTDF AREA	242928	22569	8.4	2.5
TOTAL HTDF AREA	2899857	269406	100.0	29.7
	(66.57 AC)	(26.94 HA)		
TOTAL BASIN	9766295	907319	—	100.0
	(224.20 AC)	(90.73 HA)		

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APPROVED BY:	SVD1	DATE: NOV. '07
APPROVED BY:		DATE:

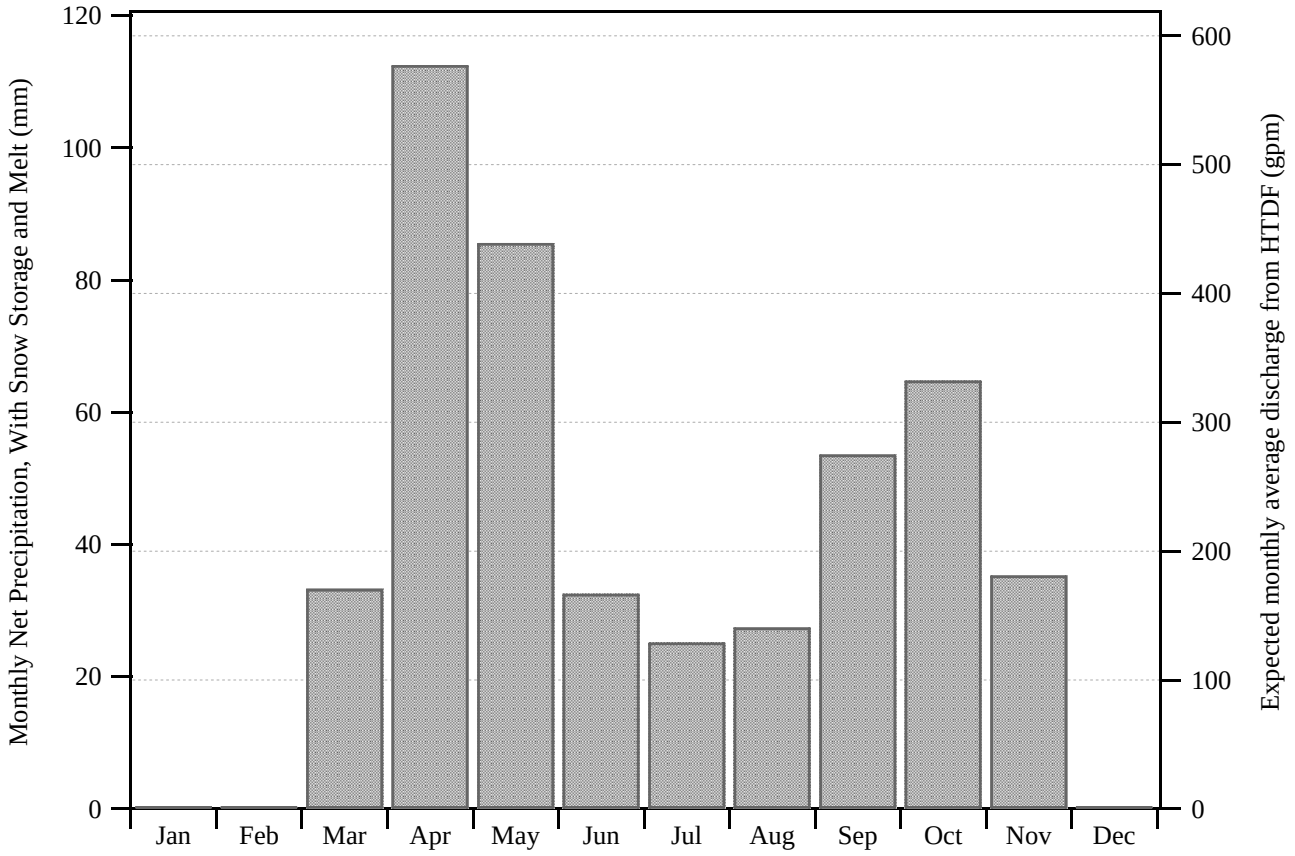
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FIGURE 2

HUMBOLDT MILL
EXPECTED HTDF DRAINAGE BASIN
FOR MASS BALANCE MODELING

Scale: 0 200' 400'
Date: NOVEMBER, 2007
Prepared By: JOW
Project No. 06W003

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9/2/2008 jrb2



Month	Precip. (in.)	Evap. (in.)	Precip-Evap (in.)	Percent Storage	Storage (in.)	Net (in.)	Net (mm)
Jan	1.82	0.15	1.67	100%	4.09	0	0
Feb	1.32	0.30	1.02	100%	5.12	0	0
Mar	2.32	0.89	1.43	80%	5.24	1.31	33.3
Apr	2.42	1.33	1.09	30%	1.90	4.43	112.6
May	3.10	1.63	1.47	0%	0.00	3.37	85.7
Jun	3.35	2.07	1.28	0%	0	1.28	32.5
Jul	3.80	2.81	0.99	0%	0	0.99	25.2
Aug	3.74	2.66	1.08	---	0	1.08	27.4
Sep	3.88	1.77	2.11	0%	0	2.11	53.5
Oct	3.29	0.74	2.55	0%	0	2.55	64.8
Nov	2.44	0.30	2.14	35%	0.75	1.39	35.4
Dec	1.82	0.15	1.67	100%	2.42	0	0
Annual	33.3	14.78	18.52			18.52	470.3

Simulated net precipitation from 1971-2000 NCDC monthly normal precipitation at Champion - Van Riper Park, Michigan and NRCS monthly normal evaporation data from Marquette Co., Michigan. Ice and snowpack storage is estimated based on temperatures and typical seasonal snowpack.

Basin flow rate calculated from net precipitation, basin area of 857,628 m^2, average of 30.67 days per month for 9 month period, and units conversion (5.451 m^3/d = 1 gpm). Flow dampening due to lake elevation changes ignored.

Outflow estimate shown in plot (above) does not consider the expected average annual groundwater inflow of 43 gpm.

Net water in any month (W) is found by :

$W_i = (1-F_i) \times (P_i-E_i+S_{i-1})$

where F is the percent storage by snow or ice, P is the precipitation, E is the evaporation, and S_{i-1} is the storage from the prior month.

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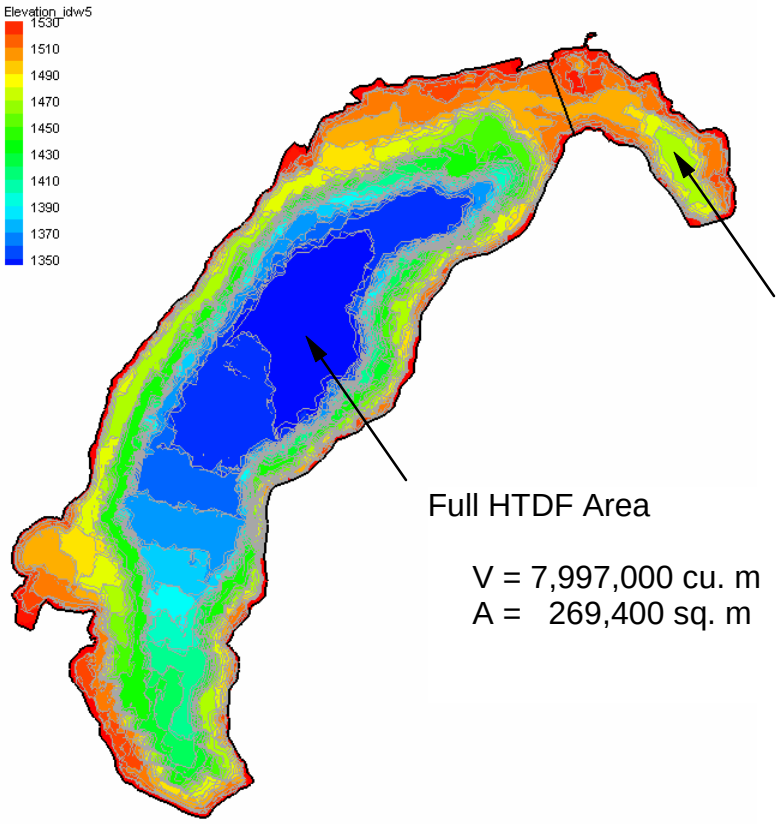
Kennecott Eagle Minerals

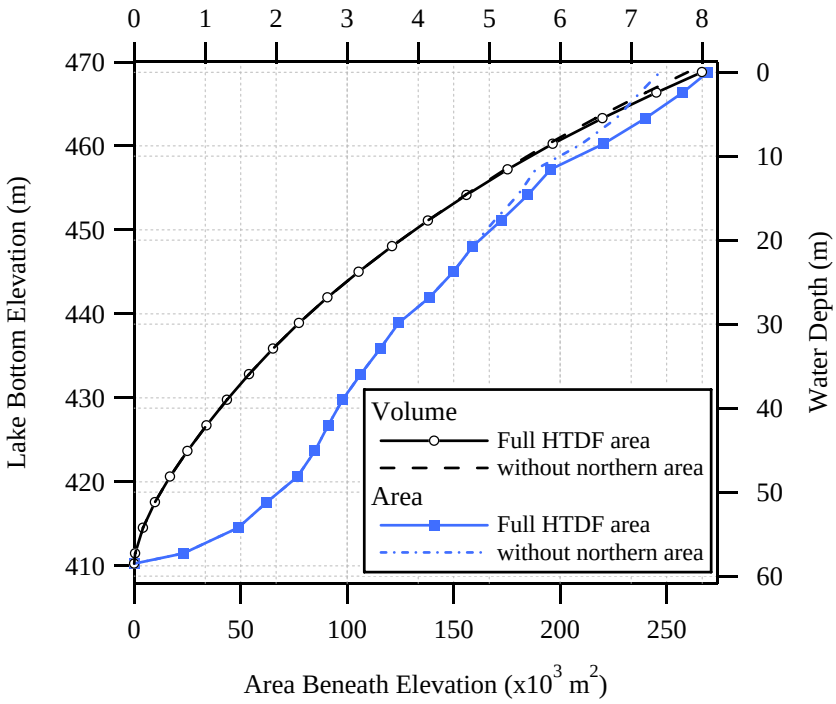
FIGURE 3

NET PRECIPITATION AND HTDF BASIN DISCHARGE - EXISTING CONDITIONS

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

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Water Depth		Elevation		Full HTDF Area		Without Northern Area	
				Bed Area	Volume	Bed Area	Volume
(ft)	(m)	(ft)	(m)	(m^2)	(m^3)	(m^2)	(m^3)
0	0	1538	468.78	269400	7997216	246831	7797434
8	2.44	1530	466.34	257504	7354816	237529	7206804
18	5.49	1520	463.30	240089	6596485	226432	6499727
28	8.53	1510	460.25	220408	5894689	210189	5834317
38	11.58	1500	457.20	195514	5260824	188546	5226646
48	14.63	1490	454.15	184789	4681243	180144	4664763
58	17.68	1480	451.10	172269	4137087	169185	4132386
68	20.73	1470	448.06	159005	3632225	159005	3632225
78	23.77	1460	445.01	149840	3161544	149840	3161544
88	26.82	1450	441.96	138674	2721849	138674	2721849
98	29.87	1440	438.91	124181	2321258	124181	2321258
108	32.92	1430	435.86	115561	1955892	115561	1955892
118	35.97	1420	432.82	106376	1617661	106376	1617661
128	39.01	1410	429.77	97813	1306477	97813	1306477
138	42.06	1400	426.72	91053	1018646	91053	1018646
148	45.11	1390	423.67	84843	750580	84843	750580
158	48.16	1380	420.62	76693	504399	76693	504399
168	51.21	1370	417.58	62281	292602	62281	292602
178	54.25	1360	414.53	48724	123429	48724	123429
188	57.30	1350	411.48	23047	14050	23047	14050
192	58.52	1346	410.26	0	0	0	0

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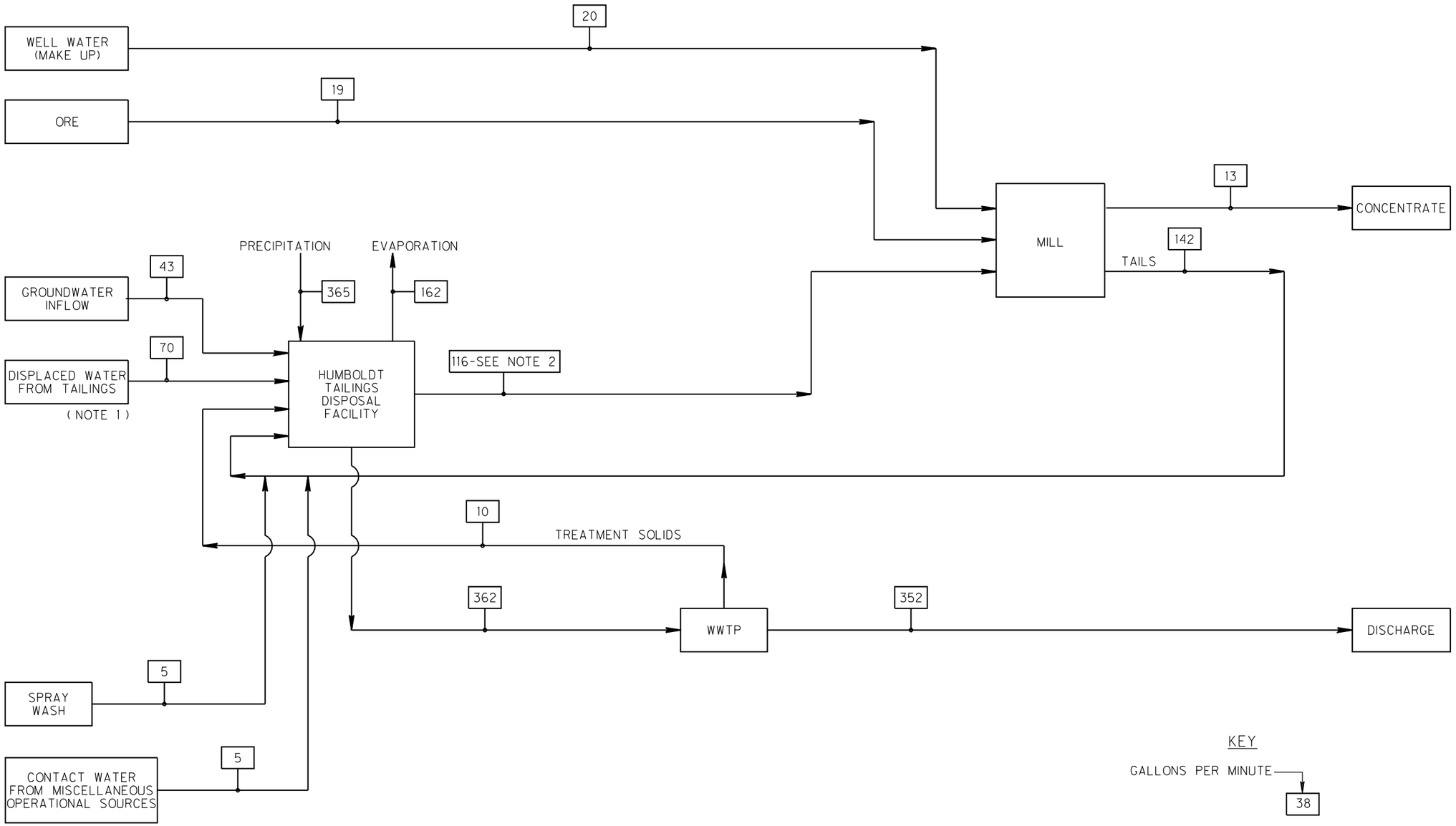
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FIGURE 4

HTDF EXISTING BATHYMETRY AND VOLUMETRIC RELATIONSHIPS

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

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NOTES:

1. THE DISPLACED WATER FROM THE TAILINGS IS THE VOLUME OF TAILINGS SOLIDS WHICH DISPLACES WATER FROM THE TAILINGS DISPOSAL FACILITY.
2. MAY VARY SLIGHTLY BASED ON OPERATIONAL REQUIREMENTS.

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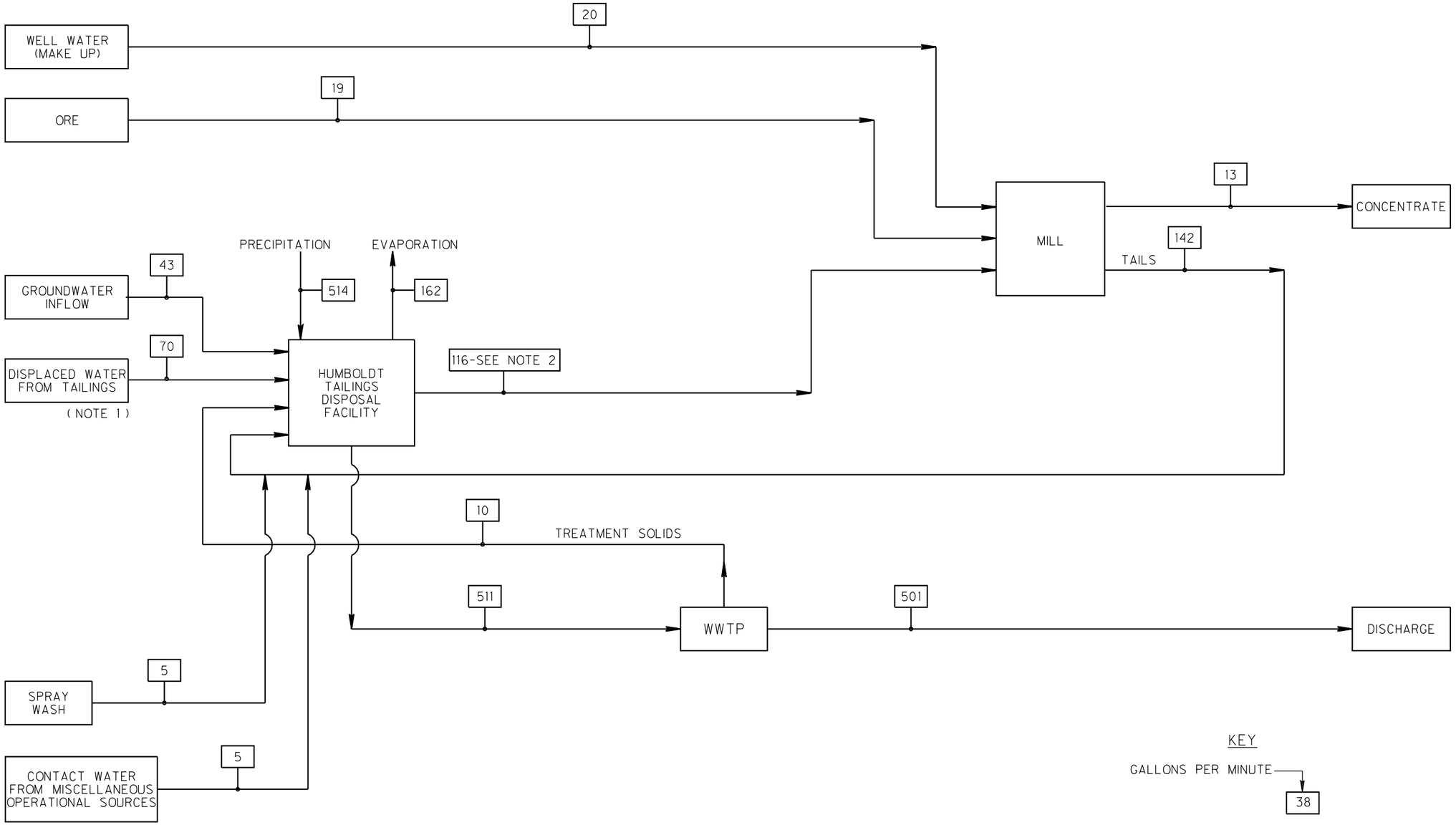
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APPROVED BY:	SVD1	DATE: NOV. '07
APPROVED BY:		DATE:

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FIGURE 5
WATER BALANCE - HTDF AVERAGE ANNUAL PRECIPITATION HUMBOLDT MILL PROJECT

Scale: NONE	Date: NOVEMBER, 2007
Prepared By: GJB	Project No. 06W003

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NOTES:

1. THE DISPLACED WATER FROM THE TAILINGS IS THE VOLUME OF TAILINGS SOLIDS WHICH DISPLACES WATER FROM THE TAILINGS DISPOSAL FACILITY.
2. MAY VARY SLIGHTLY BASED ON OPERATIONAL REQUIREMENTS.

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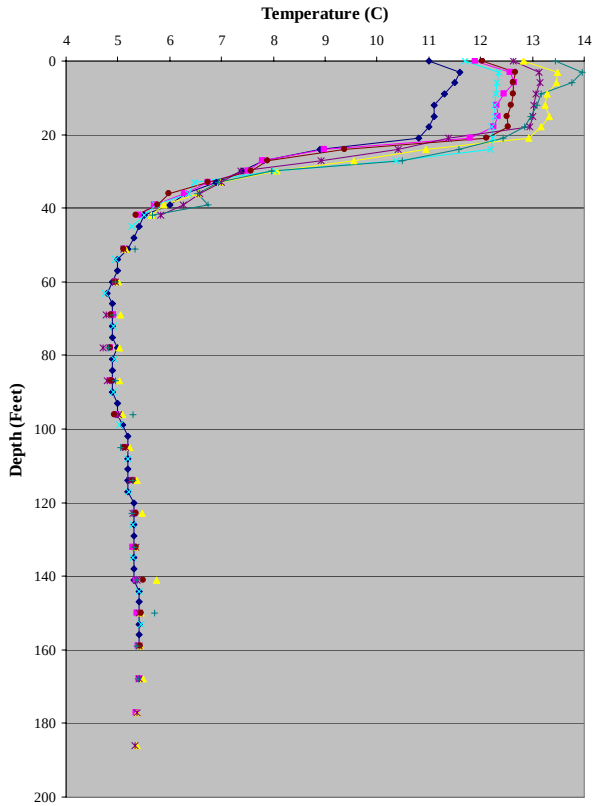
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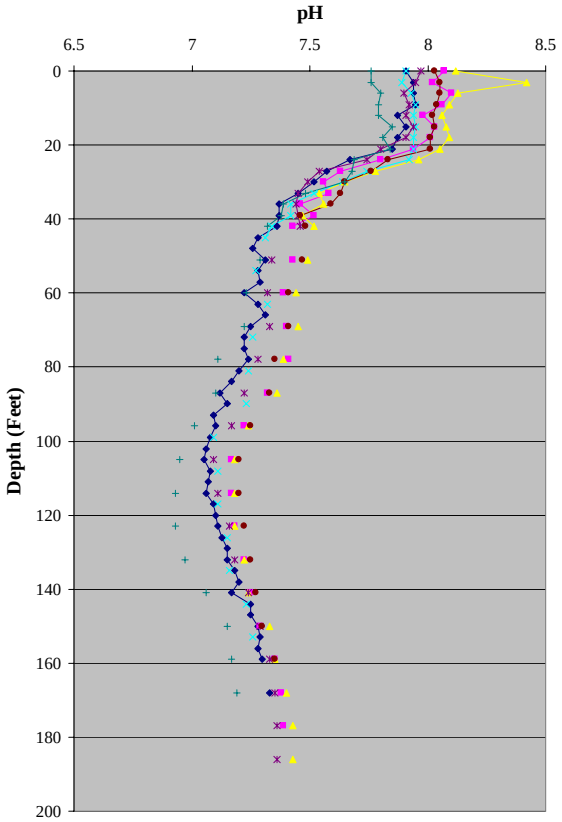
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FIGURE 6
WATER BALANCE - HTDF
MAXIMUM ANNUAL PRECIPITATION
HUMBOLDT MILL PROJECT

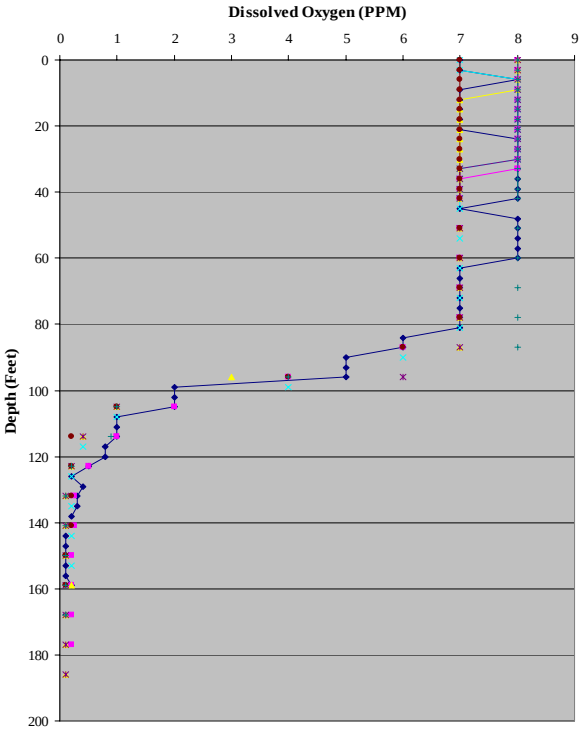
Scale: NONE	Date: NOVEMBER, 2007
Prepared By: GJB	Project No. 06W003

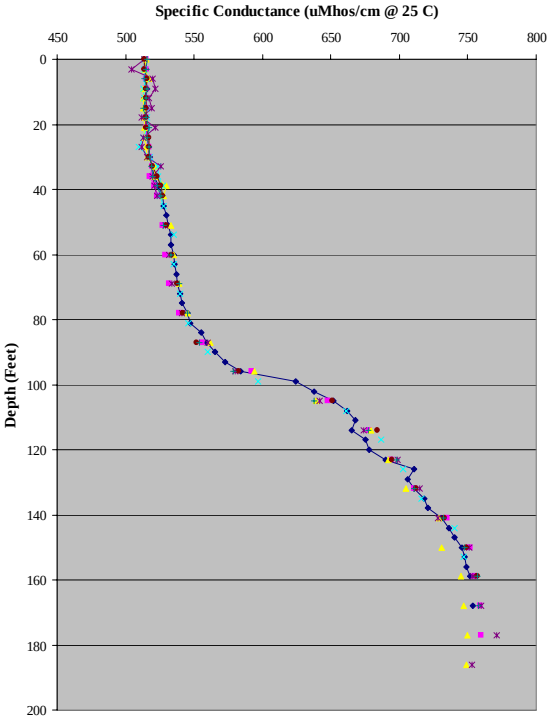
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collected
May 25, 2007

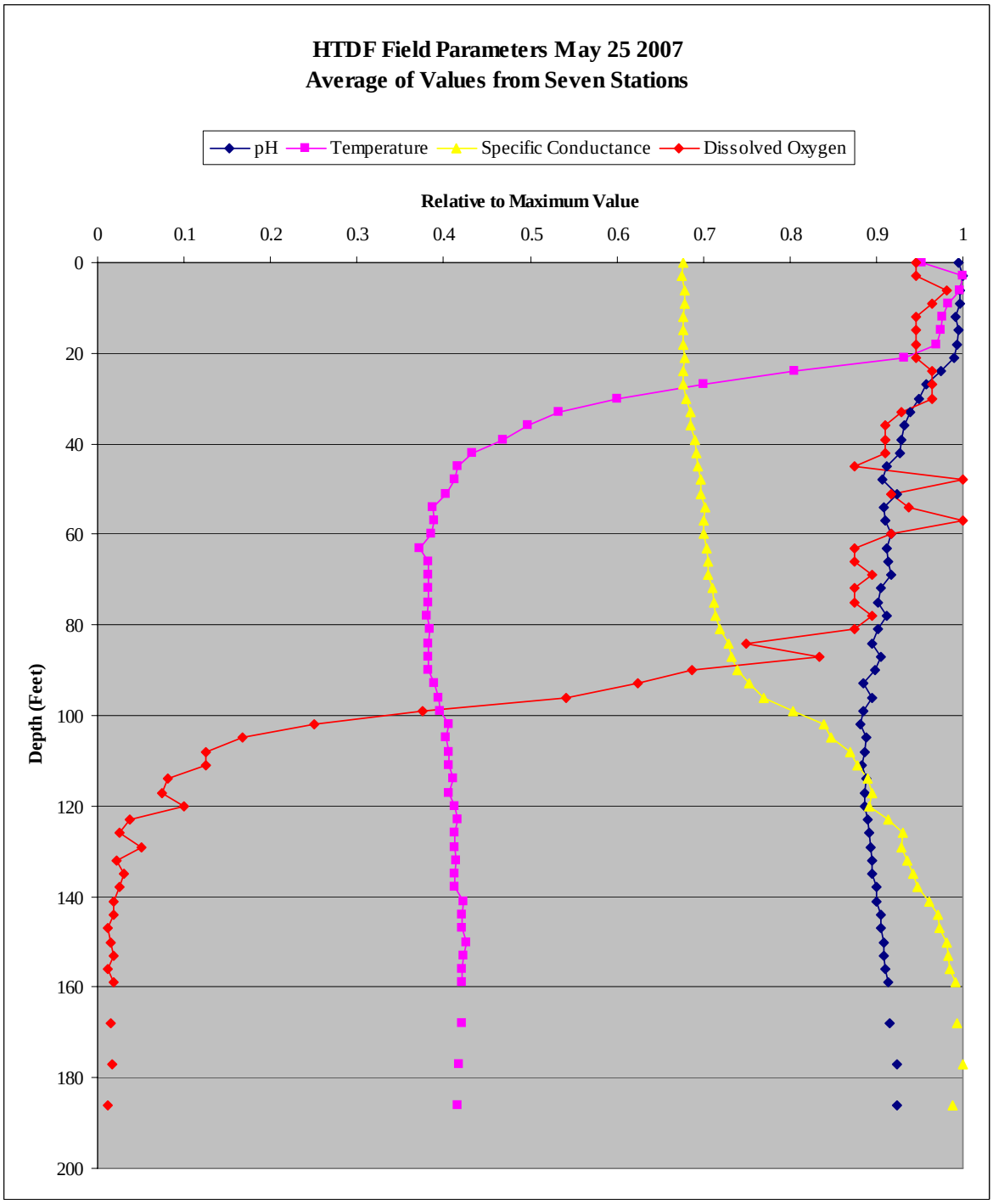




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				FIGURE 7
				HTDF VERTICAL PROFILE - SELECTED FIELD PARAMETERS
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APPROVED BY: GRE		DATE: OCT '07		Prepared by: JBM / Project No: 06W003
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Four HTDF field parameters at many water depths. Average at each depth from seven horizontal locations. Parameters are plotted relative to the maximum value for each parameter.

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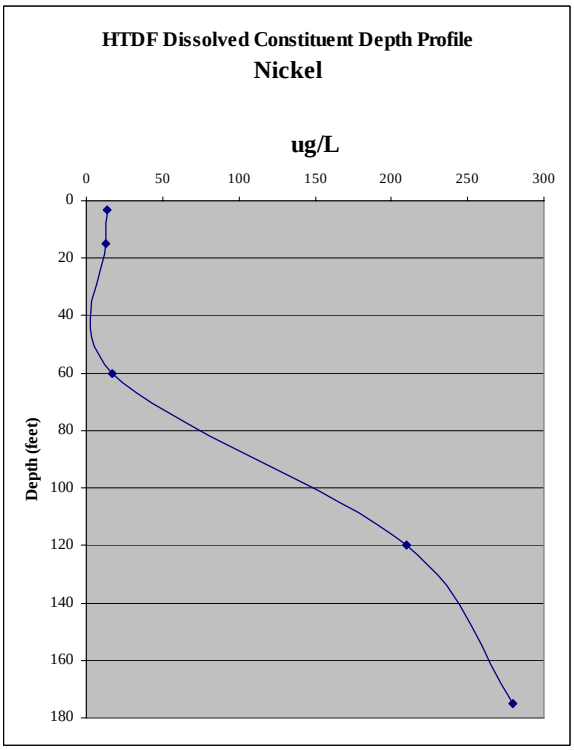
FIGURE 8

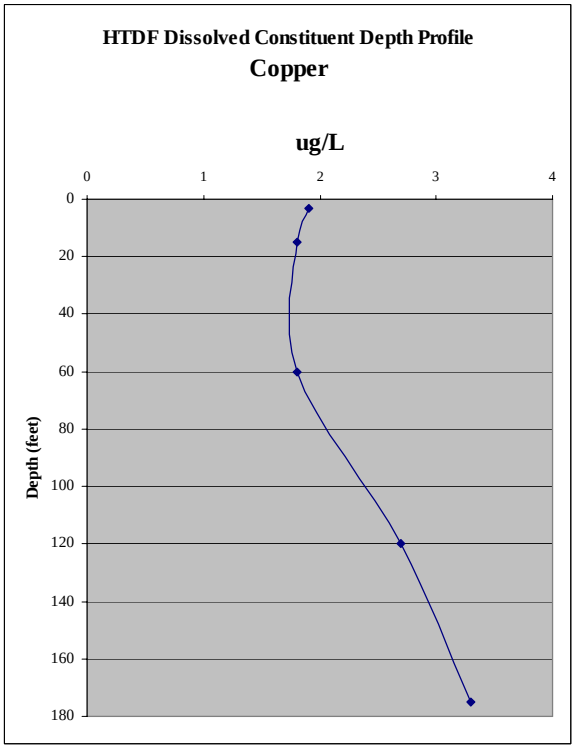
HTDF VERTICAL PROFILE - THERMOCLINE AND CHEMOCLINE

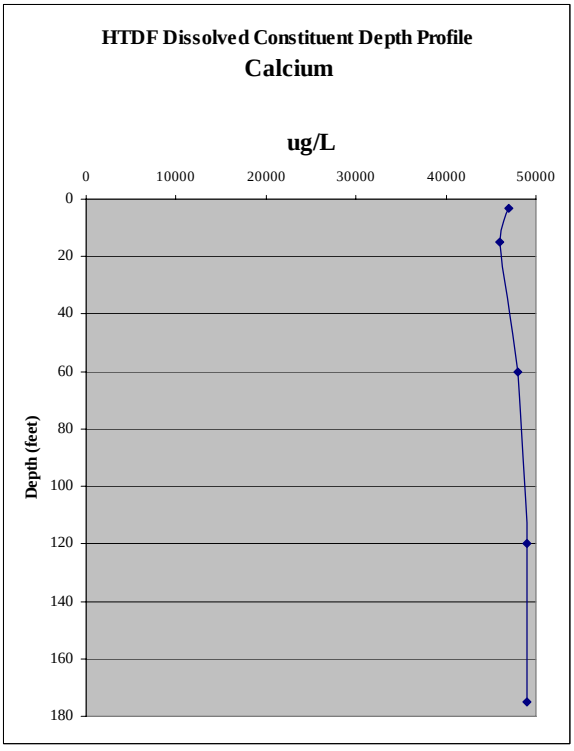
Scale:	NA	Date:	OCTOBER 2007
Prepared by:	JBM	Project No:	06W003

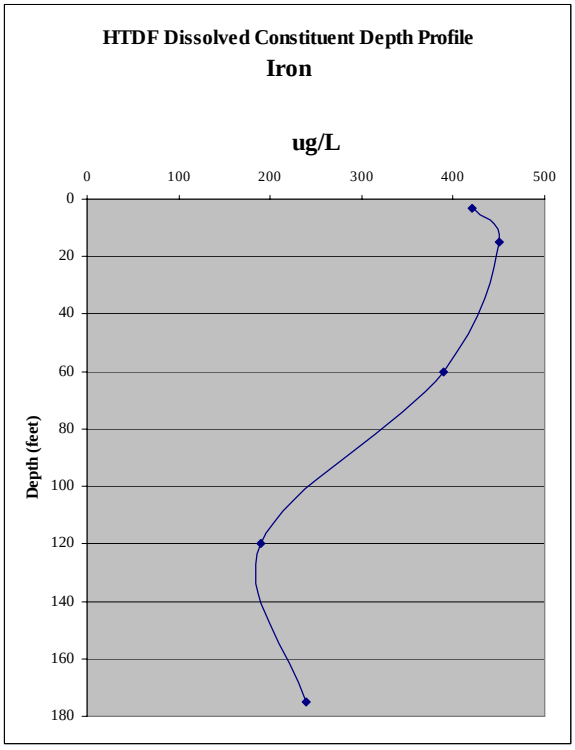
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Samples collected May 25, 2007

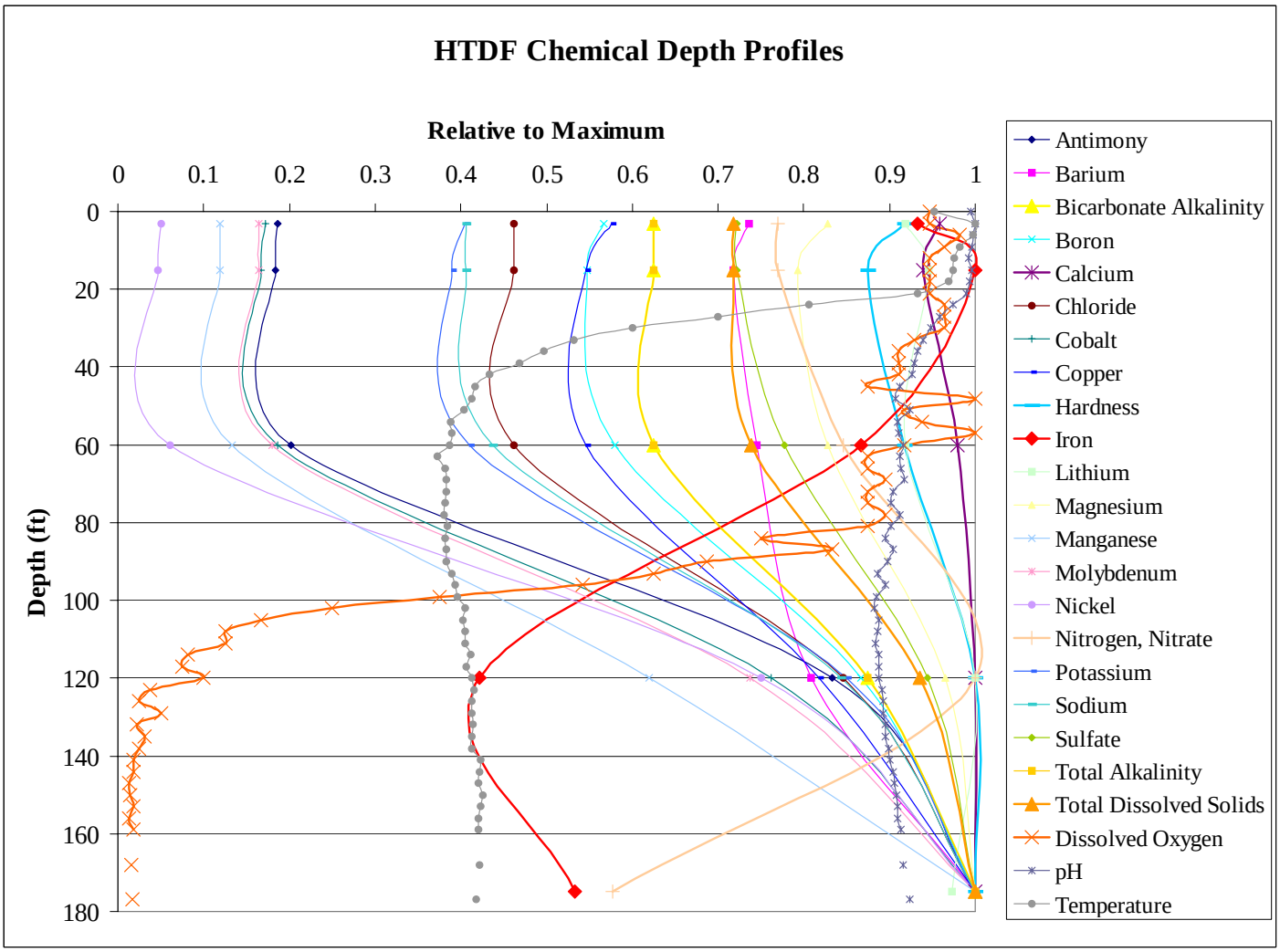
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FIGURE 9
HTDF VERTICAL PROFILE -
SELECTED CHEMICAL CONSTITUENTS

Scale:	NA	Date:	OCTOBER 2007
Prepared by:	JBM	Project No:	06W003

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Depth profiles for twenty-one chemical constituents and three field parameters measured in the HTDF. Parameters are plotted relative to the maximum value for each parameter. Samples collected May 25, 2007.

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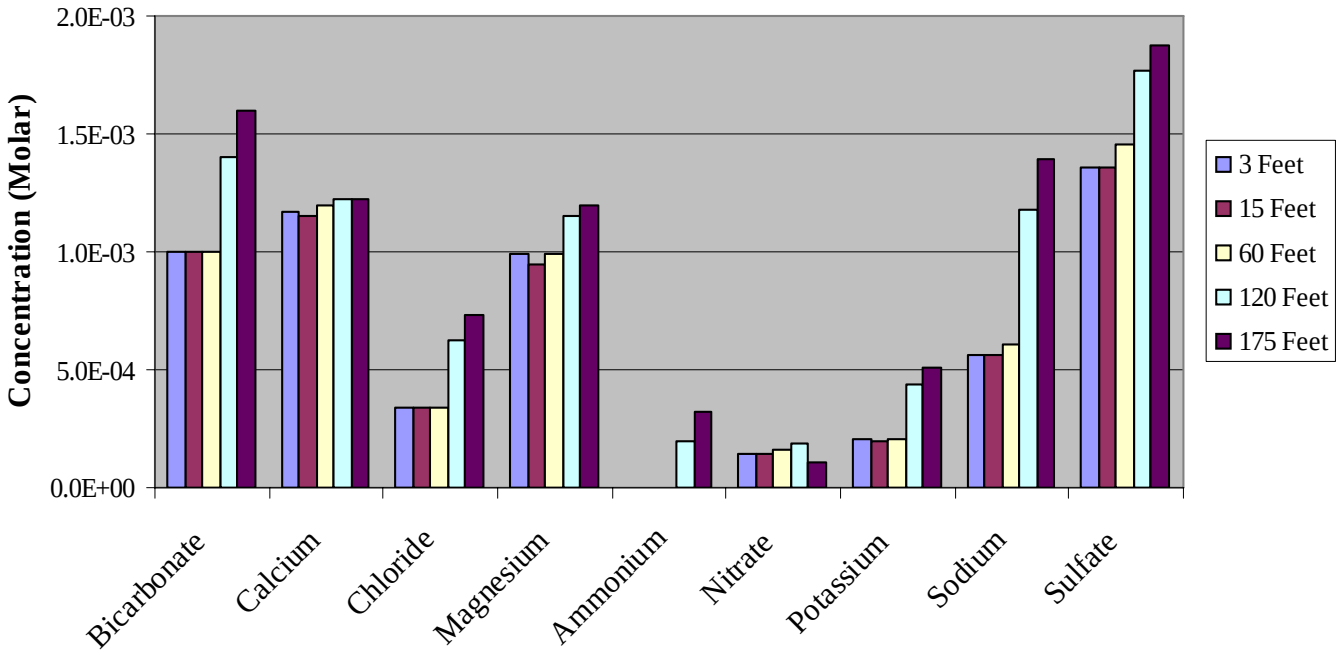
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FIGURE 10
HTDF VERTICAL PROFILE -
MULTIPLE CHEMICAL CONSTITUENTS

Scale:	NA	Date:	OCTOBER 2007
Prepared by:	JBM	Project No:	06W003

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HTDF Major Chemical Species At Five Depths - May, 2007



HTDF Intensity Parameters, Dissolved Oxygen And Water Temperature
Compartment Average July, 2007 (Molar Concentrations)

Compartment	Volume Fraction	pH	pε (25°C)	Ionic Strength	Dissolved Oxygen	Temperature (°C)
1	0.081	8.30	7.05	8.25×10^{-3}	2.7×10^{-4}	21.1
2	0.157	8.05	6.40	8.11×10^{-3}	3.0×10^{-4}	17.3
3	0.457	7.44	6.60	8.54×10^{-3}	2.7×10^{-4}	5.8
4	0.191	7.28	6.40	1.04×10^{-2}	1.2×10^{-5}	5.5
5	0.114	7.48	6.03	1.11×10^{-2}	2.9×10^{-6}	5.6
HTDF[1]	1	7.58	6.88	9.09×10^{-3}		

HTDF Alkalinity—May, 2007

Compartment	Volume (m^3)	Alkalinity (M)	Total (Tonnes $CaCO_3$)
1	646,000	9.97×10^{-4}	64
2	1,256,000	9.98×10^{-4}	125
3	3,657,000	9.99×10^{-4}	365
4	1,524,000	1.40×10^{-3}	213
5	914,000	1.60×10^{-3}	146
HTDF[1]	7,997,000	1.14×10^{-3}	914

[1]Values are sums or volume-weighted averages

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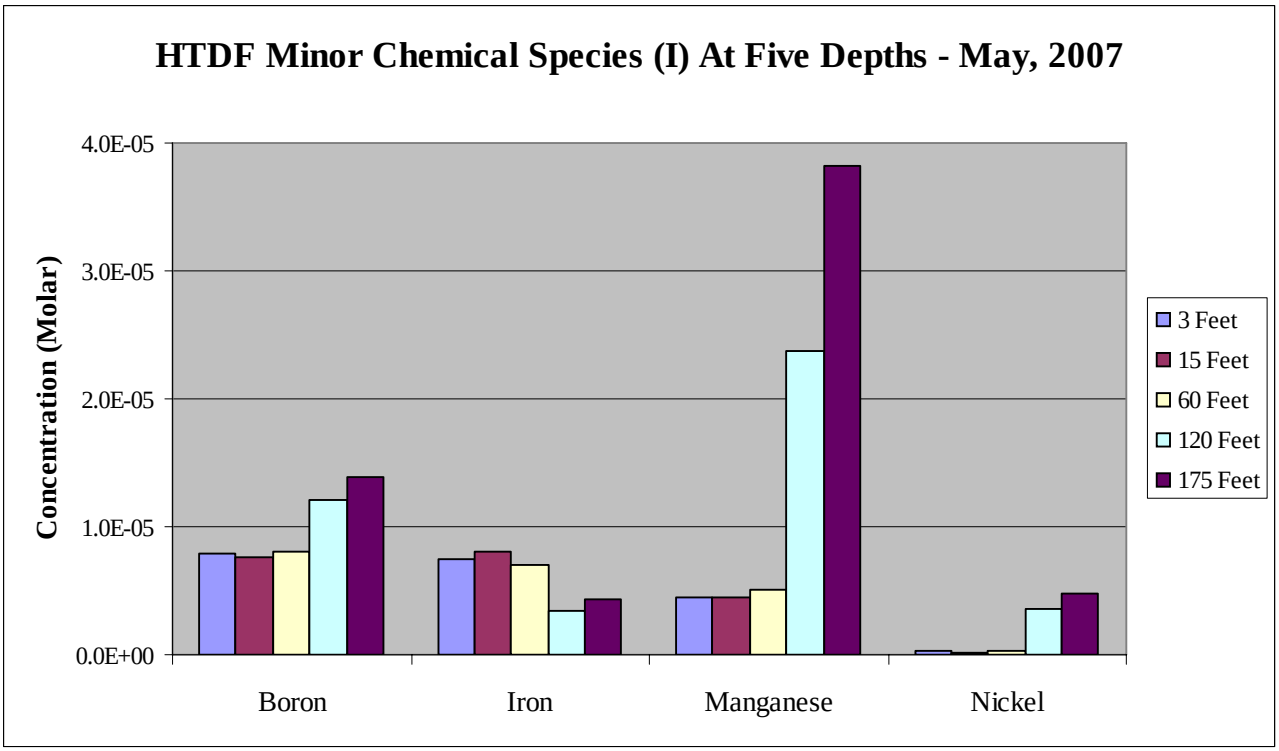
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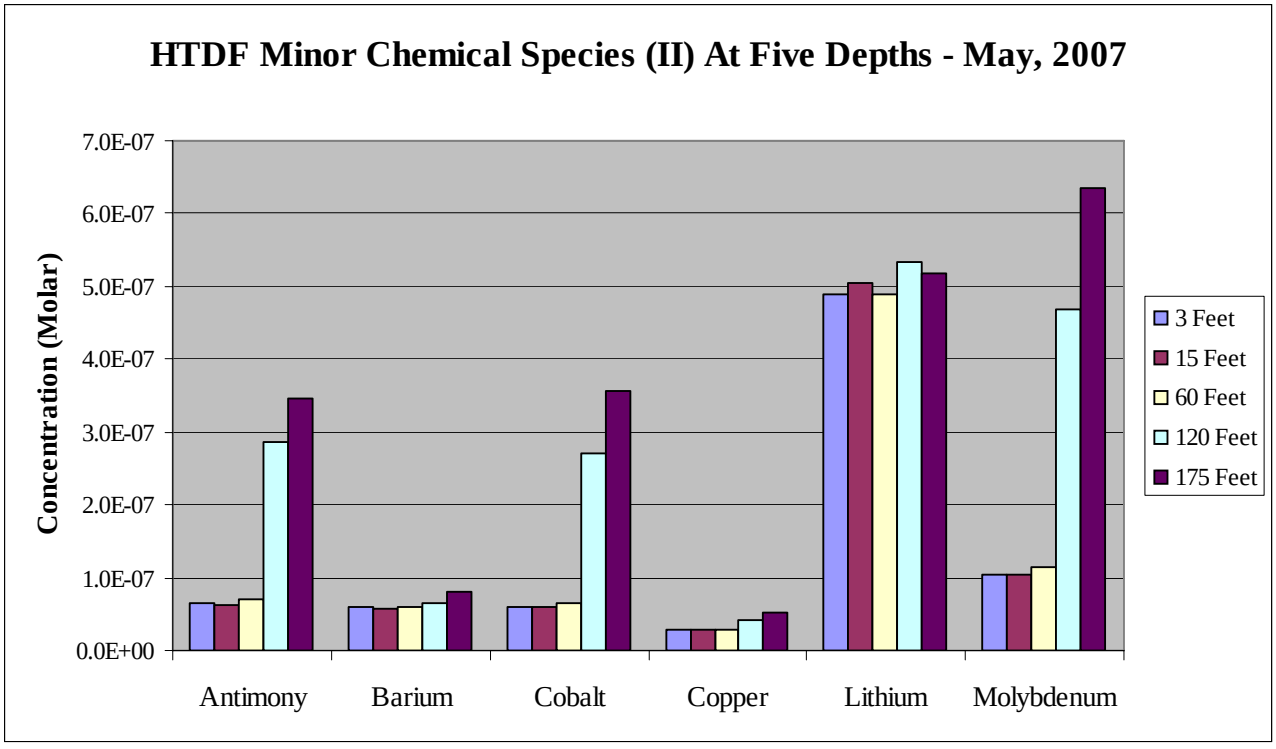
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FIGURE 11
HTDF MAJOR ELEMENT CONCENTRATIONS

Scale:	NA	Date:	SEPTEMBER 2007
Prepared by:	JBM	Project No:	06W003

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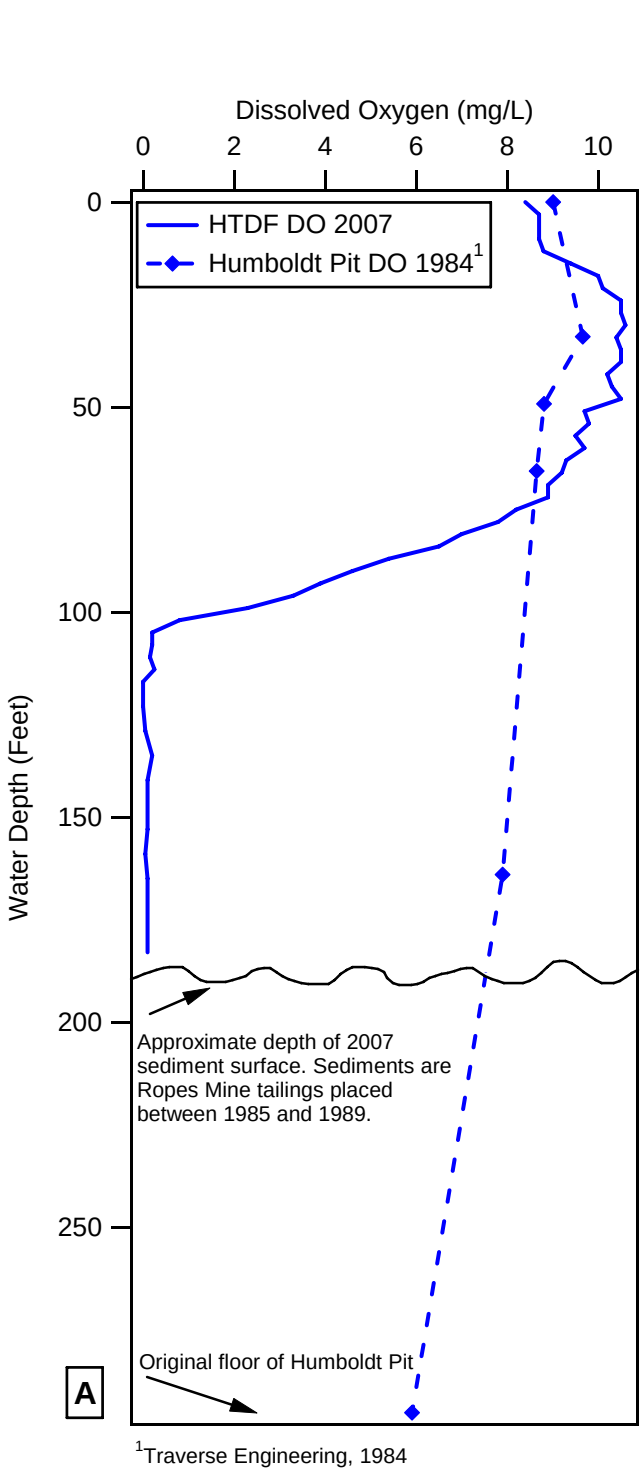
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FIGURE 12
HTDF MINOR ELEMENT CONCENTRATIONS

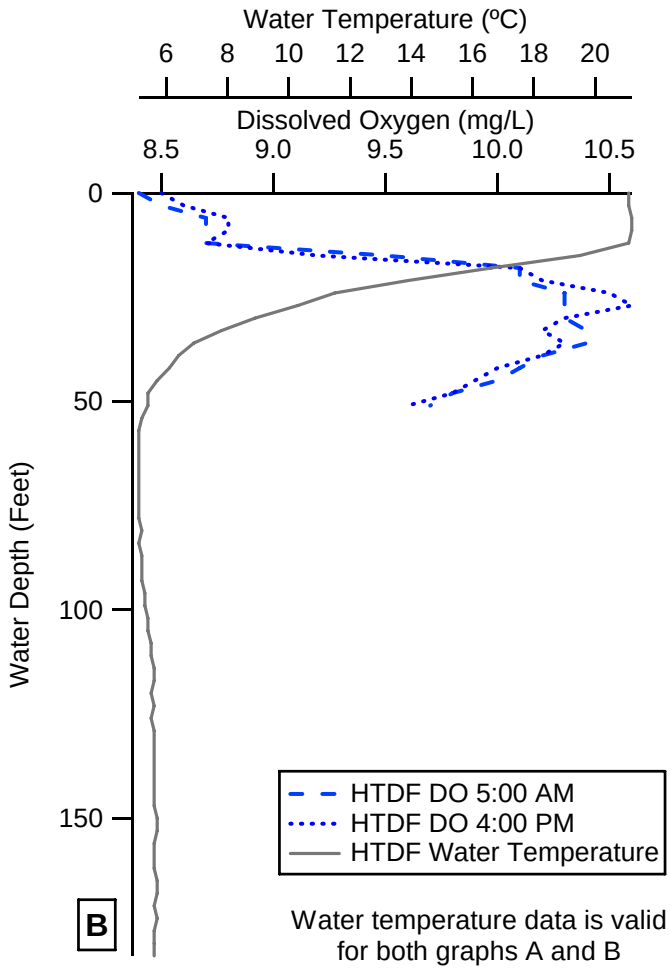
Scale:	NA	Date:	SEPTEMBER 2007
Prepared by:	JBM	Project No:	06W003

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Dissolved Oxygen In The HTDF And Humboldt Pit
Historical And Diurnal Variation



[1]Traveler Engineering, 1984



Water temperature data is valid for both graphs A and B

A - Concentration of dissolved oxygen in the water column of the HTDF in July, 2007 and Humboldt Pit in 1984. Before tailings from the Ropes Mine were placed in the Pit, dissolved oxygen was present throughout the water column. This indicates that oxygen consumption from substances such as decaying organic matter was limited. After placement of tailings, oxygen is almost completely consumed below 100 feet.

B - Measurements of dissolved oxygen in the HTDF in the early morning and late afternoon of July 12, 2007. The depth profiles are almost identical and indicate that no significant primary production (algal growth) occurred during this time.

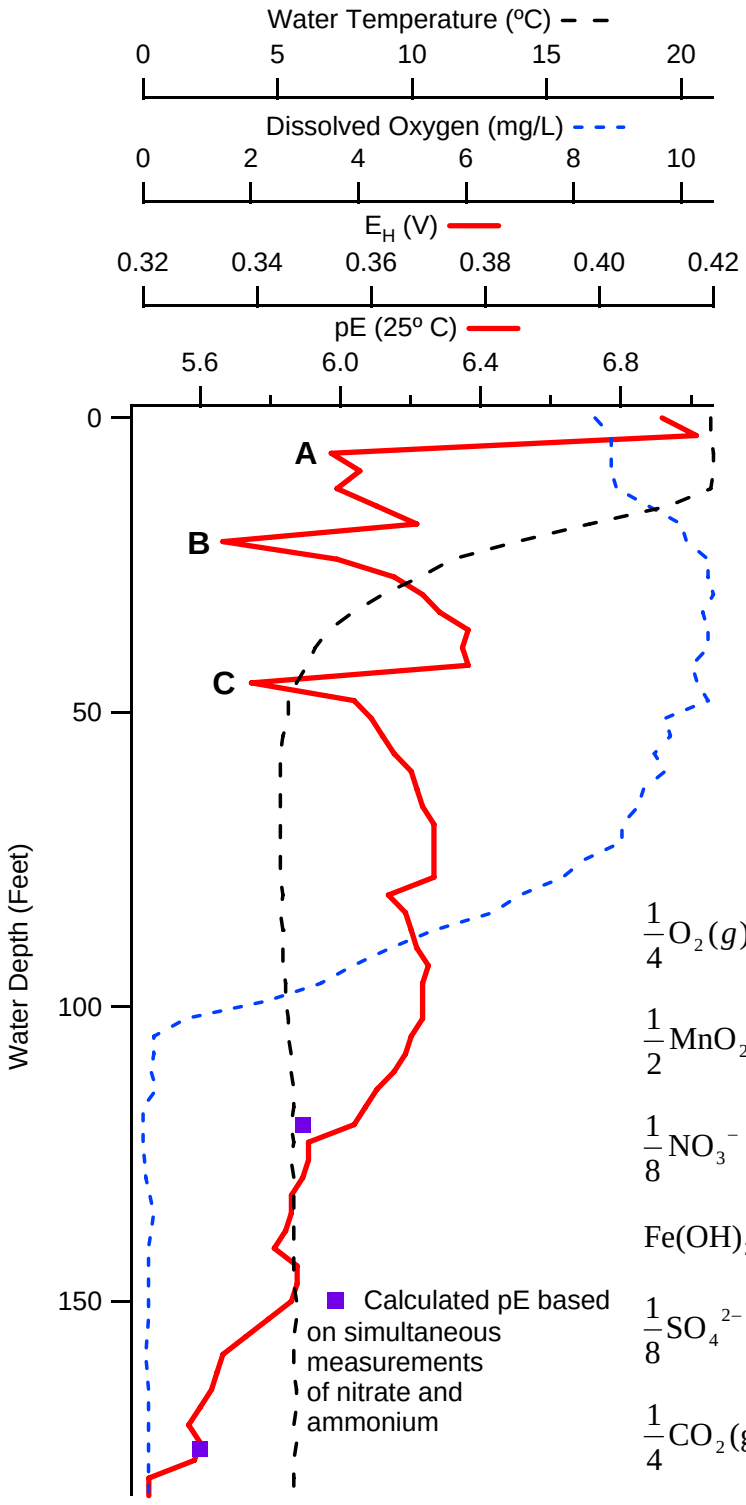
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FIGURE 13
HTDF DISSOLVED OXYGEN

Scale: NA	Date: OCTOBER 2007
Prepared by: JBM	Project No: 06W003

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Redox Potential (ORP) In The HTDF

- Redox potential measured in the HTDF (July, 2007).
- Measured with platinum electrode and Ag/AgCl reference electrode, no temperature correction.
- Standard hydrogen electrode (E_H) values calculated from ZoBell calibration.
- pE values calculated from E_H values at 25°C reference temperature.
- Several major (A, B, C) and minor redox boundaries are visible in the profile.
- Calculation of two pE values based on simultaneous measurements of nitrate (NO_3^-) and ammonium (NH_4^+) concentrations are similar to those obtained by direct measurement.

Several common aquatic redox reactions are shown below with their pE°(W) values. These values represent the pE of a solution with equimolar concentrations of reductant and oxidant, and at pH=7. (Fe^{2+}, Mn^{2+} at 10^{-6} M).

Common Aquatic Redox Reactions

$$\frac{1}{4}O_2(g) + H^+ + e = \frac{1}{2}H_2O$$ pE°(W)=+13.75

$$\frac{1}{2}MnO_2(s) + 2H^+ + e = \frac{1}{2}Mn^{2+} + H_2O$$ pE°(W)=+9.8

$$\frac{1}{8}NO_3^- + \frac{5}{4}H^+ + e = \frac{1}{8}NH_4^+ + \frac{3}{8}H_2O$$ pE°(W)=+6.15

$$Fe(OH)_3(am) + 3H^+ + e = Fe^{2+} + H_2O$$ pE°(W)=+1.0

$$\frac{1}{8}SO_4^{2-} + \frac{9}{8}H^+ + e = \frac{1}{8}HS^- + \frac{1}{2}H_2O$$ pE°(W)=-3.75

$$\frac{1}{4}CO_2(g) + H^+ + e = \frac{1}{24}(glucose) + \frac{1}{4}H_2O$$ pE°(W)=-7.20

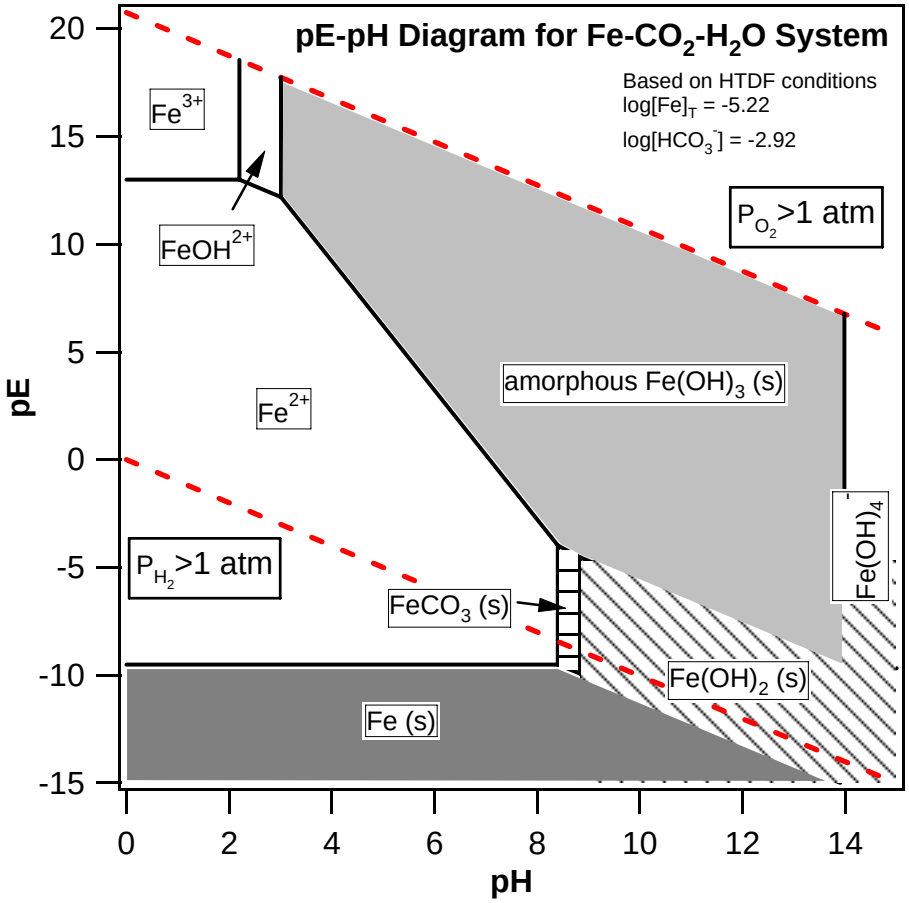
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FIGURE 14
HTDF REDOX CHEMISTRY

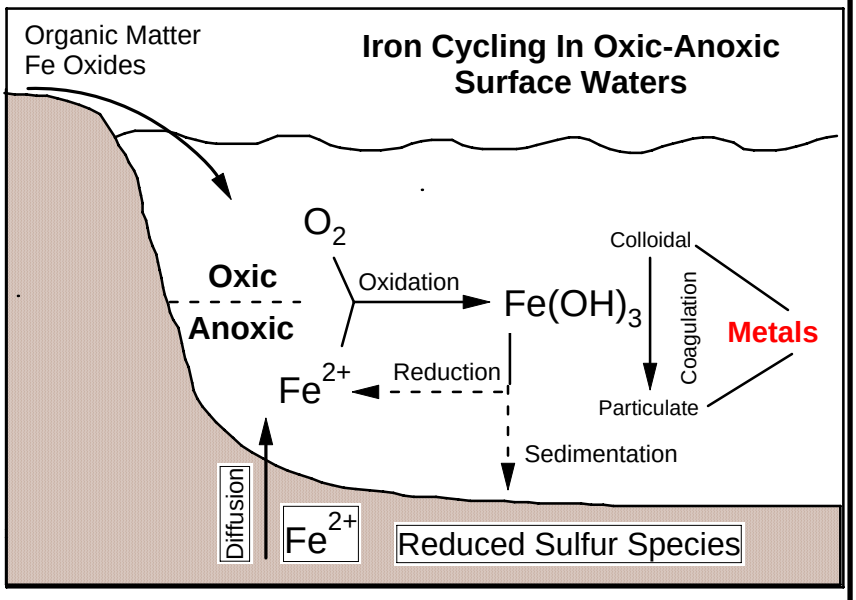
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Above: The pE-pH diagram for the iron-carbonate-water system shows the thermodynamically-favored chemical species. The system will move towards one species for a given set of pE-pH conditions. However, because of disequilibrium and slow kinetics, several nearby species are often present with the dominant species. Amorphous solid Iron (III) Hydroxide and dissolved Iron (II) are the expected dominant species in the HTDF.

Right: When bottom waters are anoxic, like those in the HTDF, an iron cycle can develop. Dissolved Iron (II) diffuses upward into oxic water and is oxidized to solid Iron (III) hydroxide, forming initially as colloids. As these colloids coagulate, they collect other metals, form particles and settle. Some particles reach the sediment, others are dissolved by reduction and continue the cycle.



Adapted from Buffle and De Vitre (1993), Stumm and Morgan (1996)

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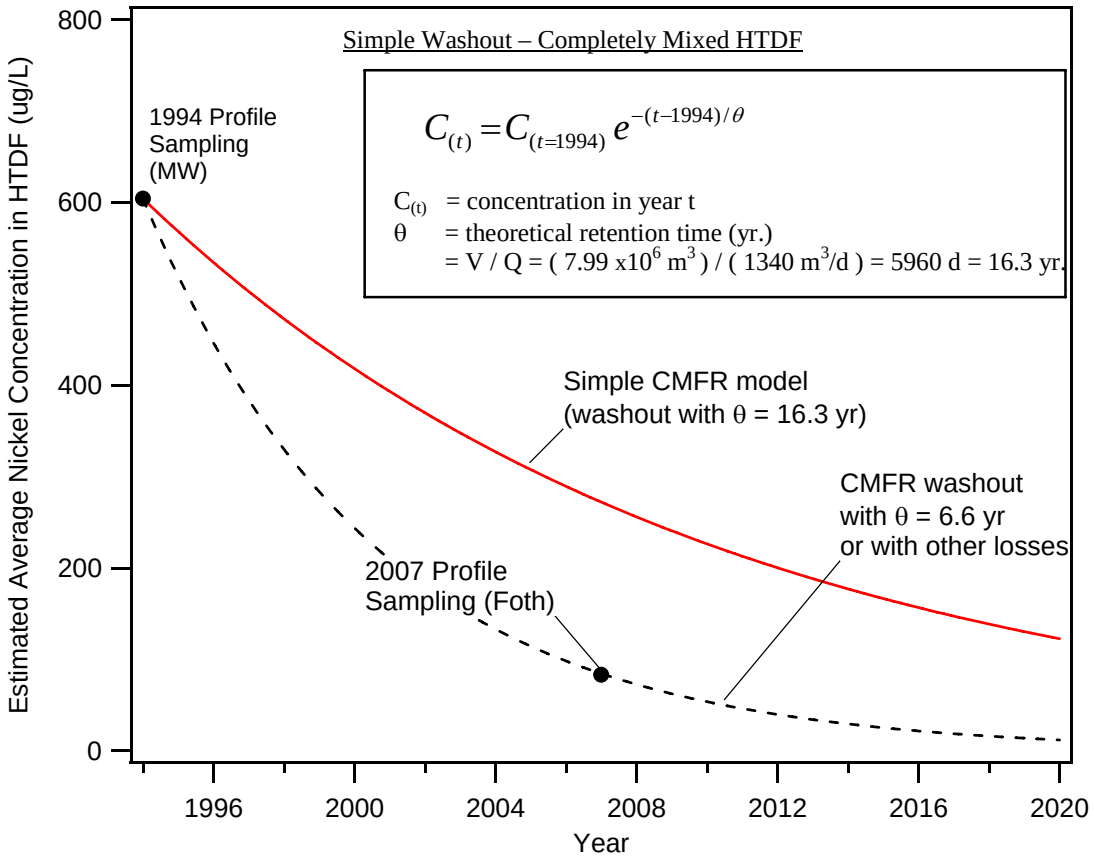
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FIGURE 15
AQUATIC IRON CYCLING

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HTDF Segmentation			Nickel Concentration and Mass from HTDF Profile Sampling						
			1994 (Montgomery Watson)		2007		Differences		
Compartment	Depth Range (ft.)	Volume ($x10^6$ m^3)	concentration (ug/L)	mass (kg)	concentration (ug/L)	mass (kg)	decrease in concentration (ug/L)	decrease in mass (kg)	Percent decrease (%)
1 + Northern HTDF	0-6	0.64	200	128	14	9	186	119	93
2	6-24	1.26	350	441	13	16	337	425	96
3	24-96	3.66	520	1903	17	62	503	1841	97
4	96-144	1.52	950	1444	210	319	740	1125	78
5	144-192	0.91	1000	910	280	255	720	655	72
Sum		7.99		4826		662		4165	86
Completely Mixed Concentration			604		83		521		



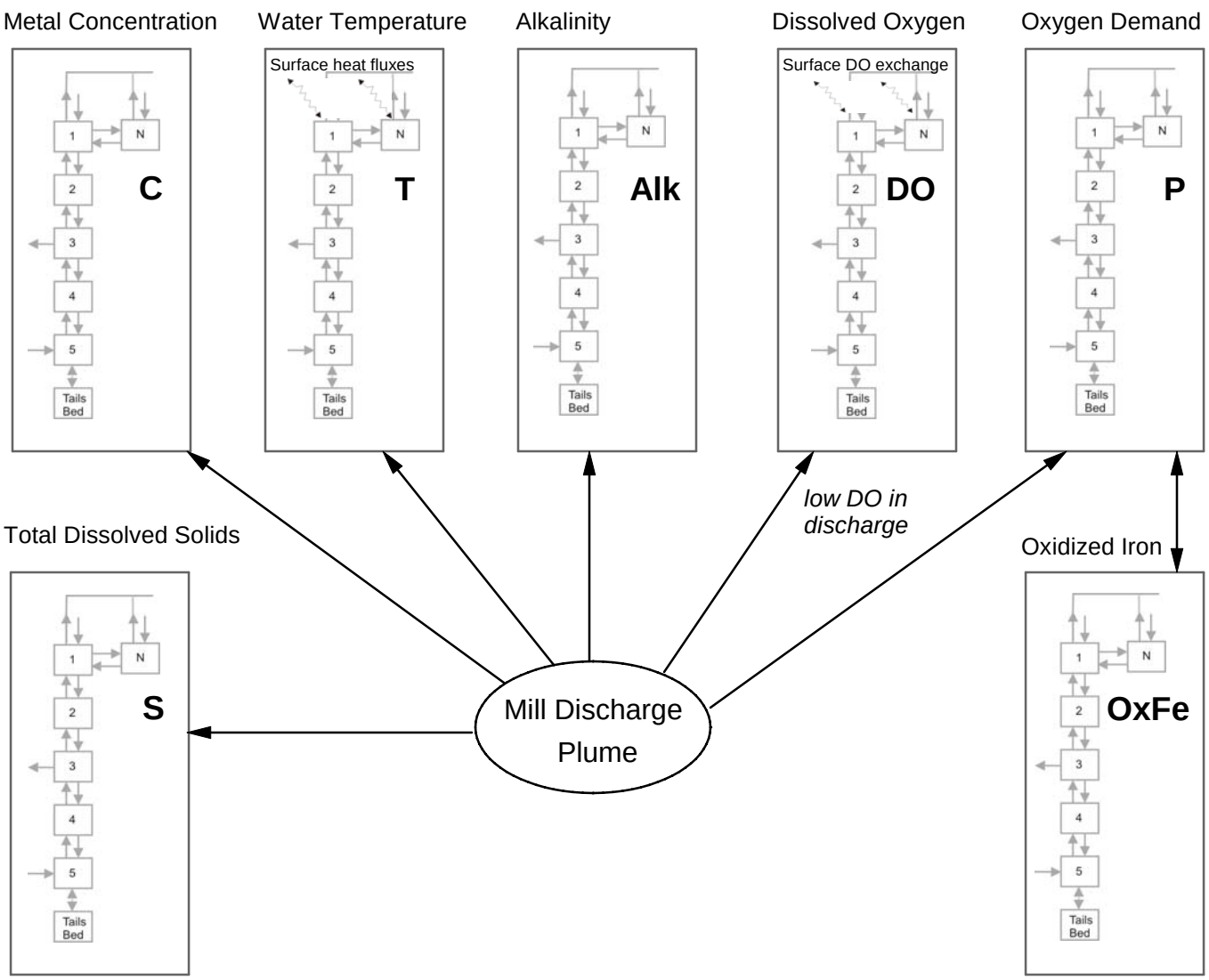
Loss of nickel within system (to sediment) must be active:

- Complete mix model washout would have to be 2.5 times higher
- HTDF is stratified, so mass flux due to washout is further constrained by lower surface concentrations
- Metals are likely scavenged by colloids within HTDF, and settle out to the HTDF bed sediments

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REVISED		BY	DESCRIPTION	FIGURE 16
				OBSERVED DECREASE IN HTDF NICKEL CONCENTRATIONS
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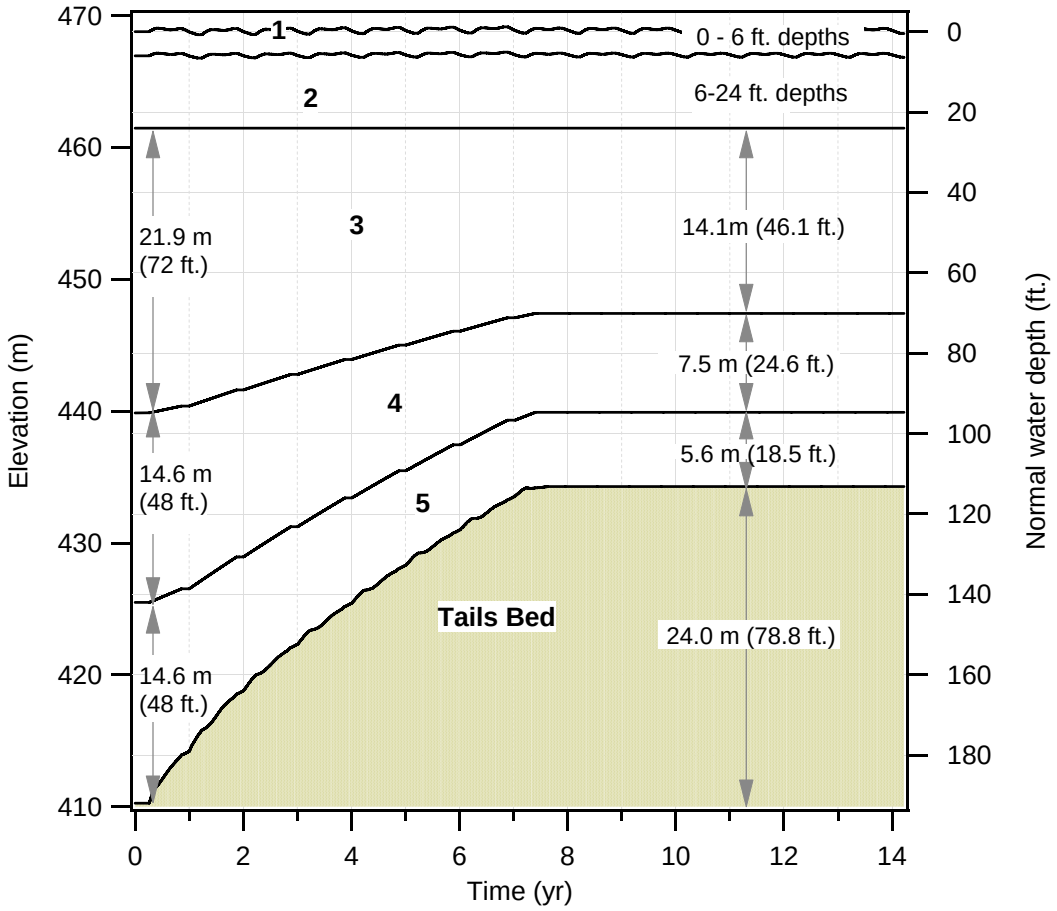
Model Interdependencies

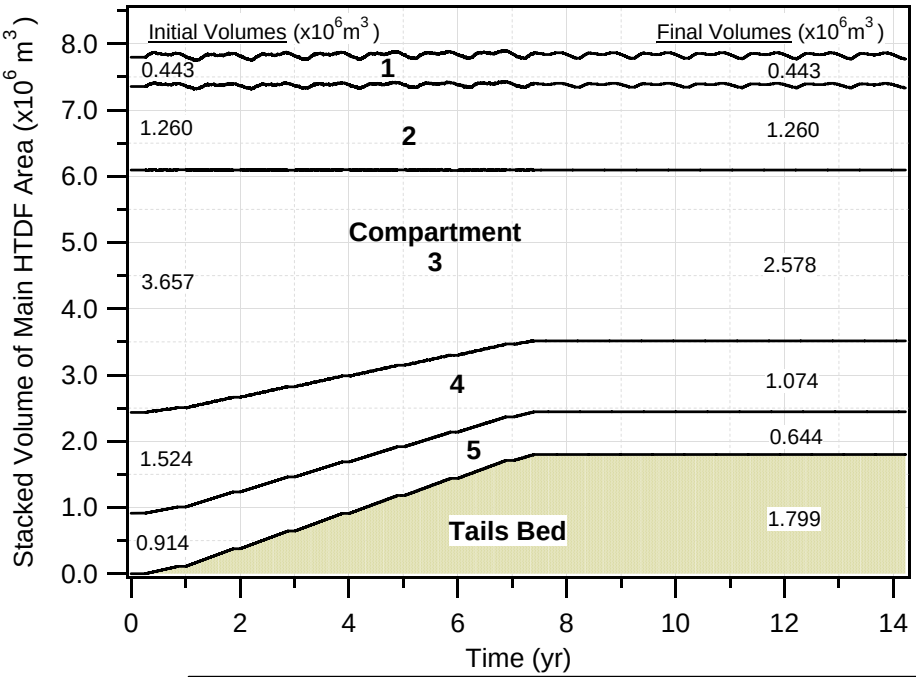
dynamics of compartments \ affect internal processes ->	Metals	Alkalinity	Dissolved Oxygen	Oxygen Demand	Oxidized Iron	Density
Metals					x	
Alkalinity	x		x		x	
Dissolved Oxygen		x		x	x	
Oxygen Demand		x	x		x	
Oxidized Iron	x	x		x		
Temperature			x	x	x	x
Total Dissolved Solids						x

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REVISED		BY	DESCRIPTION	FIGURE 17	
				PARALLEL MODEL COMPONENTS AND INTERDEPENDENCIES	
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FIGURE 18

HTDF MODEL COMPARTMENT DIMENSIONS UPON LOADING

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Overall Flow Balance

$$Q_D + Q_{nat} + Q_{gw2} = Q_R + Q_{T,out} + \dot{V}_T \quad (1)$$

Q_D = Discharge flow rate, including solids (2)
Q_{nat} = Natural, net surface flows (3)
Q_{gw2} = Groundwater inflow at southern end (4)
Q_R = Return flow rate to mill (5)
$Q_{T,out}$ = Total outflow to wastewater treatment plant (6)
$\dot{V}_T$ = Total volume rate of change in HTDF from changes in storage and loading of tails (7)

Distribution of discharge to tails bed and main compartments (1-5)

Balance at point of discharge mixing (initiation of discharge plume)

$$Q_D + Q_{5P} = Q_{PTB} + Q_{P5} + Q_{P54} \quad (8)$$

Q_{5P} = Flow from compartment 5 to discharge plume, to provide pore water and brought into discharge plume by hydrodynamic forces.

$$= n \dot{V}_{TB} + (MF_D)\, Q_D \quad (9)$$

where n = tails bed porosity, $\dot{V}_{TB}$ = volume rate that tails bed increases due to loading, MF_D = mixing factor for discharge (10)

Q_{PTB} = Flow from discharge plume to tails bed

$$= n \dot{V}_{TB} + \dot{V}_S \quad (11)$$

where $\dot{V}_S$ = discharge flow rate of solids (without pore volume) = $\dot{M}_{DT}/(G_s \gamma_w)$.

Q_{P5} = Flow from discharge plume to compartment 5

$$= (1\text{-}MF_{P5})\,(Q_D + Q_{5P} - Q_{PTB}) \quad (12)$$

where MF_{P5} = mixing factor for discharge plume to compartment 5, and MF_{Pi} is a function of fluid densities (and i = 5):

$$MF_{Pi} = MF_{min} \qquad \text{for } \rho_P \geq \rho_i \quad (13)$$

$$MF_{Pi} = \min\left\{1, \frac{\sqrt{\dfrac{\rho_i - \rho_D}{\rho_i + \rho_D}}}{DF}\right\}\left(MF_{max} - MF_{min}\right) + MF_{min}$$

$$\text{for } \rho_P < \rho_i \quad (14)$$

where DF = density factor (typically < 0.02) which scales the sensitivity of mixing function to the difference in densities, MF_{max} and MF_{min} are the maximum and minimum portions of the plume flow to bypass compartment i (typically 0.99 to 0.03).

Q_{P54} = Flow from discharge plume, bypassing 5 to compartment 4 and above.

$$= (MF_{P5})\,(Q_D + Q_{5P} - Q_{PTB}) \quad (15)$$

Balance at point of discharge to compartments 4, 3, and 2

Starting with i = 4,

$$Q_{P(i+1,i)} = Q_{Pi} + Q_{P(i,i-1)} \quad (16)$$

Q_{Pi} = Flow from discharge plume to compartment i

$$= (1\text{-}MF_{Pi})\, Q_{P(i+1,i)} \quad (17)$$

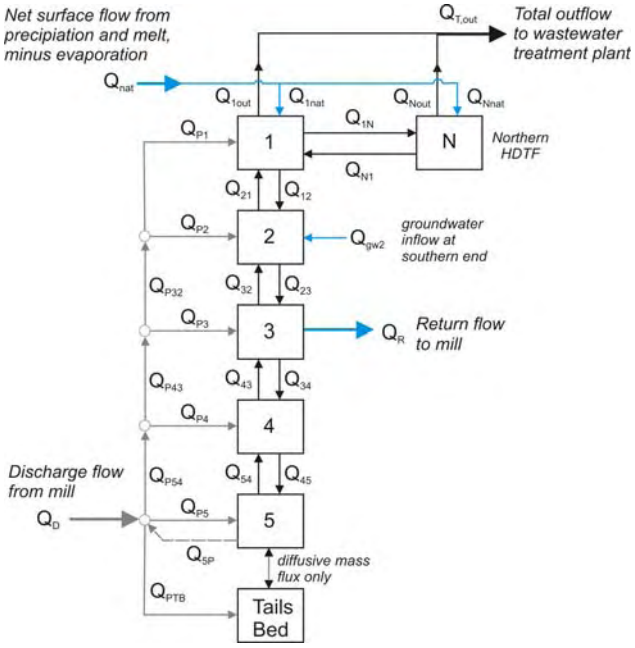
$Q_{P(i,i-1)}$ = Flow from discharge plume, bypassing i to the compartment i-1 and above

$$= (MF_{Pi})\, Q_{P(i+1,i)} \quad (18)$$

This set of equations (16-18) are repeated, with i = 3 next, then i=2.

Remainder of discharge to compartment 1

$$Q_{P1} = Q_{P21} = Q_{P32} - Q_{P2} \quad (19)$$



Flow Balance

Inter-compartmental Flows (1-5, 1-N)

$$Q_{54} = (Q_{P5} - Q_{5P}) + (Q_{45}) - (\dot{V}_5) \quad (20)$$

$Q_{P5} - Q_{5P}$ = net plume discharge (see Eqns. 9, 12)
Q_{45} = mixing flow sensitive to densities
= MF_{54} (see Eqns. 13-14) (21)

$\dot{V}_5$ = volume change in 5 = - VF_5 ($\dot{V}_{TB}$) (22)

where VF_5 = fixed volume fraction (0.15) of lower HTDF volume (=V_3 + V_4 + V_5) that decreases with tails loading.

$$Q_{43} = Q_{P4} + Q_{54} + Q_{34} - Q_{45} - \dot{V}_4 \quad (23)$$

Q_{34} = $MF_{43} Q_{mix}$ and $\dot{V}_4$ = - VF_4 ($\dot{V}_{TB}$) = -0.25 ($\dot{V}_{TB}$) (24)
Q_{mix} = intercompartmental mixing flow (15,000 m^3/d) (25)

$$Q_{32} = Q_{P3} + Q_{43} + Q_{23} - Q_R - Q_{34} - \dot{V}_3 \quad (26)$$

Q_{34} = $MF_{32} Q_{mix}$ and $\dot{V}_3$ = - VF_3 ($\dot{V}_{TB}$) = -0.60 ($\dot{V}_{TB}$) (27)

$$Q_{21} = Q_{P2} + Q_{32} + Q_{12} + Q_{gw2} - Q_{23} - \dot{V}_2 \quad (28)$$

Q_{12} = min($MF_{21} Q_{mix}$, Q_{wind}) (29)
Q_{wind} = wind-generated flows during ice-free season (typically 2000 m^3/d) (30)

$\dot{V}_2$ = - VF_2 ($\dot{V}_{US}$) = -0.74 ($\dot{V}_{US}$) (31)

$\dot{V}_{US}$ = change in upper volume (1+2), from storage (32)

$$Q_{1out} = Q_{P1} + Q_{21} + Q_{1nat} + Q_{N1} - Q_{1N} - Q_{12} - \dot{V}_1 \quad (33)$$

Q_{N1} = Q_{1N} = 0.5 Q_{Nnat} (34)

$\dot{V}_1$ = - VF_1 ($\dot{V}_{US}$) = -0.26 ($\dot{V}_{US}$) (35)

$$Q_{Nout} = Q_{1nat} - \dot{V}_N \quad (36)$$

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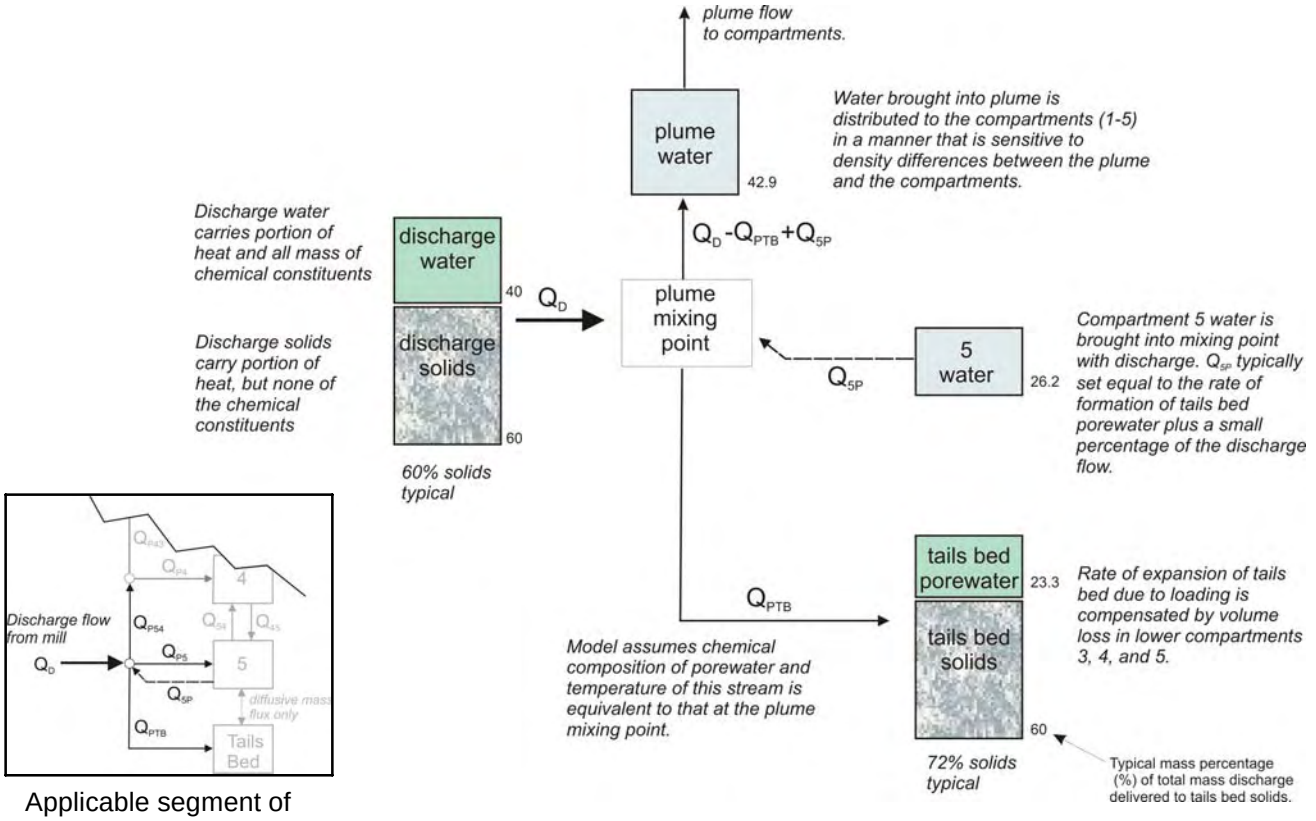
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FIGURE 19
FLUID FLOW BALANCE FOR HTDF MASS BALANCE MODEL

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Applicable segment of flow balance diagram

Mass Balance

Balance at point of discharge mixing (initiation of discharge plume)

$$C_P (Q_D - Q_{PTB} + Q_{5P}) = C_D Q_{DW} + Q_{5P} C_5 + (\text{RECYCLE}) Q_R C_3$$

$$C_P = [C_D Q_{DW} + Q_{5m} C_5 + (\text{RECYCLE}) Q_R C_3] / (Q_D - Q_{PTB} + Q_{5P}) \quad (1)$$

C_P = Concentration of discharge plume (µg/L) (2)

C_D = Concentration in mill tails pore water, without additional contribution from of recycle stream (µg/L) (3)

Q_{DW} = Flow rate for discharge (pore) water from mill (m^3/d) (4)

Q_R = Return flow rate to mill (reclaimed, m^3/d) (5)

$Q_{5P} C_5$ = Mass rate from compartment 5 drawn into mixing point, flows may include pore water and water drawn into plume by hydrodynamic forces of discharge. (6)

RECYCLE = Flag (0 or 1) to include recycle mass as part of mill discharge. (7)

$Q_R C_3$ = Mass rate in return water from compartment 3 if RECYCLE = 1. (8)

Heat Balance

Balance at point of discharge mixing (initiation of discharge plume)

Rate of heat in discharge plume to compartments:

$$T_P (Q_D - Q_{PTB} + Q_{5P}) HF_W = H_D + T_5 Q_{5P} HF_W - T_P \dot{M}_{DT} HF_{DT} - T_P \dot{n}V_{TB} HF_W \quad (9)$$

T_P = Temperature of discharge plume (°C) (10)

HF_w = Heat factor for water = $\rho_w C_p$ = 0.00419 $\frac{GJ}{°C\, m^3}$ (11)

(roughly constant with temperature, ignores salinity effect)

H_D = Heat rate from discharge (GJ/d)

$$= T_{DT} \dot{M}_{DT} HF_{DT} + T_{DW} Q_{DW} HF_W \quad (12)$$

T_{DT} = Temperature expected of dry tails (°C), used to set discharge temperature with estimated incoming water temperature (T_{DW}), which is sensitive to supply and return water temperatures. Typically set to 27°C to achieve a discharge temperature of 10°C.

HF_{DT} = Heat factor for dry tails, estimated as 0.00084 $\frac{GJ}{°C\ tonne}$

Rearranging (9) to yield temperature of discharge plume:

$$T_P = \frac{\frac{H_D}{HF_w} + T_5 Q_{5P}}{Q_D - Q_{PTB} + Q_{5P} + \dot{M}_{DT} \frac{H_D}{HF_w} + \dot{n}V_{TB}} \quad (13)$$

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FIGURE 20

HTDF MODEL MASS AND HEAT BALANCES FOR INITIATION OF DISCHARGE PLUME

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Balance of Potential and Kinetic Energy

Potential energy

$$PE_{1,initial} = M_1 g d / 2 \quad (1)$$

$$PE_{1,midpoint} = M_1 g(0) = 0 \quad (2)$$

$$PE_{2,initial} = -M_2 g d / 2 \quad (3)$$

$$PE_{2,midpoint} = M_2 g(0) = 0 \quad (4)$$

$$\Delta PE_1 = PE_{1,midpoint} - PE_{1,initial} = -M_1 g d / 2 \quad (5)$$

$$\Delta PE_2 = PE_{2,midpoint} - PE_{2,initial} = +M_2 g d / 2 \quad (6)$$

$$\Delta PE_{Total} = \Delta PE_1 + \Delta PE_2 = -\frac{gd}{2}(M_1 - M_2) \quad (7)$$

where

M = mass of weights 1 and 2
PE = potential energy of weights M_1 and M_2 at the initial and midpoint positions
g = gravitational constant
d = distance

Kinetic energy

At the midpoint, the energy of the system will be in the form of kinetic energy, and the velocity of the two weights will be equal in magnitude,

$$\Delta KE_1 = \frac{1}{2} M_1 v^2 \quad (8)$$

$$\Delta KE_2 = \frac{1}{2} M_2 v^2 \quad (9)$$

$$\Delta KE_{Total} = \Delta KE_1 + \Delta KE_2 = \frac{1}{2} v^2 (M_1 + M_2) \quad (10)$$

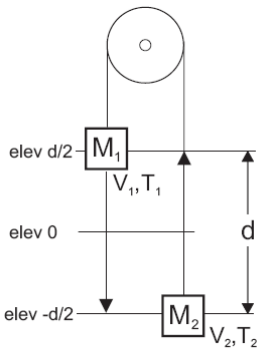
where

KE = kinetic energy of weights M_1 and M_2
v = velocity

A system energy balance requires that the decrease in potential energy be equal to the increase in kinetic energy,

$$-\Delta PE_{Total} = \Delta KE_{Total} \quad (11)$$

$$\frac{gd}{2}(M_1 - M_2) = \frac{1}{2} v^2 (M_1 + M_2) \quad (12)$$



Physical analogy for mixing: Pulley with two weights.

Interfacial Velocity of Parcels of Water with Same Volume

From the definition of density (ρ),

$$\rho = \frac{M}{V} \quad (13)$$

By substituting density and volume for mass, the system can represent parcels of water crossing an interface (midpoint) rather than weights on a rope. Because water here may be considered incompressible, the volumes of the two parcels must be equal. Substituting into Equation 12, simplifying and solving for velocity,

$$gd(\rho_1 V - \rho_2 V) = v^2(\rho_1 V + \rho_2 V) \quad (14)$$

$$v = \sqrt{gd} \times \sqrt{\frac{(\rho_1 - \rho_2)}{(\rho_1 + \rho_{2)}}} \quad (15)$$

Mixing Flow at Interface

The magnitude of mixing should be proportional to the velocity of water parcels at the interface, which is proportional only to the density term in Equation 15.

The absolute level of density-dependent mixing flow between compartments is set by proportioning of a maximum mixing flow (Q_{mix}, typically set to 15,000 m^3/d),

$$Q_{12} = MF_{12}(Q_{mix}) \quad (16)$$

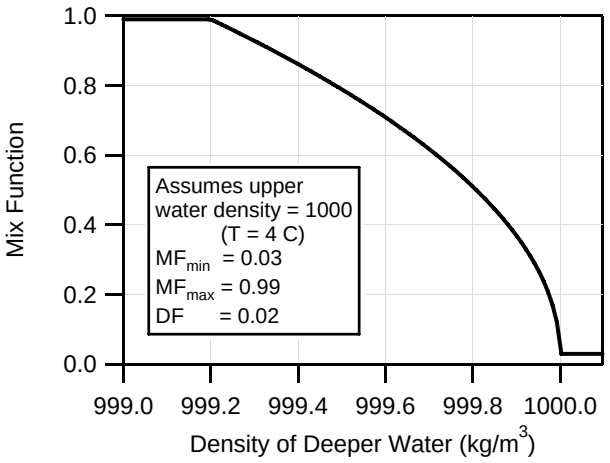
using the following mixing factors (MF):

$$MF_{12} = MF_{min} \quad \text{for } \rho_2 \geq \rho_1 \quad (17)$$

$$MF_{12} = \min\left\{1, \frac{\sqrt{\frac{\rho_1 - \rho_2}{\rho_1 + \rho_2}}}{DF}\right\}(MF_{max} - MF_{min}) + MF_{min}$$

$$\text{for } \rho_2 < \rho_1 \quad (18)$$

where DF = density factor (typically < 0.03) which scales the sensitivity of mixing function to the difference in densities, MF_{max} and MF_{min} are the maximum and minimum portions of the plume flow to bypass compartment *i* (typically 0.98 to 0.02).



Mixing Function.

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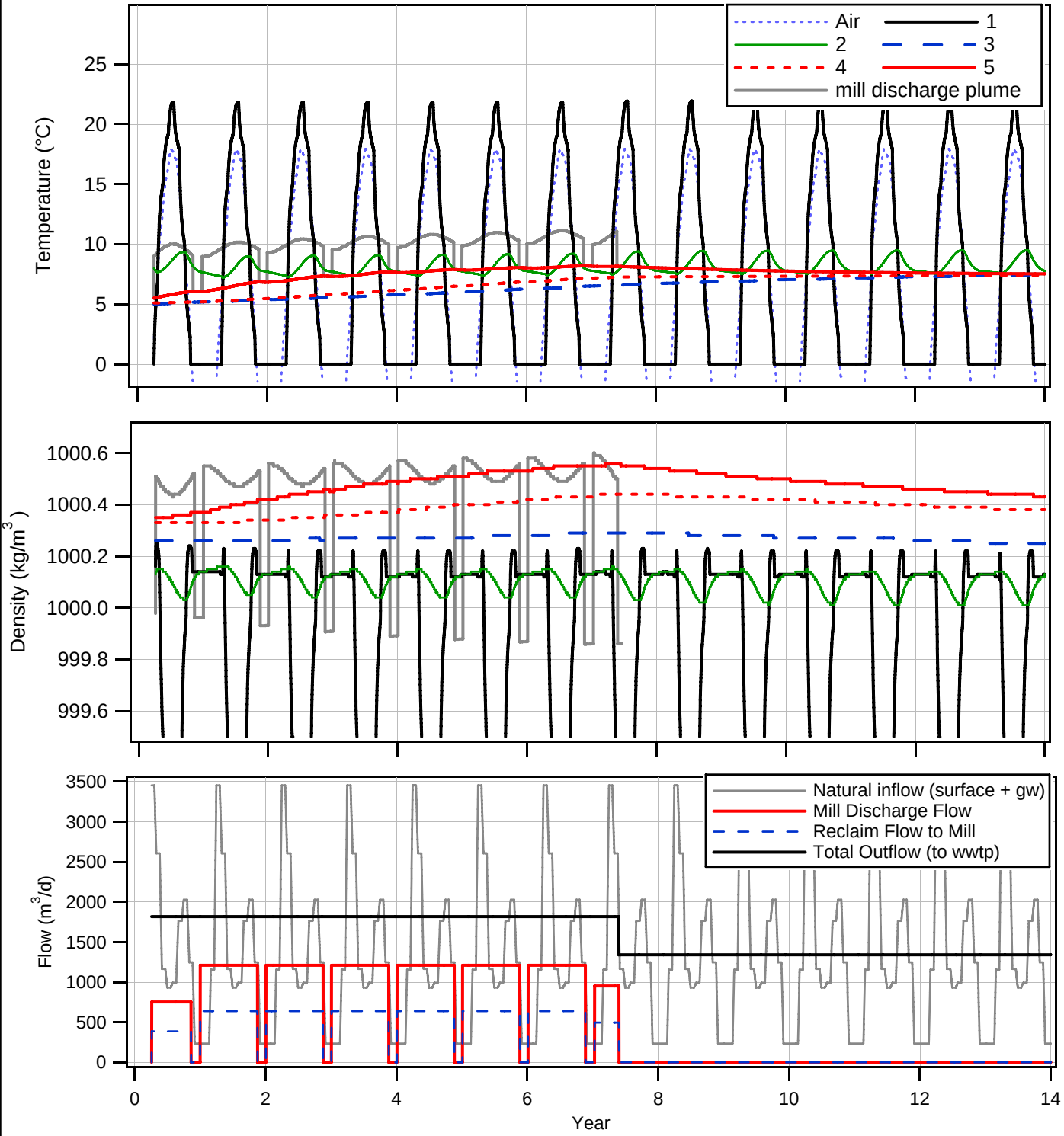
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FIGURE 21
DERIVATION OF MIXING FLOW FROM DIFFERENCES IN DENSITY

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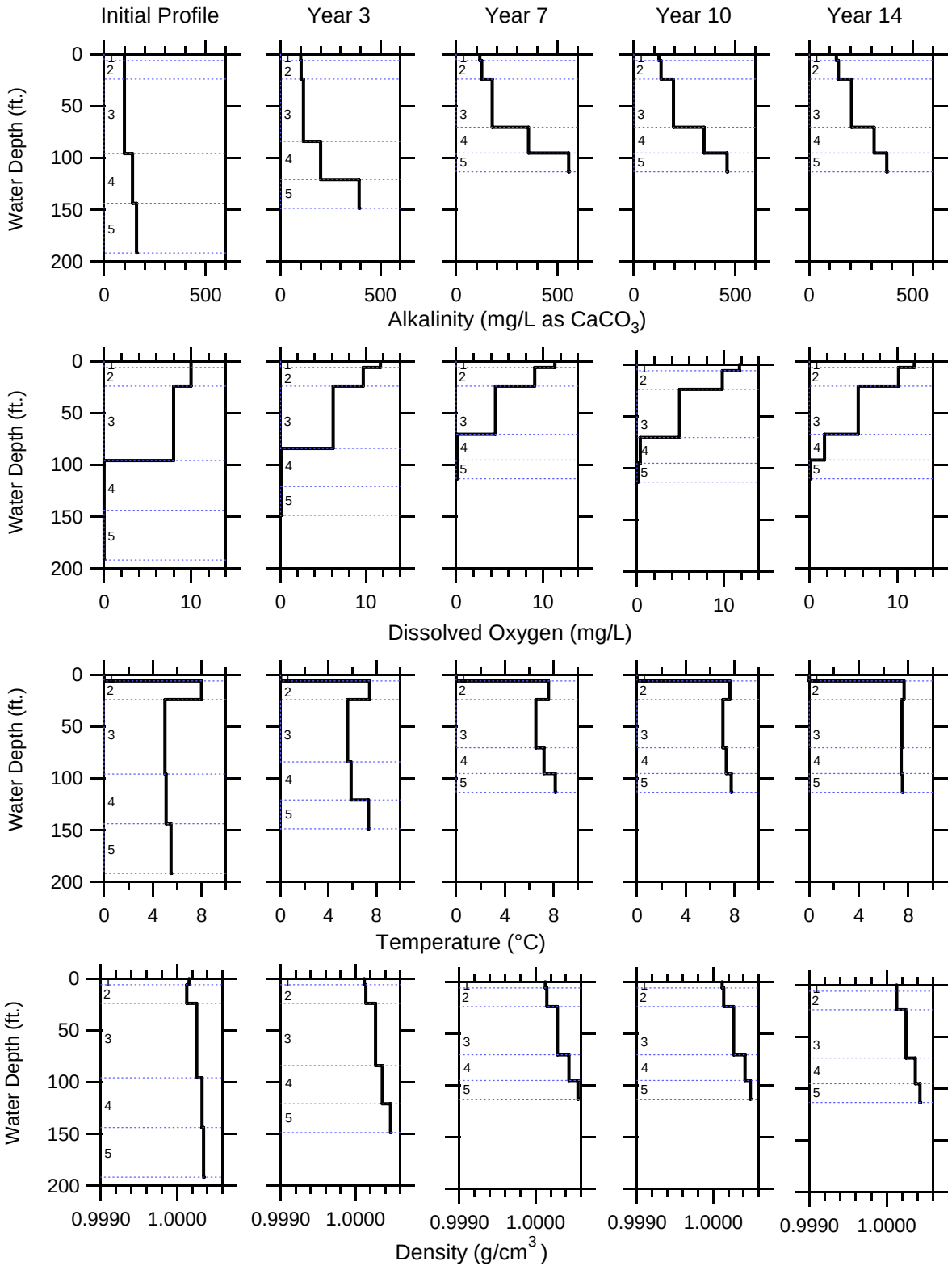
FIGURE 22

MODELED TRENDS IN TEMPERATURE DENSITY, AND FLOW

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Note: All curves drawn for 94th day of year (First week of April), with some ice cover.

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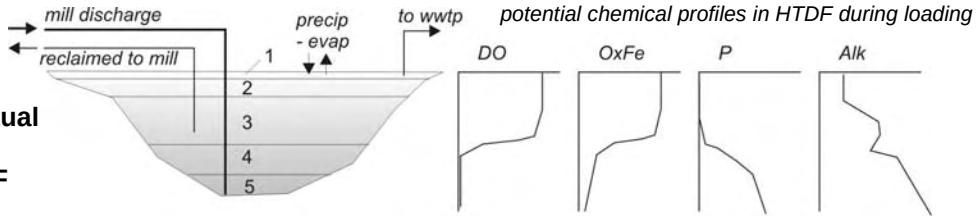
FIGURE 23

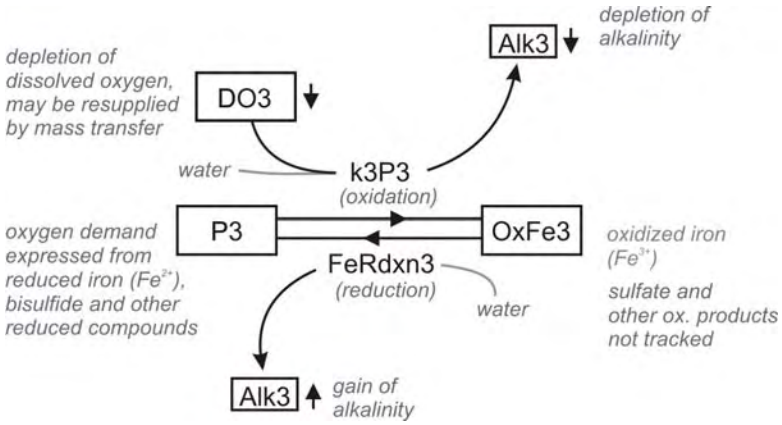
HTDF MODEL DEPTH PROFILES FOR SYSTEM VARIABLES

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Conceptual Model for HTDF





Dissolved Oxygen, Alkalinity, and Iron Reaction Dynamics for Compartment 3

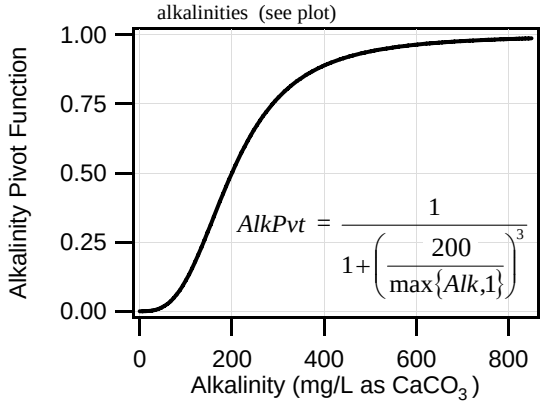
Note: Compartments 1-5 have the same processes, except that Compartments 1-2 do not have FeRdxn pathway.

Iron oxide settling rate (m/d)

$$v_{S,Fe} = v_{S,Fe,\max}\,(AlkPvt)$$

where $v_{S,Fe,\max}$ = maximum settling rate for iron oxide (typically 0.03 m/d)

AlkPvt = alkalinity pivot function which reduces settling velocity significantly for lower alkalinities (see plot)



Iron Cycle

(oxidation) $4Fe^{2+} + O_2 + 10\,H_2O \rightarrow 4Fe(OH)_3 + 8H^+$

$HS^- + 2O_2 \rightarrow SO_4^{2-} + H^+$

If oxygen demand *P* is assumed to be completely from dissolved Fe^{2+}, 1 mg *P* = 6.98 mg Fe^{2+}

(reduction) $Fe(OH)_3 + \frac{15}{8}H^+ + \frac{1}{8}HS^- \rightarrow Fe^{2+} + 2.5\,H_2O + \frac{1}{8}\,SO_4^{2-}$

Alkalinity Effects

(oxidation of Fe^{2+}) $\dfrac{8\text{g Alk consumed}}{\text{mol } O_2 \text{ consumed}} = 12.5\,\dfrac{\text{mg/L Alk as } CaCO_3}{\text{mg P}}$

(reduction of OxFe) $\dfrac{1.875\text{ eq Alk gain}}{\text{mol } Fe(OH)_3 \text{ reduced}} = 1.68\,\dfrac{\text{mg } CaCO_3}{\text{mg Fe reduced}}$

Rate of Oxidation (g DO consumed per day in compartment)

$k_3P_3 = (k_d\,\theta^{T_3-20})\,P_3\,V_3$ *for* $DO_3 \geq 1$ *mg/L*

$= (k_d\,\theta^{T_3-20})\,P_3\,V_3\,\dfrac{DO_3}{1\text{ mg/L}}$ *for* $DO_3 < 1$ *mg/L*

Rate of Iron Reduction (g Fe reduced per day in compartment)

$FeRdxn_3 = 0.01\,(k_d\,\theta^{T_3-20})\,OxFe_3V_3$ *for* $DO_3 \leq 0.5$ *mg/L*

$= 0$ *for* $DO_3 > 0.5$ *mg/L*

where

k_d	=	expected depletion rate coefficient for dissolved oxygen at 20° C (typically 0.5 d^{-1})
θ	=	temperature adjustment coefficient for reaction rate (typically 1.024)
T_3	=	temperature of compartment 3 (°C)
P_3	=	dissolved oxygen demand (mg/L)
V_3	=	volume of compartment 3 (m^3)
DO_3	=	dissolved oxygen (O_2) in compartment 3 (mg/L)
$OxFe_3$	=	oxidized iron concentration (mg Fe/L)

Scavenging of metals from iron oxide complexes

$$Ni^{2+} + \underbrace{\left[\equiv Fe(OH)_3\right]_S}_{\text{iron oxide}} \leftrightarrow \underbrace{\left[\equiv Fe(OH)_2O - Ni^+\right]_S}_{\text{surface complex}} + H^+$$

$$\alpha_{complexed} = \frac{\left[\equiv Fe(OH)_2O - Ni^+\right]_S}{Ni_T} \approx \frac{\min\left\{\dfrac{OxFe}{Total\ Ni}, 1\right\}}{1 + \dfrac{K_{complx}}{OxFe}}$$

where $Ni_T = Total\ Ni = Ni^{2+} + \left[\equiv Fe(OH)_2O - Ni^+\right]_S$

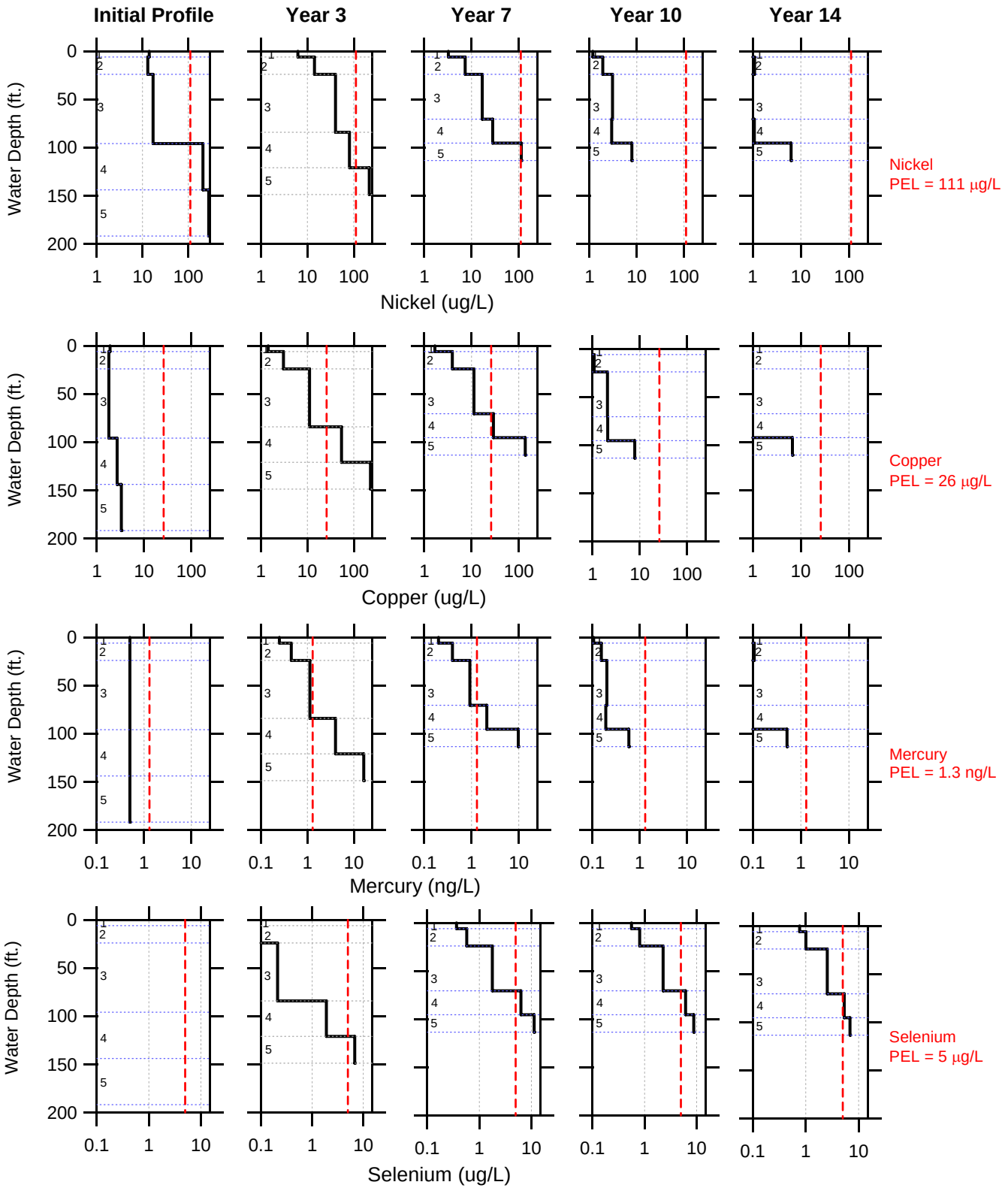
Mass flux from scavenging + iron oxide settling:

Compartment 2 to 3:

$$F_{S,23} = v_{S,Fe}\,Area_{23}\,(\alpha_{complexed,2}\,Ni_{T,2})$$

Foth Infrastructure & Environment, LLC				Kennecott Eagle Minerals	
REVISED		BY	DESCRIPTION	FIGURE 24	
				DISSOLVED OXYGEN, IRON, AND ALKALINITY MODEL DYNAMICS	
CHECKED BY: JBM		DATE: OCT '07		Scale: NA	Date: OCTOBER 2007
APPROVED BY: JBM		DATE: OCT '07		Prepared by: GRE	Project No: 06W003
APPROVED BY:		DATE:			

M: \06W003\igr\MixingFunctionDefn.pxp



Note: All curves drawn for 94th day of year (First week of April), with some ice cover.

Preliminary Effluent Limits (PEL) calculations shown in Appendix F.

Foth Infrastructure & Environment, LLC

REVISED		BY	DESCRIPTION

CHECKED BY:	JBM	DATE:	OCT '07
APPROVED BY:	JBM	DATE:	OCT '07
APPROVED BY:		DATE:	

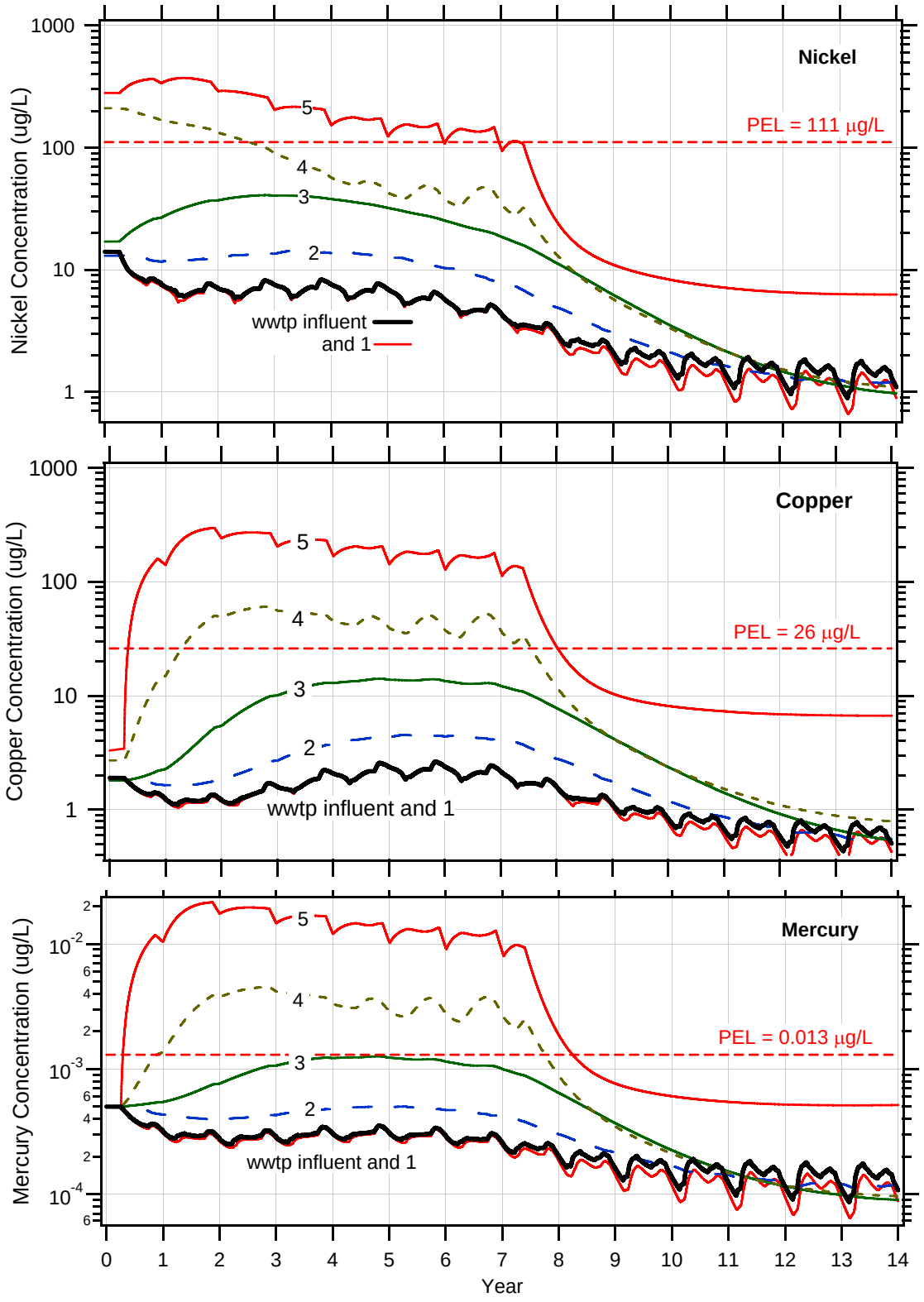
Kennecott Eagle Minerals

FIGURE 25

HTDF MODEL DEPTH PROFILES FOR SELECTED METALS

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

M: \06W003\igr\Model_Profiles.pxp



Preliminary Effluent Limit (PEL) calculations shown in Appendix F.

Foth Infrastructure & Environment, LLC

REVISED		BY	DESCRIPTION

CHECKED BY:	JBM	DATE:	OCT '07
APPROVED BY:	JBM	DATE:	OCT '07
APPROVED BY:		DATE:	

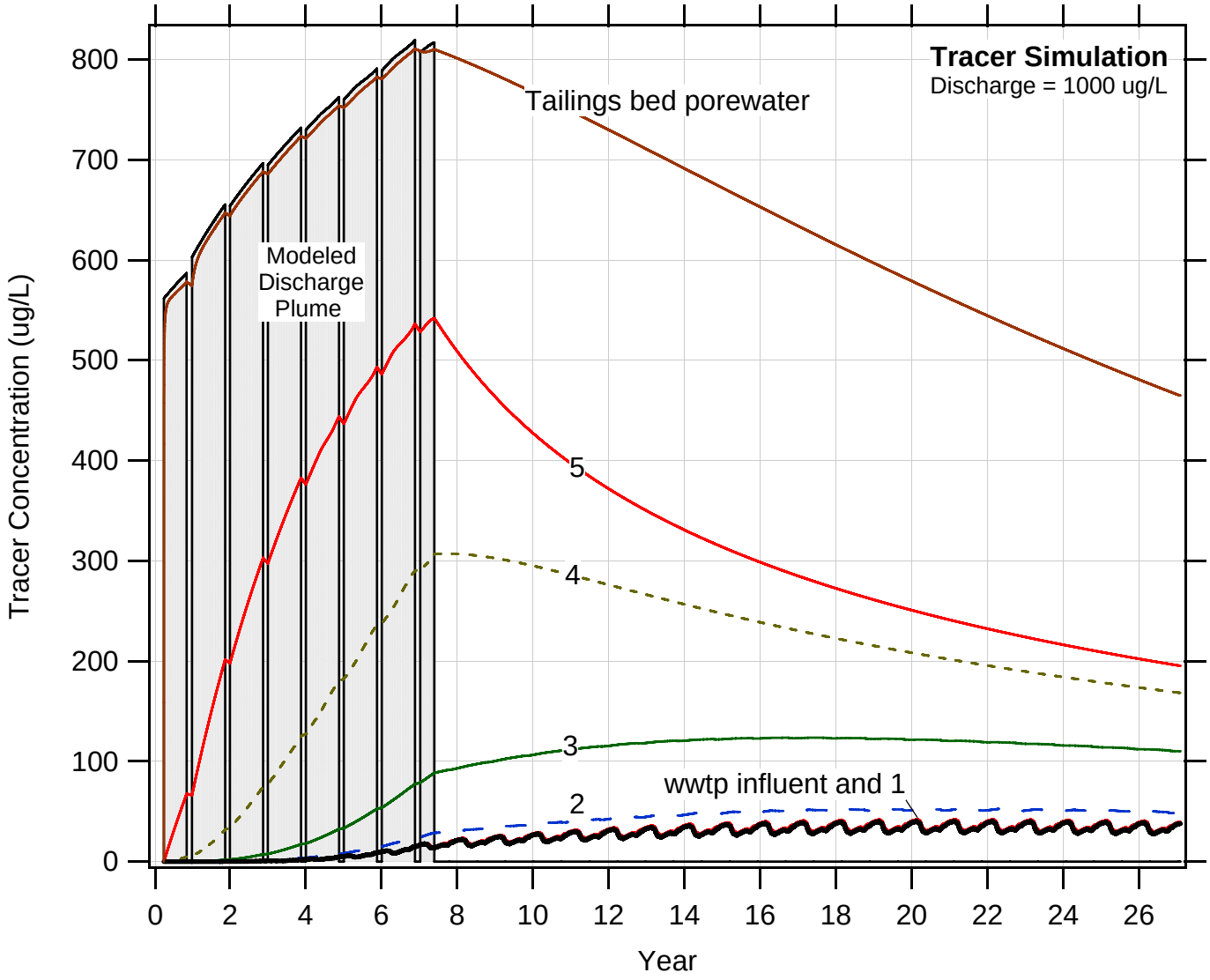
Kennecott Eagle Minerals

FIGURE 26

HTDF MODEL - SIMULATED TRENDS FOR NICKEL, COPPER, AND MERCURY

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

M: \06W003\igr\Nickel_Trends_w_Model.pxp



- Tracer simulation run for zero initial and background concentrations, and no losses due to scavenging.
- Modeled discharge plume concentrations consider full mass loadings, recycle stream, and mixing at plume mixing point.
- Increase in modeled discharge plume follows from increase in compartment 3 (recycle) and compartment 5 (mixing point).
- Decrease in tailings bed porewater concentrations are due to diffusion to compartment 5. Additional mass stored in buried tailings (beneath active bed).

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

Kennecott Eagle Minerals

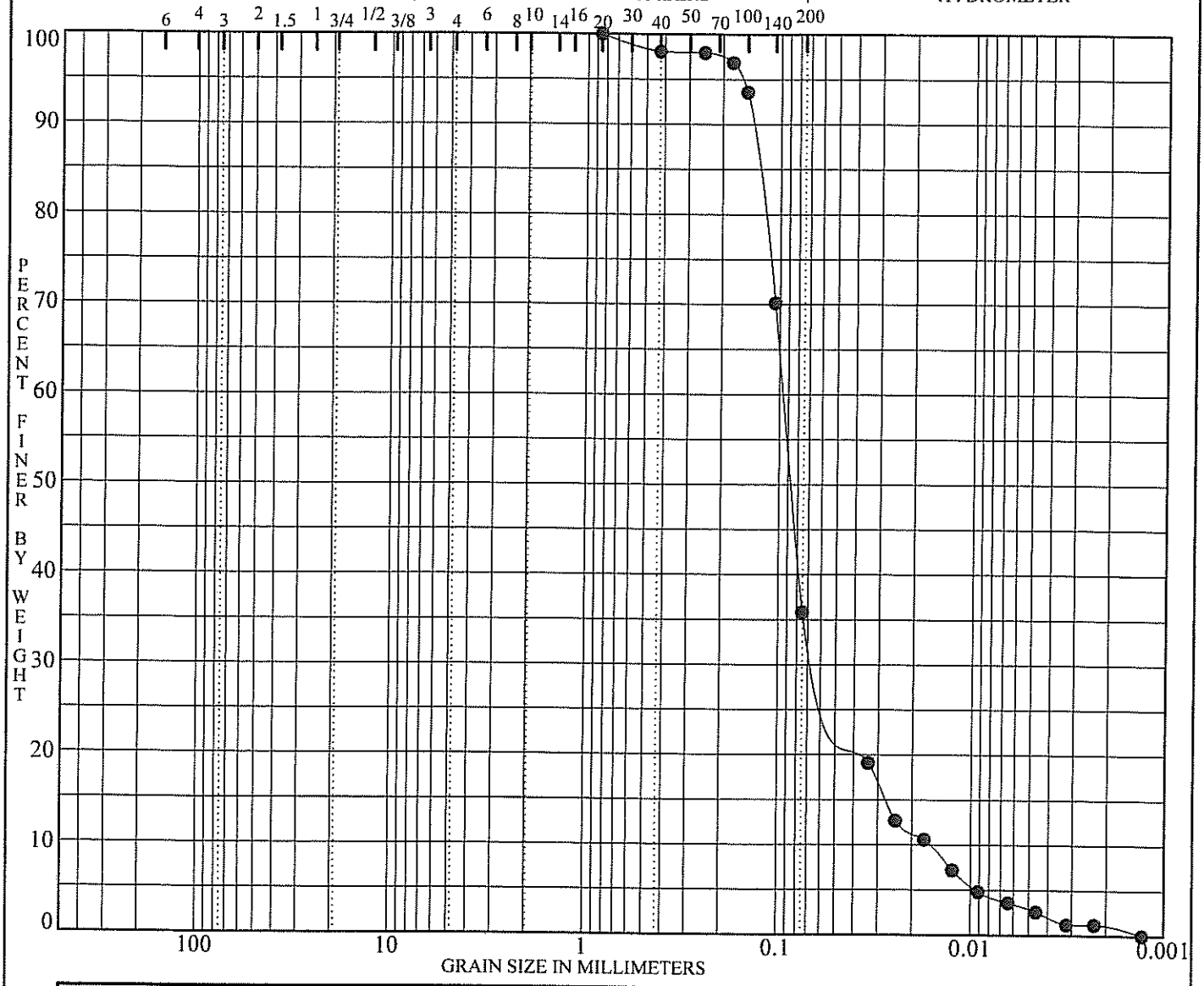
FIGURE 27
HTDF MODEL - SIMULATED TRENDS FOR TRACER INPUT CASE

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

M: \06W003\igr\Nickel_Trends_w_Model.pxp

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**

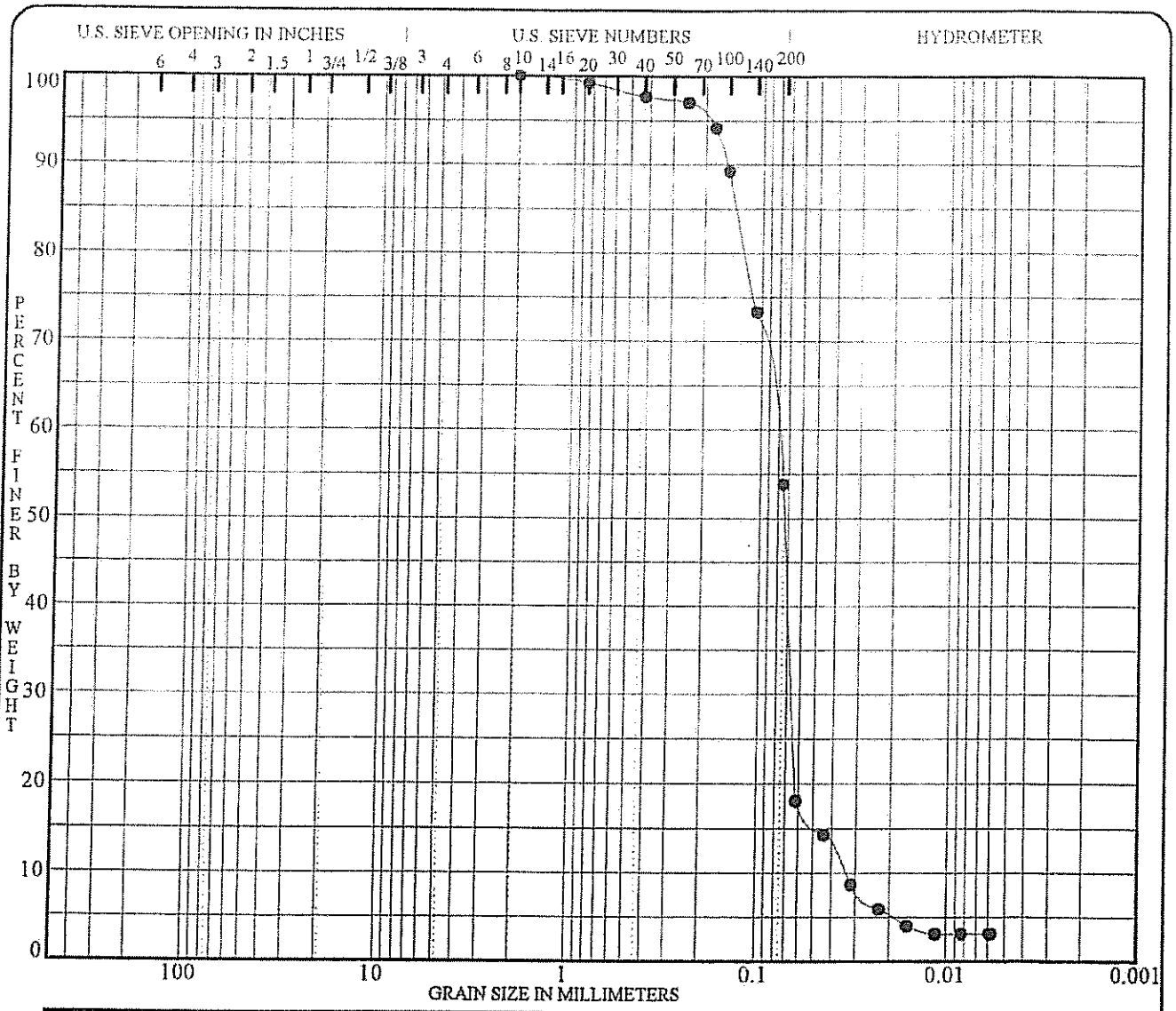
JOB NO.: **07-1-17422**
TEST DATE: **7/2/07**

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 MLLR_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 Goss

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 Calc. — Fe + S + Trace (pooled in %)

Petrographic Reports (2)

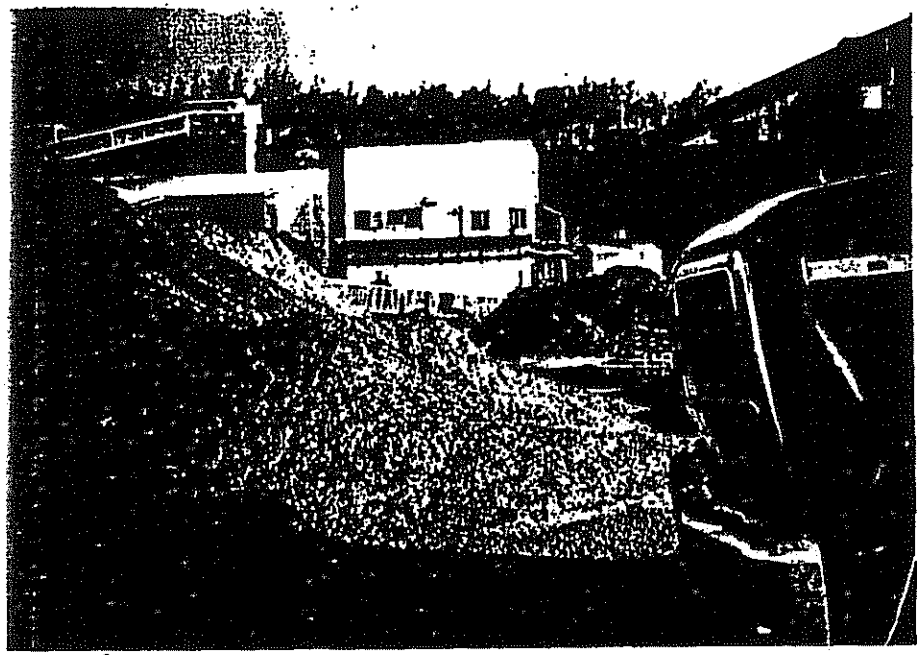
A list of minerals and compositions from gangue and flotation concentrates.

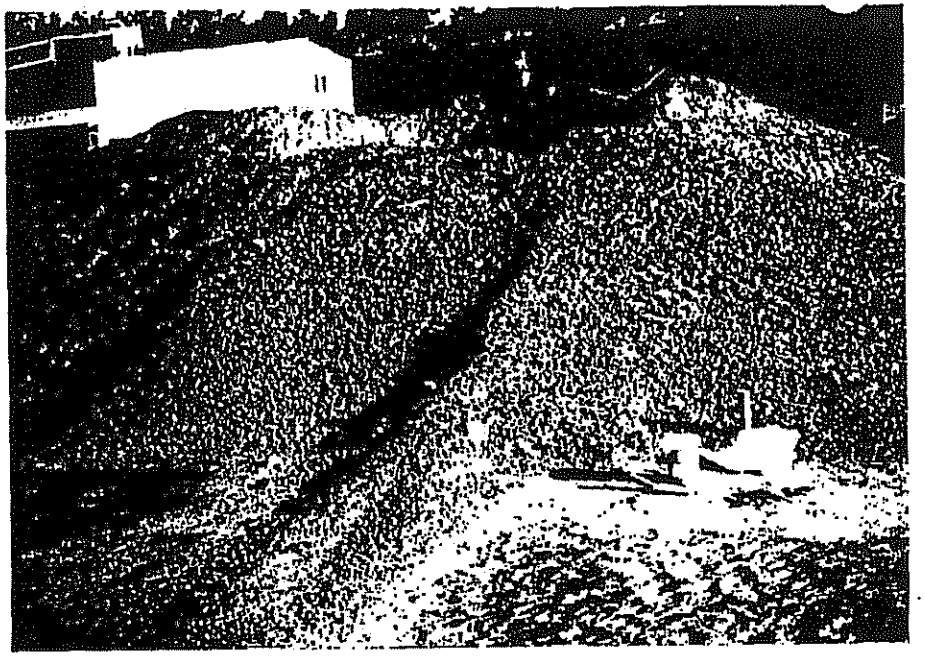
Major Gangue Constituents

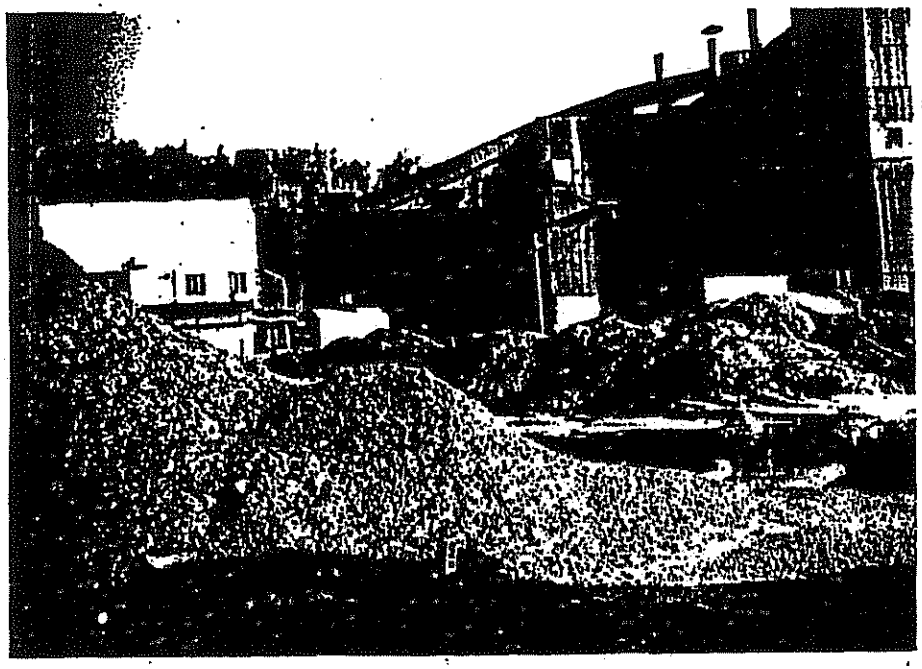
Quartz	SiO_2
Muscovite (sericite)	$KAl_2(AlSi_3O_{10})(OH)_6$
Carbonates	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Talc	$Mg_3Si_4O_{10}(OH)_2$

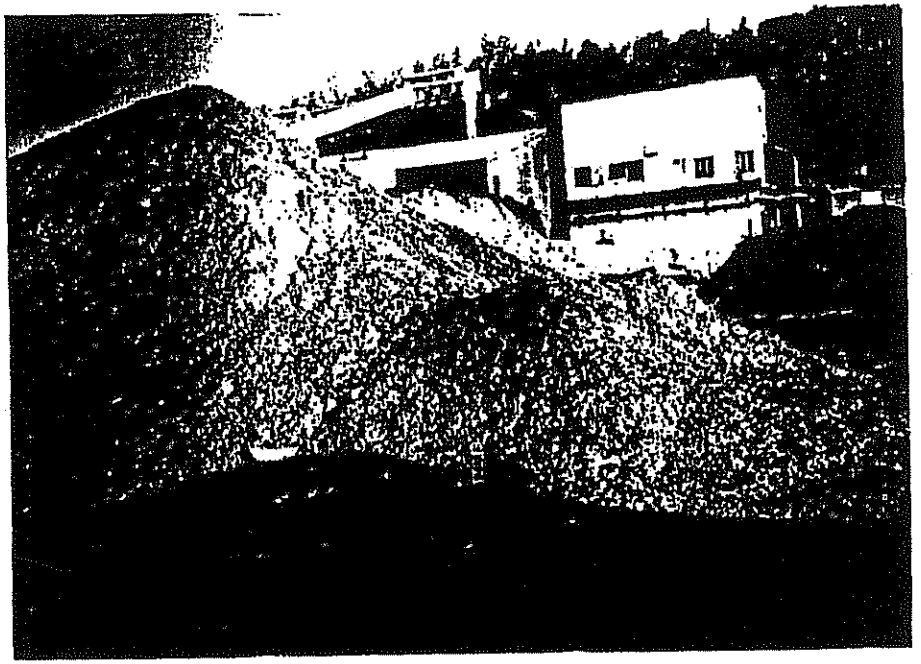
Major Flotation Concentrate Constituents

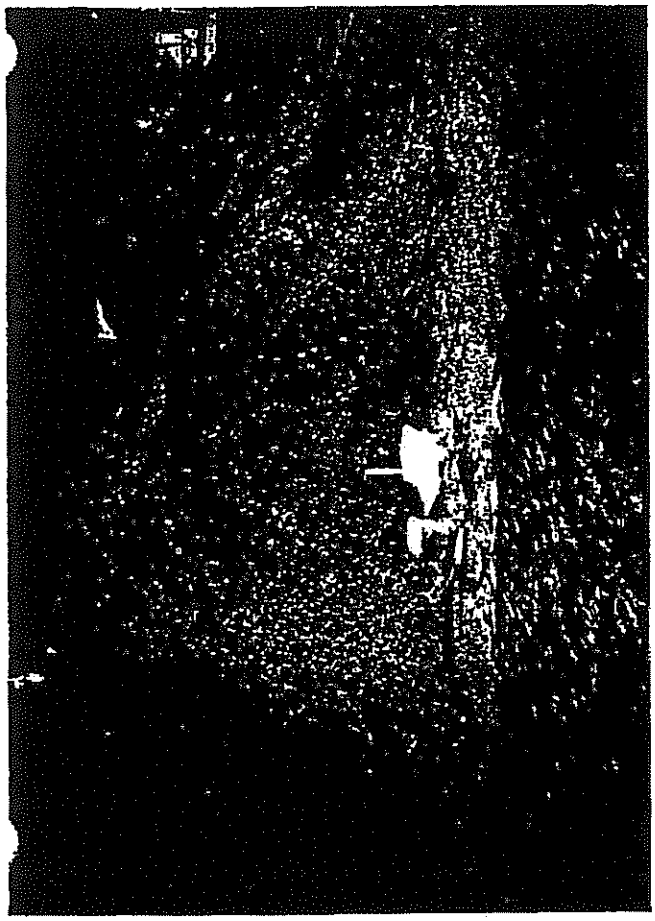
Pyrite	FeS_2
Chalcopyrite	$CuFeS_2$
Pyrrhotite	FeS
Galena	PbS
Millerite	NiS
Bravoite	$(Ni,Fe)S_2$
Sphalerite	ZnS
Metallic Silver	Ag
Metallic Gold	Au
Metallic Copper	Cu
Tetrahedrite	$Cu_{12}Sb_4S_{13}$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4















ACTLABS 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:

THER ID:

DATE RECEIVED: 11/8/95

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 %

APPROVED BY

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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%
RGANIC SULFUR		.04%	.04%

APPROVED BY

APPROVED BY

BLACK SEAL ANALYSIS

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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%

APPROVED BY _____

APPROVED BY _____

BLACK SEAL ANALYSIS

FOR YOUR PROTECTION THIS DOCUMENT HAS BEEN PRINTED ON CONTROLLED PAPER STOCK. NOT VALID IF ALTERED.

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: N. Ouchgoeitis ***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

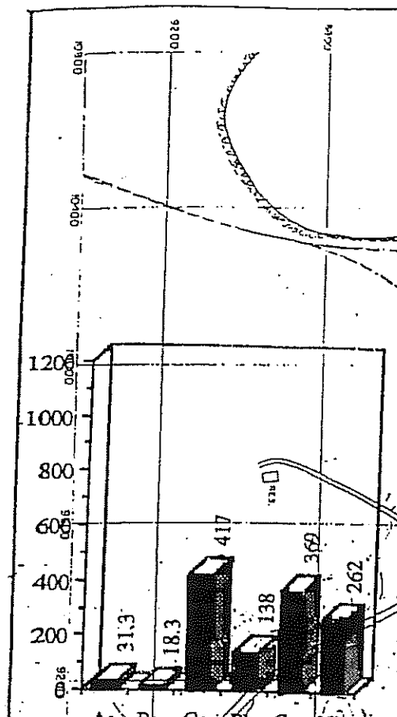
Metal	Minimum (mg/kg)	Average (mg/kg)	Maximum (mg/kg)
Cd	0.94	2.29	6.75
Hg	0.22	0.35	0.47
Se	NA	NA	<1.00
Ag	1.47	3.32	6.60

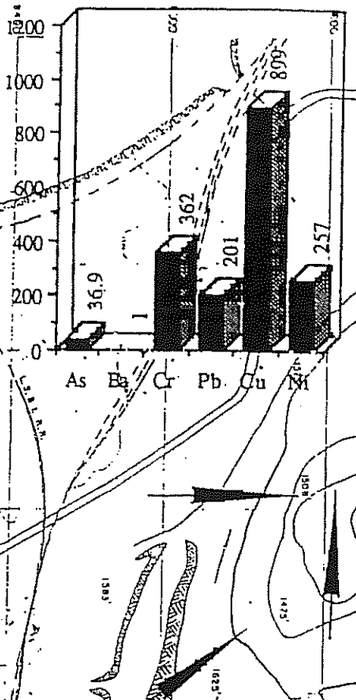
The results for metals exhibiting an average level in sediments exceeding 5 mg/kg are presented in Figure 8. All results are expressed in milligrams of metal per kilogram of wet sediment. To complete the data interpretation, total solids in sediments were evaluated. The average total solid level was 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.

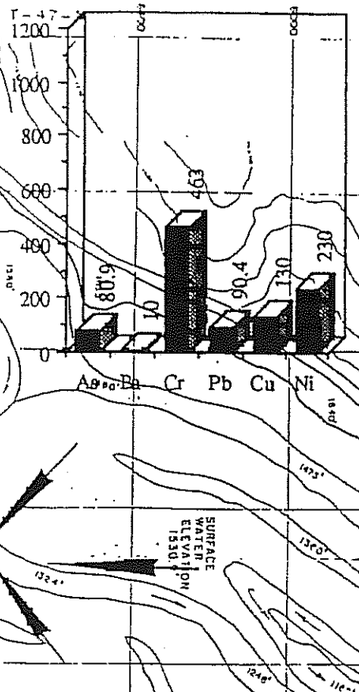
Between the year 1984, when Callahan Mining Corporation acquired the Ropes Mine, and December 31, 1988, date at which production was stopped, a total of 1.92 million tons of ore was processed. Milling tailings which represent 95 percent of the ore, were discharged in the Humboldt Pit. Thus, 1.82 million 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.

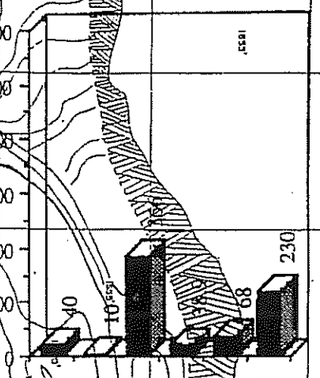
Metal concentrations are expressed in mg/kg of wet sediments

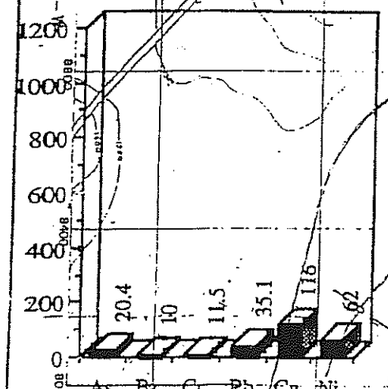
The percentage of solids in sediments samples averaged 70.2 %

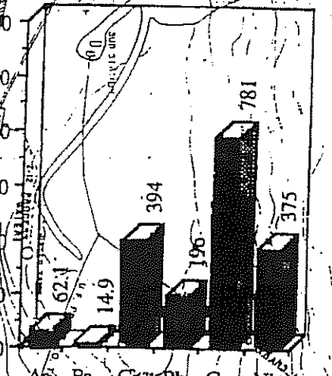


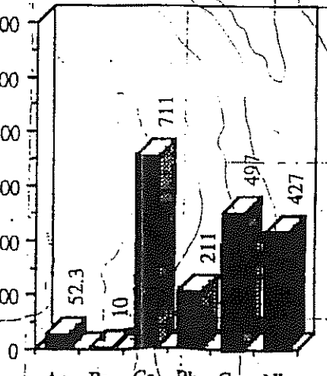


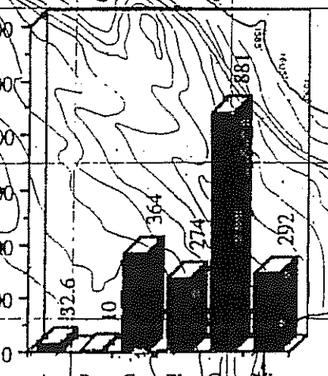


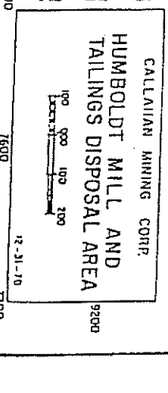




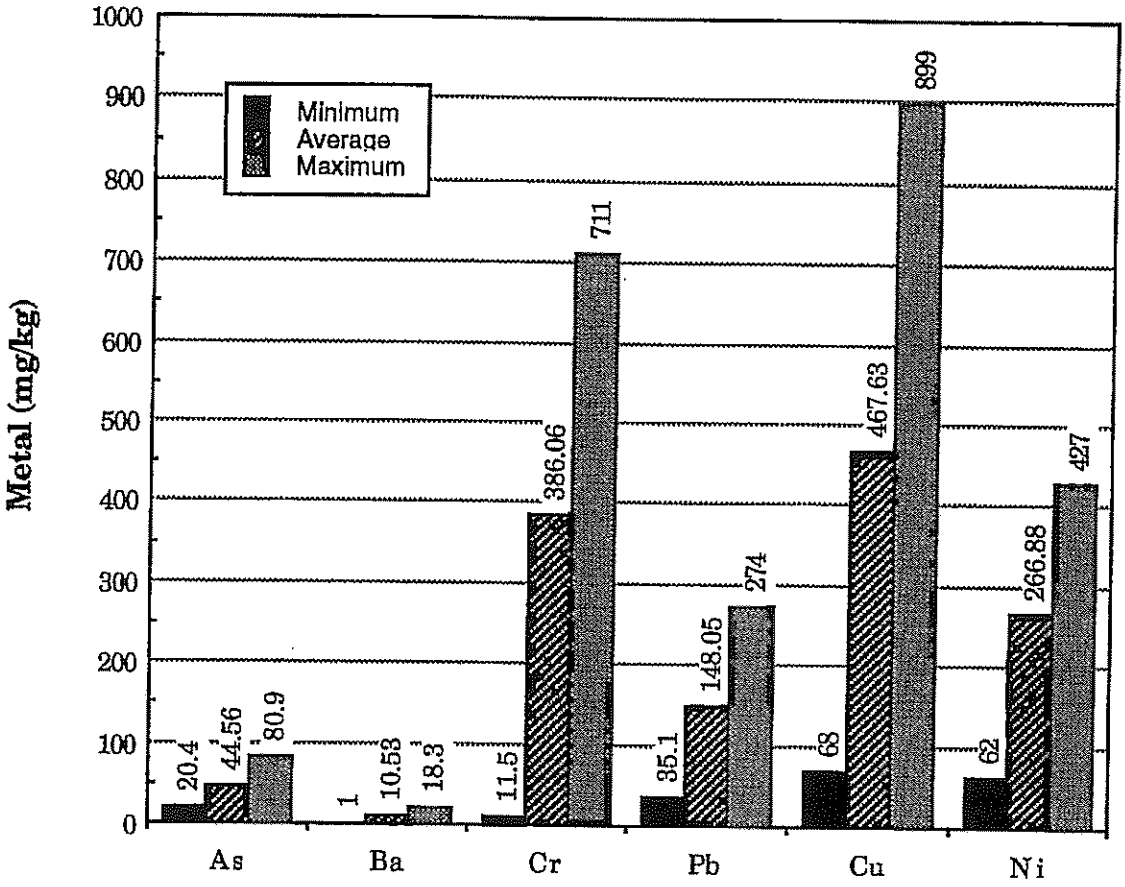








HUMBOLDT PIT SEDIMENTS TOTAL METALS ASSAY



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

Metal	Residual in Total Sediments		Residual in Estimated Noncemented Tailings[a]	
	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
Fax: 612 473 2512

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

545 Indian Mound
Wayzata, Minnesota
55391

Tel: 612 473 4224
Fax: 612 473 2512

Serving the World's Environmental Needs

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

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

545 Indian Mound
Wayzata, Minnesota
55391

Tel: 612 473 4224
Fax: 612 473 2512

Serving the World's Environmental Needs

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

OnLine I

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

OnLine L

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

OnLine I

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

Online 1

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

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

OnLine L

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:	JJF1	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

Foth

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

Foth

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

Foth

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 Values for Each Parameter

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

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

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

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

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

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

	Selenium, total	HNV		HCV			
	Lowest Value	Non-drink	WV	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 Cadmium	A	average H mg/L	B	CFa	CFb	D	Calculated Value
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

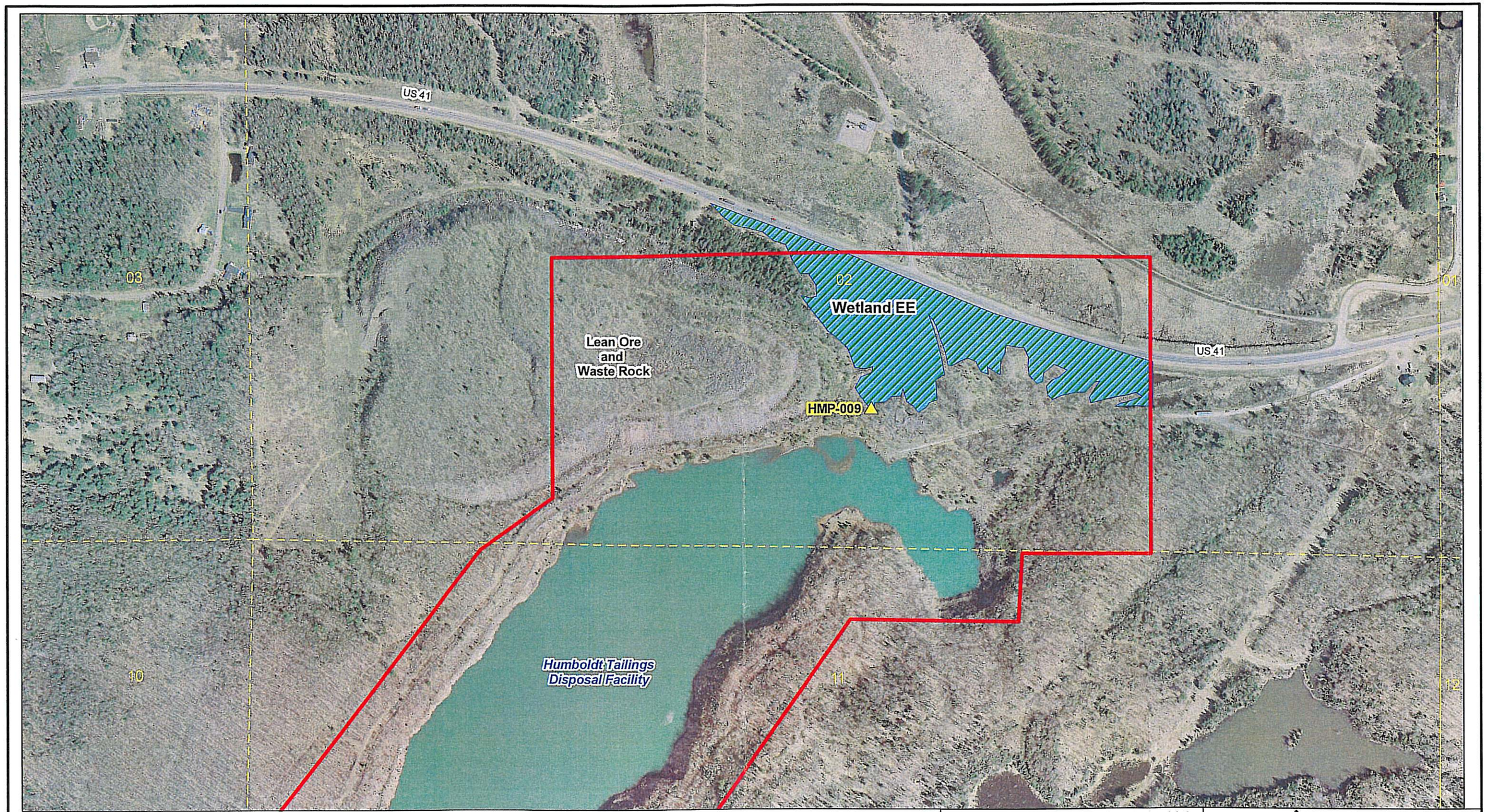
Form: exp(A*Ln H + B) * C * D

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 10, 2007

LEGEND

- PLSS Sections
- Wetland
- KEMC Property Boundary

N

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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:	

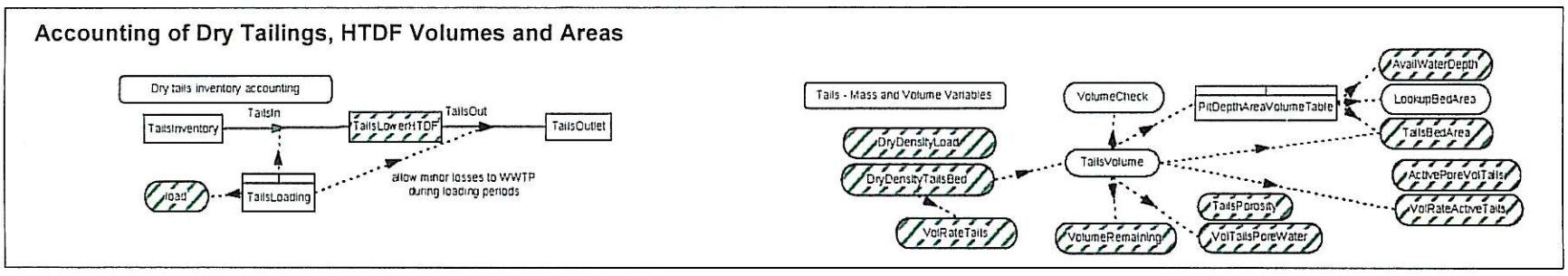
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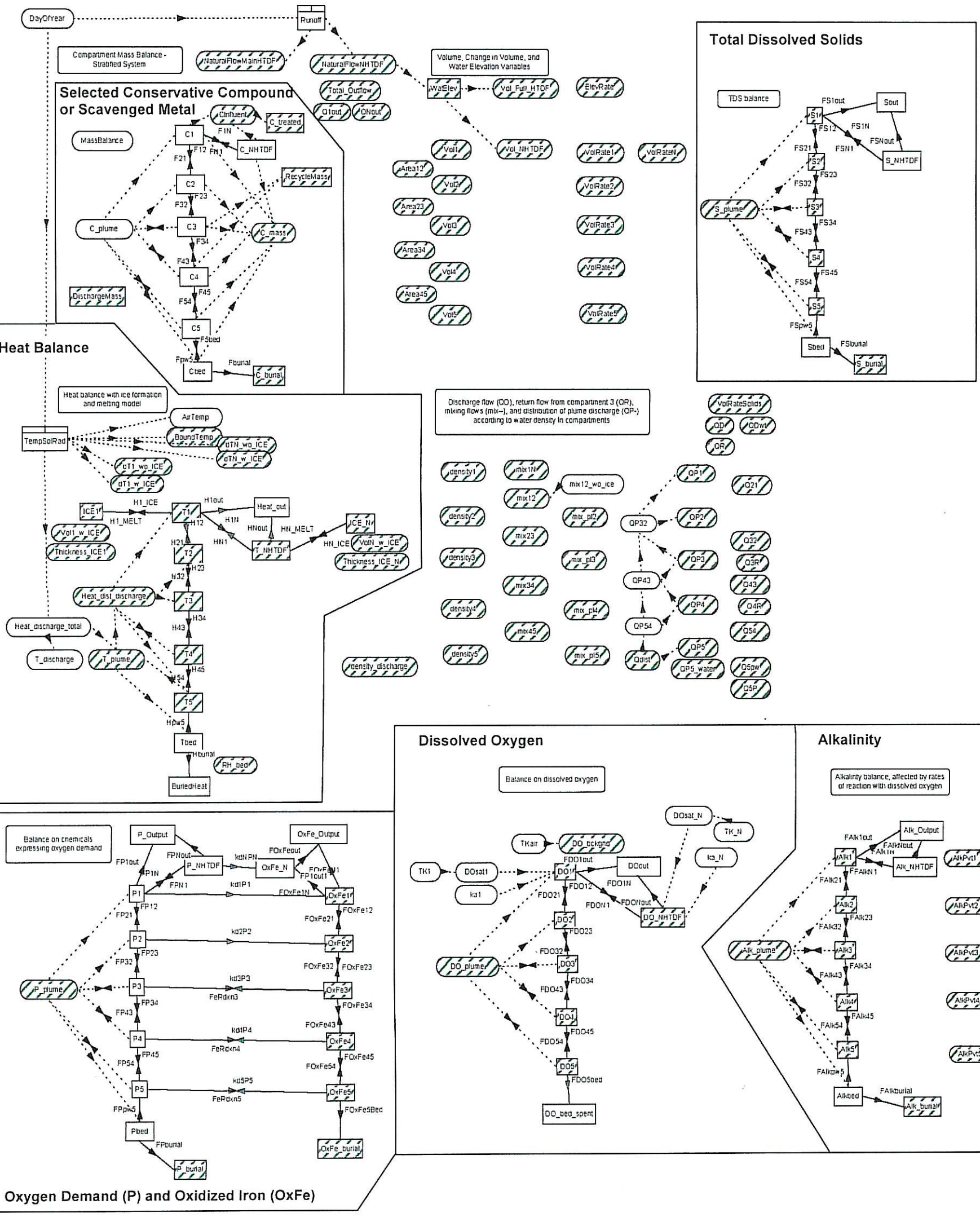
FIGURE 1
HUMBOLDT MILL PROJECT
WETLAND SAMPLING POINT

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

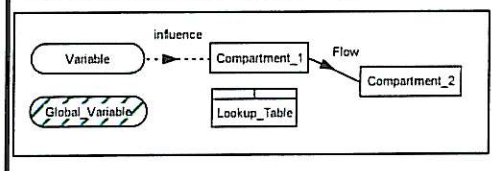
Appendix F

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





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



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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:	

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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

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 * HealFactor * RH_bed
HN1				Y			Y	Flow from T_NHTDF to T1		HN1 = mix1N * T_NHTDF * HealFactor
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-466.7824 (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

Appendix E

Surface Water Management Design Calculations

Surface Water Management Design Calculations

Scope

Design and Analysis for Non-contact Storm Water Management for Humboldt Mill Project

Conditions/Assumptions

The use of the Humboldt site will include improvements that will affect the existing drainage patterns at the site. Proper lay-out and sizing of the resulting drainage facilities will provide efficient use of the site during operations.

In addition to nuisance drainage control and peak flow management, storm water quality issues must be properly addressed. Non-contact storm water runoff, storm water runoff that has not contacted contamination sources, will need proper treatment to control erosion and remove sediments which might typically be generated by any industrial facility. This document summarizes the storm water management features planned for this site to convey and treat the non-contact storm water runoff.

Detailed hydrology was completed for this preliminary design phase of the project. Runoff flows and hydrographs were estimated at key points for the 10, 25, and 100-year storm events. The rainfall amount associated with the 10-year (3.48 in), 25-year (4.17 in), and 100-yr (5.32 in) events were taken from the Natural Resources Conservation Service (NRCS) data listed for Marquette County. Soils characteristics were based on NRCS soils information and site inspection which confirm a highly permeable condition.

Analysis Methodology

The NRCS hydrologic methodology detailed in *Technical Release No. 55 – Urban Hydrology for Small Watersheds* (NRCS, 1986) was used to develop runoff flows at various design points throughout the site. The factors used in this hydrologic model include soils, land use, drainage area (thirteen different sub-watersheds were delineated), time of concentration (estimated travel time of runoff to reach a design point based on path length and velocity), and rainfall. For the soils, a hydrologic soil group A/B was used to model the highly permeable soils predominating this area. For land use, industrial areas including building and bituminous areas were assumed to be impervious and were assigned a curve number (CN) of 98. For undisturbed areas, either a forest cover/rock mixture (CN = 70) or gravel (CN = 85) were used for most areas, with smaller areas designated either as woods/grass (CN = 70) or brush (CN = 67). Calculations are presented in Attachment A to this document.

Although the detailed development of hydrographs and peak flow rates for critical points in the drainage system was completed, some modifications to the sizing of the sedimentation basin, culverts, and ditches may be required during the final design phase. For this effort, the drainage lay-out was completed based on the attempt to collect, convey, and treat as much of the site storm water as possible in one treatment (sedimentation basin) location (see Figure 1). The treatment facility planned is a sedimentation basin designed to remove 5 micron sized particles for the 25-yr, 24-hour storm resulting in over 80% suspended solids removal. Routinely, storm water will infiltrate the basin which is sized hydraulically for a 100-year, 24-hour storm event. Overflow will take place through a 12 inch basin outlet (Figure 2) to a ditch and culvert. Based on basin routing using Haestad Methods PONDPACK software and particle settling performance curves based on Stokes Law, the preliminary basin sizing will provide the peak flow reduction and suspended solids removal performance as shown in Table 1. The lay-out of the sedimentation basin is shown on the Figure 1, with details shown on Figure 2.

Table 1 Sedimentation Basin Design Parameters

Storm Event (24-hr)	Rainfall Depth (in)	Proposed Peak Inflow (cfs)	Proposed Peak Outflow (cfs)	Peak Elevation (feet MSL)	Stored Volume (acre-foot)	Particle Removal Size (Micron)
10-year	3.48	68.8	3.99	1577.85	2.50	4
25-year	4.17	89.0	4.43	1578.57	3.30	4.5
100-year	5.32	124.0	5.08	1579.70	4.73	5.5

cfs – cubic feet per second
MSL – Mean Sea Level
Micron – 0.01 inch

The site drainage patterns generally follow existing or proposed grades, with culverts located where needed to pass the water under roads or rail facilities. Figure 1 shows thirteen storm water drainage basins used as a basis to design the culvert and ditch system. Preliminary culvert sizing is based on the 25-year flows generated above each specific culvert location. The preliminary sizing of the culverts is based on culvert nomographs with inlet control and estimated headwater before road overtop, and is summarized in Table 2.

Table 2 Culvert Size Parameters

Culvert Number	Storm Water Drainage Basin	25-year Flow (cfs)	Minimum Headwater (feet)	Preliminary Culvert Size (inches)
1*	Basin 1	14.5	3.0	18
2	Basin 1,2	21.3	3.0	24
3 A/B**	Basin 3	15.6	3.5	18
4	Basin 6	20.5	3.0	24
5	Basin 7	16.7	2.5	24
6	Basin 6,8	26.2	3.5	24
7	Basin 5,6,8,9,10	65.3	5.0	2 - 24
8	Basin 11	0.42	0.5	12
9	Basin 12	7.3	1.5	18
10***	Basin 13	8.8	2.0	24

cfs – cubic feet per second
*- This existing 12” culvert will be replaced with an 18” culvert.
** - These two culverts drain storm water basin #3.
***- This existing culvert is 24” and will remain in place as is.

Results

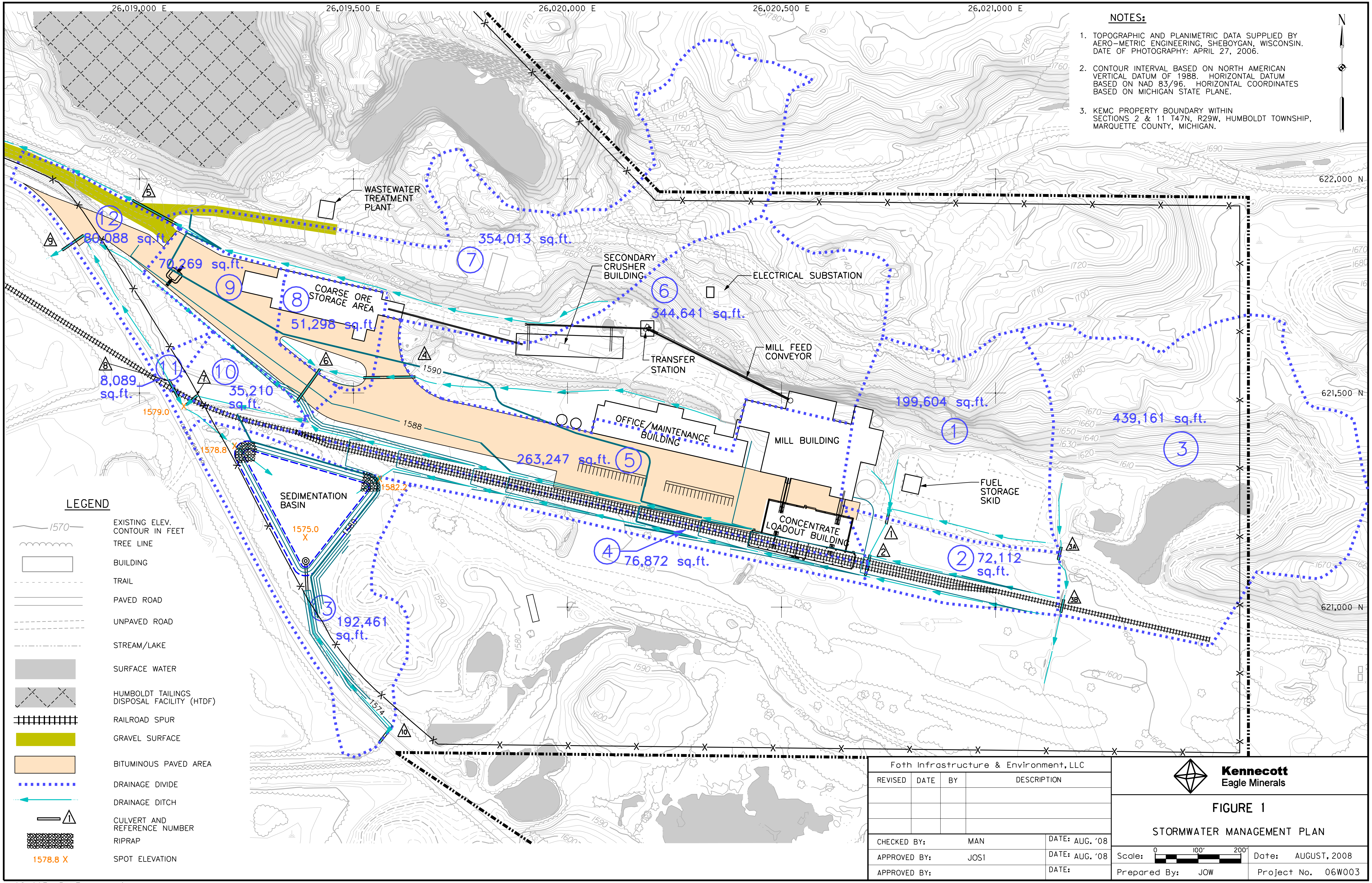
The results of the surface water management design for the Humboldt Mill site are shown on the attached Figure 1 with details on Figure 2. With this lay-out, nearly all of the site’s stormwater runoff will be conveyed to the sedimentation basin for treatment before discharge to waters of the state. The sedimentation basin has been sized for a 100-year, 24-hour storm event. The sedimentation basin will remove a 5 micron particle size for a 25-yr, 24-hr storm event. Only off-site runoff and very small areas at the extreme west and east portions of the site (storm water basins 3, 7, and 12) will be discharged without passing through the sedimentation basin. These areas will see minimal effects from site operations and they are expected to have minimal sediment loads.

Conclusions/Recommendation

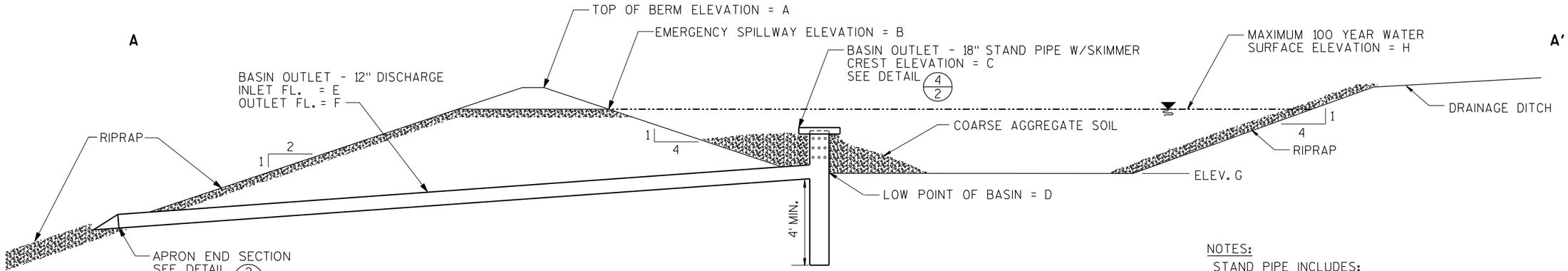
By implementing the surface water management design presented in this document, the desired nuisance, peak flow, and water quality of the storm water from the Humboldt Mill site should meet applicable rules and expected permit requirements. Storm water runoff from the site will be safely collected, conveyed, and treated to satisfactory levels before discharge to waters of the state.

References

NRCS, 1986. *Technical Release No. 55 – Urban Hydrology for Small Watersheds*. July, 2008. Natural Resources Conservation Service, U.S. Department of Agriculture.



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12/15/2008 jow



BASIN ID.	A	B	C	D	E	F	G	H	I
SITE BASIN	1580.0	1579.7	1578.0	1575.0	1575.5	1574.0	1575.0	1579.7	4

NOTES:

STAND PIPE INCLUDES:

1.) 27" DIA. SKIMMER HOOD.

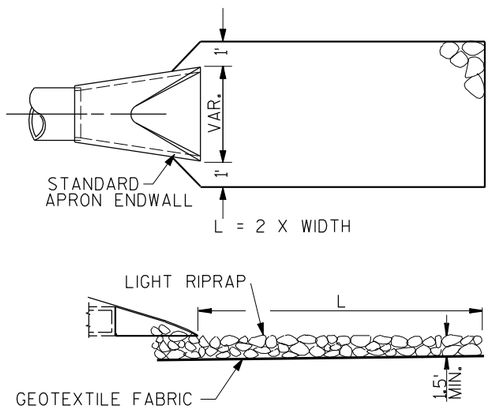
2.) (9)-1/2" DIA. HOLES PER ROW, ROWS 6" ON CENTER.

3.) ALL RIPRAPPED AREAS UNDERLAIN WITH GEOTEXTILE.

I- MICRON PARTICLE SIZE SETTLED BASED ON SURFACE AREA IN SQUARE FEET PER CFS OUTFLOW FOR 25-YR/24-HR STORM EVENT

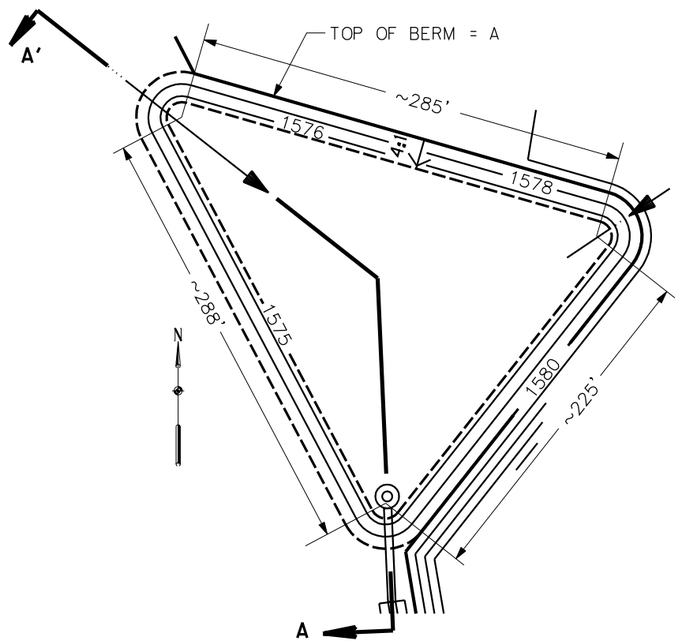
1/2 **TYPICAL SECTION - SEDIMENTATION BASIN**

NOT TO SCALE



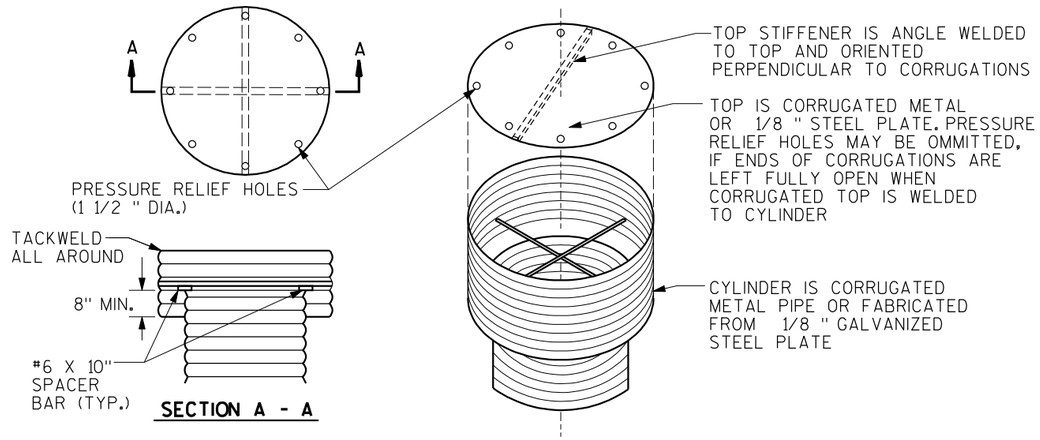
2/2 **RIPRAP CULVERT END DETAIL**

NOT TO SCALE



3/2 **TYPICAL PLAN VIEW - SEDIMENTATION BASIN**

NOT TO SCALE



4/2 **CONCENTRIC SKIMMER AND ANTI-VORTEX DEVICE DETAIL**

NOT TO SCALE

Foth Infrastructure & Environment, LLC

REVISED	DATE	BY	DESCRIPTION

CHECKED BY:	MAN	DATE: AUG. '08
APPROVED BY:	JOS1	DATE: AUG. '08
APPROVED BY:		DATE:

Kennecott Eagle Minerals

FIGURE 2

SEDIMENTATION BASIN DETAILS

Scale:	NOT TO SCALE	Date:	AUGUST, 2008
Prepared By:	JOW	Project No.	06W003

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12/15/2008 jow

Attachment A

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project		
Prepared by:	MAN	Date:	08/14/08
Checked by:	JOS1 / AKM	Date:	08/22/08

Stormwater Peak Flow Calculations

Per NRCS, the following 24-hr precipitation depths for Marquette Co., MI were used:
2 - yr: 2.39 in 10 - yr: 3.48 in 25 - yr: 4.17 in 100 - yr: 5.32 in

Watershed Number	Area (acres)	Curve Number Description	% Area	CN	Time of Concentration Sheet Flow	SCF	Channel Flow
1	4.58	rock & woods	50	70	300' @ 33%	150' @ 3.3 %	350' @ 1.14%
		gravel	50	85			
2	1.66	gravel	100	85	50' @ 4%	50' @ 4%	450' @ 0.89%
3	10.08	rock & woods	50	70	300' @ 20%	200' @ 3%	200' @ 1%
		woods/grass	50	58			
4	1.76	gravel	100	85	25' @ 2 %	-	1600' @ 1.25%
5	6.04	lot/buildings	100	98	300' @ 1.33%		1300' @ 1.5%
6	7.91	rock & woods	70	70	300' @ 41.7	100' @ 10%	1800' @ 1.22%
		gravel	10	85			
		building	5	98			
		dirt	15	82			
7	8.12	rock & woods	50	70	300' @ 23%	350' @ 28.5%	1000' @ 1.6%
		brush - poor	50	67			
8	1.18	lot/buildings	100	98	200 @ 5%	-	-
9	1.61	lot	100	98	150' @ 6.7%	-	450' @ 2.0%
10	0.81	woods/grass	100	70	25' @ 2%	125' @ 4.8%	-
11	0.19	woods/grass	100	70	100 @ 6%	-	-
12	1.84	lot	40	98	50' @ 12%	-	300' @ 0.67%
		gravel	20	85			
		woods/grass	40	70			
13	4.42	woods - fair	100	60	100' @ 10%	100' @ 10%	500' @ 1.2%

Notes:
- The following Manning's n numbers were used: rock (0.02), lot/buildings (0.015), grass/channel (0.03)
- Channel flow dimensions are as follows: 2.0' deep, 3:1 sideslopes, area = 12 ft^2, perimeter = 12.64 ft.

Client:	Kennecott Eagle Minerals Company	Project ID.:	06W003
Project:	Humboldt Mill Project		
Prepared by:	MAN	Date:	08/14/08
Checked by:	JOS1 / AKM	Date:	08/22/08

Sediment Pond Particle Removal Calculations

Design for 5 micron removal for 25 yr, 24-hr storm

From PONDPACK, total runoff into pond = 5.693 ac-ft (247, 987 ft^3)

From Dane Co, WI Stormwater Manual, settling velocity of a 5 micron particle = 0.000073 ft/s

From PONDPACK, maximum depth in sediment pond = 3.6 ft (1578.6 - 1575.0 msl)

Time needed to settle 5 micron particle:

$$\frac{3.6 \text{ ft}}{0.000073 \text{ ft/s}} = 49{,}315 \text{ sec}$$

Maximum allowable pond discharge to obtain 5 micron settling:

$$\frac{247, 987 \text{ ft3}}{49{,}315 \text{ sec}} = 5.03 \text{ cfs}$$

Per PONDPACK, the maximum pond discharge for the 25-yr storm is 4.43 cfs. Sinc this is < 5.03 cfs, the 5 micron particle will settle in the pond.

Pond Pack Watershed Layout

Prepared by: MAN
Checked by: JOS1/AKM

PONDPACK

Model Ouput

25 yr, 24 hr storm

Watershed 1

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 1 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 4.580 acres Runoff CN= 78

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = 14.56 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 14.52 cfs
==========

DRAINAGE AREA

ID:WS 1
CN = 78
Area = 4.580 acres
S = 2.8205 in
0.2S = .5641 in

Cumulative Runoff

2.0233 in
.772 ac-ft

HYG Volume... .772 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 1)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 62.30 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 2

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 2 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.660 acres Runoff CN= 85

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 6.76 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 6.76 cfs
==========

DRAINAGE AREA

ID:WS 2
CN = 85
Area = 1.660 acres
S = 1.7647 in
0.2S = .3529 in

Cumulative Runoff

2.6103 in
.361 ac-ft

HYG Volume... .361 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 2)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 22.58 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 3

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS3 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 10.080 acres Runoff CN= 64

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9397 hrs
Computed Peak Flow = 15.57 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 15.56 cfs
==========

DRAINAGE AREA

ID:WS3
CN = 64
Area = 10.080 acres
S = 5.6250 in
0.2S = 1.1250 in

Cumulative Runoff

1.0694 in
.898 ac-ft

HYG Volume... .898 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS3)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 137.11 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 4

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 4 25
Tc = .1001 hrs
Drainage Area = 1.760 acres Runoff CN= 85

==========
Computational Time Increment = .01334 hrs
Computed Peak Time = 11.9271 hrs
Computed Peak Flow = 6.96 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 6.93 cfs
==========

DRAINAGE AREA

ID:WS 4
CN = 85
Area = 1.760 acres
S = 1.7647 in
0.2S = .3529 in

Cumulative Runoff

2.6103 in
.383 ac-ft

HYG Volume.... .383 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .10006 hrs (ID: WS 4)
Computational Incr, Tm = .01334 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 19.93 cfs
Unit peak time Tp = .06671 hrs
Unit receding limb, Tr = .26683 hrs
Total unit time, Tb = .33353 hrs

Watershed 5

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 5 25
Tc = .1464 hrs
Drainage Area = 6.040 acres Runoff CN= 98

==========
Computational Time Increment = .01951 hrs
Computed Peak Time = 11.9626 hrs
Computed Peak Flow = 29.32 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9601 hrs
Peak Flow, Interpolated Output = 29.30 cfs
==========

DRAINAGE AREA

ID:WS 5
CN = 98
Area = 6.040 acres
S = .2041 in
0.2S = .0408 in

Cumulative Runoff

3.9347 in
1.980 ac-ft

HYG Volume... 1.981 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .14636 hrs (ID: WS 5)
Computational Incr, Tm = .01951 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 46.76 cfs
Unit peak time Tp = .09757 hrs
Unit receding limb, Tr = .39030 hrs
Total unit time, Tb = .48787 hrs

Watershed 6

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 6 25
Tc = .1267 hrs
Drainage Area = 7.918 acres Runoff CN= 75

==========
Computational Time Increment = .01690 hrs
Computed Peak Time = 11.9641 hrs
Computed Peak Flow = 20.49 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9601 hrs
Peak Flow, Interpolated Output = 20.46 cfs
==========

DRAINAGE AREA

ID:WS 6
CN = 75
Area = 7.918 acres
S = 3.3333 in
0.2S = .6667 in

Cumulative Runoff

1.7952 in
1.185 ac-ft

HYG Volume... 1.184 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .12674 hrs (ID: WS 6)
Computational Incr, Tm = .01690 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 70.79 cfs
Unit peak time Tp = .08449 hrs
Unit receding limb, Tr = .33797 hrs
Total unit time, Tb = .42246 hrs

Watershed 7

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 7 25
Tc = .0912 hrs
Drainage Area = 8.120 acres Runoff CN= 69

==========
Computational Time Increment = .01217 hrs
Computed Peak Time = 11.9339 hrs
Computed Peak Flow = 16.74 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 16.70 cfs
==========

DRAINAGE AREA

ID:WS 7
CN = 69
Area = 8.120 acres
S = 4.4928 in
0.2S = .8986 in

Cumulative Runoff

1.3784 in
.933 ac-ft

HYG Volume.... .933 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .09124 hrs (ID: WS 7)
Computational Incr, Tm = .01217 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 100.84 cfs
Unit peak time Tp = .06083 hrs
Unit receding limb, Tr = .24330 hrs
Total unit time, Tb = .30413 hrs

Watershed 8

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 8 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.180 acres Runoff CN= 98

==========

Computational Time Increment	=	.01111 hrs
Computed Peak Time	=	11.9175 hrs
Computed Peak Flow	=	6.38 cfs
Time Increment for HYG File	=	.0200 hrs
Peak Time, Interpolated Output	=	11.9201 hrs
Peak Flow, Interpolated Output	=	6.36 cfs

==========

DRAINAGE AREA

ID:WS 8
CN = 98
Area = 1.180 acres
S = .2041 in
0.2S = .0408 in

Cumulative Runoff

3.9347 in
.387 ac-ft

HYG Volume... .387 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 8)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 16.05 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 9

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 9 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.610 acres Runoff CN= 98

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 8.71 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 8.68 cfs
==========

DRAINAGE AREA

ID:WS 9
CN = 98
Area = 1.610 acres
S = .2041 in
0.2S = .0408 in

Cumulative Runoff

3.9347 in
.528 ac-ft

HYG Volume.... .528 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 9)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 21.90 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 10

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 10 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = .810 acres Runoff CN= 70

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = 1.79 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 1.78 cfs
==========

DRAINAGE AREA

ID:WS 10
CN = 70
Area = .810 acres
S = 4.2857 in
0.2S = .8571 in

Cumulative Runoff

1.4444 in
.097 ac-ft

HYG Volume... .097 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 10)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 11.02 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 11

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 11 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = .190 acres Runoff CN= 70

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = .42 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = .42 cfs
==========

DRAINAGE AREA

ID:WS 11
CN = 70
Area = .190 acres
S = 4.2857 in
0.2S = .8571 in

Cumulative Runoff

1.4444 in
.023 ac-ft

HYG Volume... .023 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 11)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 2.58 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 12

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 12 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.850 acres Runoff CN= 84

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 7.30 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 7.29 cfs
==========

DRAINAGE AREA

ID:WS 12
CN = 84
Area = 1.850 acres
S = 1.9048 in
0.2S = .3810 in

Cumulative Runoff

2.5215 in
.389 ac-ft

HYG Volume... .389 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 12)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 25.16 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 13

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 25 year storm
Duration = 24.0000 hrs Rain Depth = 4.1700 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 13 25
Tc (Min. Tc) = .0833 hrs
Drainage Area = 4.420 acres Runoff CN= 60

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 12.0063 hrs
Computed Peak Flow = 5.09 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 12.0001 hrs
Peak Flow, Interpolated Output = 5.07 cfs
==========

DRAINAGE AREA

ID:WS 13
CN = 60
Area = 4.420 acres
S = 6.6667 in
0.2S = 1.3333 in

Cumulative Runoff

.8467 in
.312 ac-ft

HYG Volume... .312 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 13)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 60.12 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Culvert 1

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 1 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
TO WS1 CULVERT	WS 1	work_pad.hyg	WS 1	25

INFLOWS TO: WS 1 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 1	25	.772	11.9200	14.52

TOTAL FLOW INTO: WS 1 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 1 CULVERT	25	.772	11.9200	14.52

Culvert 2

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 2 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
TO WS2	WS 1 CULVERT	work_pad.hyg	WS 1 CULVERT	25
TO WS2 CULVERT	WS 2	work_pad.hyg	WS 2	25

INFLOWS TO: WS 2 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 1 CULVERT	25	.772	11.9200	14.52
work_pad.hyg	WS 2	25	.361	11.9200	6.76

TOTAL FLOW INTO: WS 2 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 2 CULVERT	25	1.133	11.9200	21.28

Culvert 3A/3B

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 3 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
WS3 DITCH	WS3	work_pad.hyg	WS3	25

INFLOWS TO: WS 3 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS3	25	.898	11.9400	15.56

TOTAL FLOW INTO: WS 3 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 3 CULVERT	25	.898	11.9400	15.56

Culvert 4

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 6 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
TO WS6 CULVERT	WS 6	work_pad.hyg	WS 6	25

INFLOWS TO: WS 6 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 6	25	1.184	11.9600	20.46

TOTAL FLOW INTO: WS 6 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 6 CULVERT	25	1.184	11.9600	20.46

Culvert 5

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 7 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
WS7 DITCH	WS 7	work_pad.hyg	WS 7	25

INFLOWS TO: WS 7 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 7	25	.933	11.9400	16.70

TOTAL FLOW INTO: WS 7 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 7 CULVERT	25	.933	11.9400	16.70

Culvert #6

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 6_8 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
WS8 OUTLET	WS 8	work_pad.hyg	WS 8	25
FROM WS6	WS 6 CULVERT	work_pad.hyg	WS 6 CULVERT	25

INFLOWS TO: WS 6_8 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 8	25	.387	11.9200	6.36
work_pad.hyg	WS 6 CULVERT	25	1.184	11.9600	20.46

TOTAL FLOW INTO: WS 6_8 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 6_8 CULVERT	25	1.571	11.9400	26.19

Culvert #7

SUMMARY FOR HYDROGRAPH ADDITION
at Node: CULVERT UNDER RR

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
FROM WS10	WS 10	work_pad.hyg	WS 10	25
FROM WS9	WS 9	work_pad.hyg	WS 9	25
FROM WS5	WS 5	work_pad.hyg	WS 5	25
FROM WS6_8	WS 6_8 CULVERT	work_pad.hyg	WS 6_8 CULVERT	25

INFLOWS TO: CULVERT UNDER RR

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 10	25	.097	11.9400	1.78
work_pad.hyg	WS 9	25	.528	11.9200	8.68
work_pad.hyg	WS 5	25	1.981	11.9600	29.30
work_pad.hyg	WS 6_8 CULVERT	25	1.571	11.9400	26.19

TOTAL FLOW INTO: CULVERT UNDER RR

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	CULVERT UNDER RR	25	4.177	11.9400	65.27

Culvert 8

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS11 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
FROM WS11	WS 11	work_pad.hyg	WS 11	25

INFLOWS TO: WS11 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 11	25	.023	11.9200	.42

TOTAL FLOW INTO: WS11 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS11 CULVERT	25	.023	11.9200	.42

Culvert 9

SUMMARY FOR HYDROGRAPH ADDITION
at Node: WS 12 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
WS12 DITCH	WS 12	work_pad.hyg	WS 12	25

INFLOWS TO: WS 12 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 12	25	.389	11.9200	7.29

TOTAL FLOW INTO: WS 12 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 12 CULVERT	25	.389	11.9200	7.29

Culvert #10

SUMMARY FOR HYDROGRAPH ADDITION
at Node: 601 CULVERT

HYG Directory: C:\Program Files\Haestad\PPKW\Sample\

Upstream Link ID	Upstream Node ID	HYG file	HYG ID	HYG tag
TO 601 CULVERT	WS 13	work_pad.hyg	WS 13	25
WARNING: Adding in hydrograph that is truncated on right...				
POND DISCHARGE	SED POND	IN	work_pad.hyg	POND DISCHARGE 25

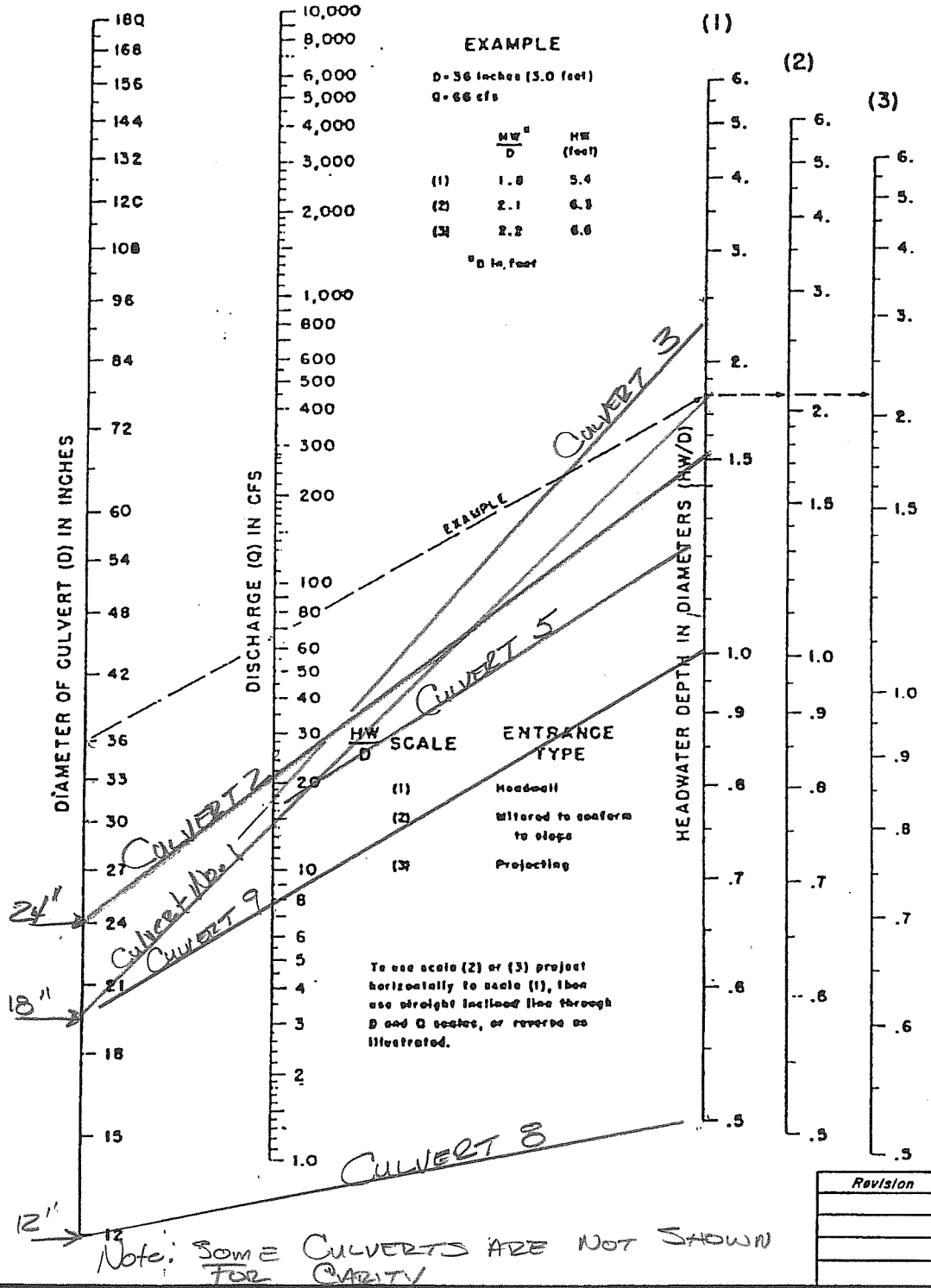
INFLOWS TO: 601 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	WS 13	25	.312	12.0000	5.07
work_pad.hyg	POND DISCHARGE	25	5.570	13.3000	4.43

TOTAL FLOW INTO: 601 CULVERT

HYG file	HYG ID	HYG tag	Volume ac-ft	Peak Time hrs	Peak Flow cfs
work_pad.hyg	601 CULVERT	25	5.882	12.0000	8.83

NOMOGRAPH - INLET CONTROL CMP



Revision	Date

Note: Some Culverts are Not Shown For Clarity

WRC ENGINEERING	REFERENCE: USDOT, FHWA, HDS No. 5, 1985	FIGURE 1007

REFERENCE: Hydrologic Criteria and Drainage Design Manual, August 12, 1999

Sediment Basin

LEVEL POOL ROUTING SUMMARY

HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
Inflow HYG file = work_pad.hyg - SED POND IN 25
Outflow HYG file = work_pad.hyg - SED POND OUT 25

Pond Node Data = SED POND
Pond Volume Data = SED POND
Pond Outlet Data = Outlet

No Infiltration

INITIAL CONDITIONS

Starting WS Elev	= 1575.00	ft
Starting Volume	= .000	ac-ft
Starting Outflow	= .00	cfs
Starting Infiltr.	= .00	cfs
Starting Total Qout	= .00	cfs
Time Increment	= .0200	hrs

INFLOW/OUTFLOW HYDROGRAPH SUMMARY

Peak Inflow	= 89.00	cfs	at	11.9600 hrs
Peak Outflow	= 4.44	cfs	at	13.3000 hrs
Peak Elevation	= 1578.57	ft		
Peak Storage	= 3.308	ac-ft		

MASS BALANCE (ac-ft)

+ Initial Vol	=	.000
+ HYG Vol IN	=	5.716
- Infiltration	=	.000
- HYG Vol OUT	=	5.570
- Retained Vol	=	.146
Unrouted Vol	=	-.000 ac-ft (.001% of Inflow Volume)

WARNING: Outflow hydrograph truncated on right side.

PONDPACK

Model Ouput

100 yr, 24 hr storm

Watershed 1

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 1 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 4.580 acres Runoff CN= 78

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = 21.45 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 21.45 cfs
==========

DRAINAGE AREA

ID:WS 1
CN = 78
Area = 4.580 acres
S = 2.8205 in
0.2S = .5641 in

Cumulative Runoff

2.9854 in
1.139 ac-ft

HYG Volume... 1.139 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 1)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 62.30 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 2

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 2 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.660 acres Runoff CN= 85

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 9.39 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 9.38 cfs
==========

DRAINAGE AREA

ID:WS 2
CN = 85
Area = 1.660 acres
S = 1.7647 in
0.2S = .3529 in

Cumulative Runoff

3.6650 in
.507 ac-ft

HYG Volume... .507 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 2)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 22.58 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 3

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS3 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 10.080 acres Runoff CN= 64

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = 27.53 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 27.35 cfs
==========

DRAINAGE AREA

ID:WS3
CN = 64
Area = 10.080 acres
S = 5.6250 in
0.2S = 1.1250 in

Cumulative Runoff

1.7921 in
1.505 ac-ft

HYG Volume... 1.505 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS3)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 137.11 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 4

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 4 100
Tc = .1001 hrs
Drainage Area = 1.760 acres Runoff CN= 85

==========
Computational Time Increment = .01334 hrs
Computed Peak Time = 11.9271 hrs
Computed Peak Flow = 9.68 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 9.61 cfs
==========

DRAINAGE AREA

ID:WS 4
CN = 85
Area = 1.760 acres
S = 1.7647 in
0.2S = .3529 in

Cumulative Runoff

3.6650 in
.538 ac-ft

HYG Volume... .538 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .10006 hrs (ID: WS 4)
Computational Incr, Tm = .01334 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 19.93 cfs
Unit peak time Tp = .06671 hrs
Unit receding limb, Tr = .26683 hrs
Total unit time, Tb = .33353 hrs

Watershed 5

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 5 100
Tc = .1464 hrs
Drainage Area = 6.040 acres Runoff CN= 98

==========
Computational Time Increment = .01951 hrs
Computed Peak Time = 11.9626 hrs
Computed Peak Flow = 37.53 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9601 hrs
Peak Flow, Interpolated Output = 37.50 cfs
==========

DRAINAGE AREA

ID:WS 5
CN = 98
Area = 6.040 acres
S = .2041 in
0.2S = .0408 in

Cumulative Runoff

5.0827 in
2.558 ac-ft

HYG Volume... 2.559 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .14636 hrs (ID: WS 5)
Computational Incr, Tm = .01951 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 46.76 cfs
Unit peak time Tp = .09757 hrs
Unit receding limb, Tr = .39030 hrs
Total unit time, Tb = .48787 hrs

Watershed 6

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 6 100
Tc = .1267 hrs
Drainage Area = 7.918 acres Runoff CN= 75

==========
Computational Time Increment = .01690 hrs
Computed Peak Time = 11.9472 hrs
Computed Peak Flow = 31.09 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9601 hrs
Peak Flow, Interpolated Output = 31.08 cfs
==========

DRAINAGE AREA

ID:WS 6
CN = 75
Area = 7.918 acres
S = 3.3333 in
0.2S = .6667 in

Cumulative Runoff

2.7112 in
1.789 ac-ft

HYG Volume... 1.789 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .12674 hrs (ID: WS 6)
Computational Incr, Tm = .01690 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 70.79 cfs
Unit peak time Tp = .08449 hrs
Unit receding limb, Tr = .33797 hrs
Total unit time, Tb = .42246 hrs

Watershed 7

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 7 100
Tc = .0912 hrs
Drainage Area = 8.120 acres Runoff CN= 69

==========
Computational Time Increment = .01217 hrs
Computed Peak Time = 11.9339 hrs
Computed Peak Flow = 27.35 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 27.18 cfs
==========

DRAINAGE AREA

ID:WS 7
CN = 69
Area = 8.120 acres
S = 4.4928 in
0.2S = .8986 in

Cumulative Runoff

2.1930 in
1.484 ac-ft

HYG Volume... 1.484 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .09124 hrs (ID: WS 7)
Computational Incr, Tm = .01217 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 100.84 cfs
Unit peak time Tp = .06083 hrs
Unit receding limb, Tr = .24330 hrs
Total unit time, Tb = .30413 hrs

Watershed 8

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 8 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.180 acres Runoff CN= 98

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 8.17 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 8.14 cfs
==========

DRAINAGE AREA

ID:WS 8
CN = 98
Area = 1.180 acres
S = .2041 in
0.2S = .0408 in

Cumulative Runoff

5.0827 in
.500 ac-ft

HYG Volume... .500 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 8)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 16.05 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 9

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 9 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.610 acres Runoff CN= 98

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 11.14 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 11.11 cfs
==========

DRAINAGE AREA

ID:WS 9
CN = 98
Area = 1.610 acres
S = .2041 in
0.2S = .0408 in

Cumulative Runoff

5.0827 in
.682 ac-ft

HYG Volume... .682 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 9)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 21.90 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 10

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 10 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = .810 acres Runoff CN= 70

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = 2.88 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 2.87 cfs
==========

DRAINAGE AREA

ID:WS 10
CN = 70
Area = .810 acres
S = 4.2857 in
0.2S = .8571 in

Cumulative Runoff

2.2766 in
.154 ac-ft

HYG Volume... .154 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 10)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 11.02 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 11

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 11 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = .190 acres Runoff CN= 70

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9286 hrs
Computed Peak Flow = .68 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = .67 cfs
==========

DRAINAGE AREA

ID:WS 11
CN = 70
Area = .190 acres
S = 4.2857 in
0.2S = .8571 in

Cumulative Runoff

2.2766 in
.036 ac-ft

HYG Volume... .036 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 11)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 2.58 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 12

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 12 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 1.850 acres Runoff CN= 84

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9175 hrs
Computed Peak Flow = 10.22 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9201 hrs
Peak Flow, Interpolated Output = 10.21 cfs
==========

DRAINAGE AREA

ID:WS 12
CN = 84
Area = 1.850 acres
S = 1.9048 in
0.2S = .3810 in

Cumulative Runoff

3.5644 in
.550 ac-ft

HYG Volume... .549 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 12)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 25.16 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Watershed 13

SCS UNIT HYDROGRAPH METHOD

STORM EVENT: 100 year storm
Duration = 24.0000 hrs Rain Depth = 5.3200 in
Rain Dir = C:\Program Files\Haestad\PPKW\Sample\
Rain File -ID = - TypeII 24hr
Unit Hyd Type = Default Curvilinear
HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
HYG File - ID = work_pad.hyg - WS 13 100
Tc (Min. Tc) = .0833 hrs
Drainage Area = 4.420 acres Runoff CN= 60

==========
Computational Time Increment = .01111 hrs
Computed Peak Time = 11.9397 hrs
Computed Peak Flow = 9.71 cfs

Time Increment for HYG File = .0200 hrs
Peak Time, Interpolated Output = 11.9401 hrs
Peak Flow, Interpolated Output = 9.70 cfs
==========

DRAINAGE AREA

ID:WS 13
CN = 60
Area = 4.420 acres
S = 6.6667 in
0.2S = 1.3333 in

Cumulative Runoff

1.4919 in
.550 ac-ft

HYG Volume... .550 ac-ft (area under HYG curve)

***** SCS UNIT HYDROGRAPH PARAMETERS *****

Time Concentration, Tc = .08330 hrs (ID: WS 13)
Computational Incr, Tm = .01111 hrs = 0.20000 Tp

Unit Hyd. Shape Factor = 483.432 (37.46% under rising limb)
K = 483.43/645.333, K = .7491 (also, K = 2/(1+(Tr/Tp))
Receding/Rising, Tr/Tp = 1.6698 (solved from K = .7491)

Unit peak, qp = 60.12 cfs
Unit peak time Tp = .05553 hrs
Unit receding limb, Tr = .22213 hrs
Total unit time, Tb = .27767 hrs

Sediment Pond

LEVEL POOL ROUTING SUMMARY

HYG Dir = C:\Program Files\Haestad\PPKW\Sample\
Inflow HYG file = work_pad.hyg - SED POND IN 100
Outflow HYG file = work_pad.hyg - SED POND OUT 100

Pond Node Data = SED POND
Pond Volume Data = SED POND
Pond Outlet Data = Outlet

No Infiltration

INITIAL CONDITIONS

Starting WS Elev	=	1575.00 ft
Starting Volume	=	.000 ac-ft
Starting Outflow	=	.00 cfs
Starting Infiltr.	=	.00 cfs
Starting Total Qout	=	.00 cfs
Time Increment	=	.0200 hrs

INFLOW/OUTFLOW HYDROGRAPH SUMMARY

Peak Inflow	=	124.01 cfs	at	11.9400 hrs
Peak Outflow	=	5.08 cfs	at	13.6400 hrs
Peak Elevation	=	1579.70 ft		
Peak Storage	=	4.732 ac-ft		

MASS BALANCE (ac-ft)

+ Initial Vol	=	.000
+ HYG Vol IN	=	7.902
- Infiltration	=	.000
- HYG Vol OUT	=	7.701
- Retained Vol	=	.202
Unrouted Vol	=	-.000 ac-ft (.001% of Inflow Volume)

WARNING: Outflow hydrograph truncated on right side.

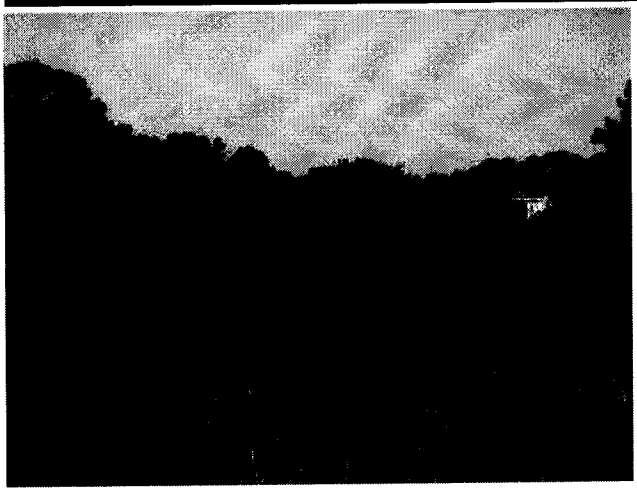
Appendix F

NRCS Native Grass Planting Guide

NATIVE GRASS PLANTING

CONSERVATION RESERVE ENHANCEMENT PROGRAM CREP-CP2

Natural Resources Conservation Service (NRCS) Oct. 2000



WHAT IS A NATIVE GRASS PLANTING?

The purpose of a native grass planting is to establish a vegetative cover of native grasses that will enhance the landscape. Native grasses were present in Michigan when Europeans arrived. Many of these grasses are associated with native prairies, barrens and savannahs.

Native grass plantings of warm-season species provide excellent winter cover for wildlife. These tall, stiff, upright grasses stand up well to snow and ice. They also put most of their growth on in the heat of the summer unlike the cool-season grasses of your lawn which grow most in the spring and fall.

Native grasses will live a long time after establishment. However, like most long-lived plant species, they generally establish slowly. Therefore, it is very important to establish these grasses properly and to have patience when evaluating the results.

ELIGIBILITY

To be eligible for this practice with the Conservation Reserve Enhancement Program, the land must be within the approved watershed, have a cropping history (two out of the last five years), must have an Erodibility Index (EI) of 8 or greater for wind and/or water erosion, and be within 1000 feet of permanent water such as a lake, stream or river.

PLANTING

It is very important to plant warm season grasses into a weed-free, firm seedbed.

Begin weed control efforts the summer before the planned spring planting. Use an herbicide or tillage to eliminate competing vegetation. If necessary for erosion control, seed a temporary cover of oats in late August. Oats will die with freezing temperatures. Again, eliminate competing vegetation at planting time with tillage or herbicides.

Plant during the period of April 15th to June 15th. Use a no-till or conventional drill that is able to handle the *fluffy* grass seeds. Most warm-season grasses are *fluffy*. The seeds contain multiple awns or beards that give them a fluffy appearance. These fluffy seeds stick together and do not easily flow in a grain drill. Many times a special planter is required. It is also possible to purchase "debearded" seed that is no longer fluffy. Apply lime and fertilizer according to needs determined by a soil test.

Warm-season grasses prefer a firm seedbed to ensure good soil to seed contact. That is one reason why some of the best results have been with no-till methods. Plant the seed at a depth of 1/8 inch in the soil.

OTHER MANAGEMENT CONSIDERATIONS

Noxious weeds and other undesirable plants, insects, and pests shall be controlled, including such maintenance as necessary to avoid detrimental effects to the surrounding land.

For optimum wildlife habitat, plant a diversity of grasses and wildflowers. This mixture will provide insect production for young birds to feed on while providing flowers for pollinating insects.

Plant a mixture of introduced grasses and legumes, CREP-CP1, to provide brood rearing habitat. A minimum of 30 percent of the area must be planted to the CP1 practice. Plant the introduced grasses in blocks or wide strips with irregular boundaries to provide the best habitat.

If the field contains areas that were wetlands in the past, consider restoring these areas to a wetland using the "CREP-CP23 Wetland Restoration" practice. To develop shallow water areas for wildlife, consider installing the "CREP-CP9 Shallow Water Areas for Wildlife" practice.

NRCS, Michigan
Oct. 2000

OPERATION AND MAINTENANCE

These plantings may not be used for pasture or hay production.

Since warm-season grasses are slow starters, it is important to control unwanted vegetation, especially the first year. Use mowing or herbicides as needed the first summer to control unwanted vegetation. Potential herbicides include 2-4D for mixtures without wildflowers. For mixtures with wildflowers, consider Plateau (not on switchgrass) or Pursuit. For additional information on herbicide controls, see Conservation Management Sheet "Establishing Prairie Grass Buffer Strips." Always apply herbicides according to labeled directions.

After the first year, use mowing or burning to manage the stand according to your CREP conservation plan. The field can only be mowed or burned to maintain stand health, maintain stand diversity or control noxious weeds. Burning must be in accordance with a prescribed burn plan. See the Conservation Information Sheet "Prescribed Burning" for further information. No more than one-third of the field can be disturbed in any year. A system of mowing or burning the field in alternating strips or blocks is best for wildlife. This ensures that a portion of the field has undisturbed vegetation and provides additional vegetation diversity to the field. Mow or burn before April 1 or between Aug 1st and Aug 20th.

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NATIVE GRASS PLANTINGS DESIGN WORKSHEET CP-2

Participant: Field: Tract: Date:

Requirements

Before planting:

_____ Lime according to soil test _____ Fertilize according to soil test (1 year after planting) _____ Weed – free seedbed	_____ Plant April 15th to June 15th _____ Firm Seedbed _____ Plant 1/8 inch deep

Seeding mixture#1: (lbs. per acre PLS) Upland Soils	**Or Other mixture:**
Big blue stem @ 2 lbs.\acre (pls) Indiangrass @ 2 lbs.\acre (pls) Little blue stem @ 2 lb.\acre (pls) Upland Wildflower mixture @ 0.5lb.\acre **Seeding mixture #2: (lbs. per acre PLS) Wet Soils** Big blue stem @ 2 lb.\acre (pls) Switchgrass @ 2lbs.\acre (pls) Little blue stem @ 1 lbs\acre (pls) Lowland Wildflower mixture @ 0.5lb.\acre	

Considerations:

_____ Mow or herbicide first year as needed
_____ Food plots
_____ Restore wetlands
_____ Plant blocks or strips of CREP-CP1
_____ Impacts on Threatened and Endangered Species

Acres to be seeded:

Mixture #1

Mixture #2

Maintenance

_____ Mow or burn the area to maintain the health of the stand, improve diversity or control noxious weeds.

_____ No more than one-third of the field can be mowed or burned in any year.

_____ Other:

Seeding

Description

Seeding is the establishment of a temporary or permanent vegetative cover by planting seed. For the purposes of this BMP, "grass" and "turf" will be used interchangeably.

This BMP does not address planting individual sprigs of grasses or other vegetation. See the Trees, Shrubs, and Ground Covers BMP for information on planting sprigs.

Other Terms Used to Describe

Hydroseeding
Vegetative Cover

Pollutants Controlled and Impacts

Once established, turf helps keep soil on site, absorbs nutrients, and allows groundwater recharge.

Application

Land Use
This BMP is applicable to all land uses.

Soil/Topography/Climate
Vegetative establishment is important on all exposed areas, but particularly on sloping terrain and areas adjacent to waterbodies or wetlands. It is also important in areas which frequently flood or which are impacted by spring runoff or strong winds.

When to Apply
Seed should be applied immediately after grading and preparation of the seed bed is finished on each small segment of a construction project. Mulch and/or soil erosion control blankets should be used to keep seed in place until the vegetation is established.

Where to Apply
Apply on all construction or earth change sites which require temporary or permanent vegetative stabilization.

Relationship With Other BMPs

Seeding can be used in conjunction with almost all temporary and permanent soil erosion and sedimentation control measures. Any fertilizer or lime that is applied should be done based on the results of soil tests. See the Soil Management BMP. Mulching should be used in conjunction with seeding to ensure establishment of an effective vegetative cover.

Proper grading is needed to ensure the seed bed is adequate for seed application. See the "Site Preparation" section, below.

Specifications

Planning Considerations:

1. The proper **species** of seed should be selected following basic integrated pest management practices (see the Pesticide Management BMP). To reduce the amount of fertilizer, pesticides and other inputs needed, choose adapted varieties based on environmental conditions, management level desired, and the intended use. Consider mixes because they are more adaptable than single species.

2. The proper **time to seed** is dependent upon the climate of the area. In Michigan, there are three different climatic areas which determine when seeding should occur. These are included in Exhibits 1 and 2.

   Seeding dates for permanent cover and dormant seeding are given in Exhibit 1. Dormant seeding is done after the normal growing season, using seed which will lay dormant in the winter but start growing as soon as soil conditions are favorable. Note that perennial grasses should be used for all permanent cover.

   To determine seeding dates for temporary cover use Exhibit 2. Note that the seeds listed here are annual grasses. Be sure to use annual grasses for all temporary cover. Seed mixtures for temporary seeding usually consist of rye or wheat. These species grow better after over-wintering (via a process called vernalization).

3. **Seeding mixture** for permanent cover. For permanent cover, the appropriate seeding mixture is determined in a two-step process. First, consult Exhibit 3, which lists various land uses and site conditions. Determine conditions at your site and use the table to come up with an appropriate seeding mixture number. Exhibits 4 and 5 indicate the various species and seeding rates associated with the selected seeding mixture number on a pound per acre and 1,000 square foot basis, respectively.

   Seeding mixtures for dormant seedings. Use Exhibits 3, 4, and 5 to determine proper seeding mixtures. Dormant seedings are completed in the late fall after the soil temperature remains consistently below 50°F. Perennial grasses are to be used with all dormant seedings.

   Seeding mixtures for temporary cover. Temporary vegetative cover is provided to protect Spoil Piles and larger areas which are staged. Seeding mixtures for temporary vegetative cover are given in Exhibit 2.

4. Subsurface Drains may be needed where water movement may cause seeps or soil slippage. Wet waterways should be tiled to ensure the vegetation is established.

5. Note: Some wildflower seed packages contain seeds of plant species which will compete with native plants. For example, some packages contain purple loosestrife, which is detrimental to cattail populations. The Department therefore does not recommend wildflower plantings unless the seed can be certified as being native to Michigan and is appropriate to the soil and other site conditions.

Site Preparation:

1. Consider protecting seeded areas from pedestrian access using the Construction Barriers BMP.

2. Where possible, divert concentrated flows away from the seeded area at least until the vegetation is established. Follow specifications in the Diversions BMP.

3. Soil tests should be done to determine the nutrient and pH content of the soil. Depending on the results of soil tests, Soil Management may be necessary to adjust the pH to between 6.5 and 7.0 (for most conditions). All lime, fertilizer and other soil amendments should be addressed following the Soil Management specifications. Note that sandy loam, loam, and silt loam are the preferred soils for seeding. Consideration should be given to incorporating these soils into the seedbed.

4. Prepare a 3-5-inch deep seedbed, with the top 3-4 inches consisting of topsoil. Note that the earth bed upon which the topsoil is to be placed should be at the required grade.

5. The seedbed should be firm but not compact. The top three inches of soil should be loose, moist and free of large clods and stones. For most applications, all stones larger than 2 inches in diameter, roots, litter and any foreign matter should be raked and removed. The topsoil surface should be in reasonably close conformity to the lines, grades and cross sections shown on the grading plans.

6. Slopes steeper than 3:1 should be roughened.

Planting:

1. Seed should be applied as soon after seedbed preparation as possible, when the soil is loose and moist. If the seedbed has been idle long enough for the soil to become compact, the topsoil should be harrowed with a disk, a spring tooth drag, a spike tooth drag, or other equipment designed to condition the soil for seeding. Harrowing should be done horizontally across the face of the slope.

2. Always apply seed before mulch.

3. Apply seed at the rates specified in the attached Exhibits using calibrated spreaders, cyclone seeders, mechanical drills, or hydroseeders.

4. Ideally, broadcast seed should be incorporated into the soil by raking or chain dragging, or otherwise floated, then lightly compacted to provide good seed-soil contact.

5. For hydroseeding operations:

   - Seed should be applied at recommended rates. If no rates are given, use 150-200 lbs/acre.

   - Use 2 tons/acre straw mulch, unless otherwise recommended. Use 3 tons/acre when dormant.

- If recycled newsprint is used, follow specifications in the Mulching BMP.

6. All newly seeded areas should be protected from erosive forces by mulch. See the Mulching BMP.

7. Species of grasses which cannot be planted with seed should be planted by sprigging or sodding. See the Trees, Shrubs and Ground Covers BMP for information on sprigging, and the Sodding BMP for information on sodding.

8. Excess topsoil should be disposed of following specifications in the Spoil Piles BMP.

Maintenance

Newly seeded areas need to be inspected frequently for the first few months to ensure the grass is growing. If the seeded area is damaged due to runoff, additional stormwater measures may be needed. Spot Seeding can be done on small areas to fill in bare spots where grass didn't grow properly.

Once the vegetation is well established:

1. Construction Barriers may be removed.

2. Water the grass following specifications in the Lawn Maintenance BMP.

3. If the grass is to be mowed, keep it to a height appropriate for the species selected and the intended use. Follow mowing specifications in the Lawn Maintenance BMP.

4. Occasional soil tests should be collected and analyzed to determine if the soil is appropriately fertilized. Follow the procedures in the Soil Management BMP.

5. Control pests following specifications in the Pesticide Management BMP.

6. Refer to the Lawn Maintenance BMP for determining the steps which can be taken to improve unhealthy turf.

Exhibits

Exhibit 1: Seeding Dates for Permanent Cover. Modified from the Soil Conservation Service Technical Guide, #342.

Exhibit 2: Seeding Dates for Temporary Vegetation. USDA Soil Conservation Service Technical Guide, #342.

Exhibit 3: Determining the Appropriate Seed Mixture. Extracted from USDA Soil Conservation Service Technical Guide, #342.

Exhibit 4: Seeding Mixture (in pounds/acre). Extracted from USDA Soil Conservation Service Technical Guide, #342.

Exhibit 5: Seeding Mixture (in pounds/1,000 ft^2). Extracted from USDA Soil Conservation Service Technical Guide, #342.

Exhibit 1

Seeding Dates for Permanent Cover

Zones	Normal Seeding Dates	Dormant* Seeding Dates
Lower Peninsula, South of U.S. 10	May 1 to October 10	Nov. 1 to freeze up
Lower Peninsula, North of U.S. 10	May 1 to October 1	Oct. 25 to freeze up
Upper Peninsula, entire area	May 1 to Sept. 20	Oct. 20 to freeze up

* Dormant seeding may be done in the late fall after the soil temperature remains consistently below 50°F. This is appropriate if construction on a site is completed in the fall but seed was not planted prior to Normal Seeding Dates. Since the initial temperature for seed germination is approximately 50 degrees F (soil temperature), this practice intends germination will not occur until spring. Extra cereal rye, a cool season annual grass, may be added to attempt to get some fall growth.

- Mulching must be used on any dormant seed. This is particularly important on erosive sites.
- Do not seed when the ground is frozen or snow covered.
- Do not use a dormant seeding on Grassed Waterways.

Source: Modified from USDA Soil Conservation Service Technical Guide.

Exhibit 2

Seeding Dates for Temporary Vegetation Cover

Planting Zones:

1. Lower Peninsula, South of US 10.
2. Lower Peninsula, North of US 10.
3. Upper Peninsula.

Zone			Kind of Seed	Amount	
1	2	3		Per 1,000 Sq. Feet	Per Acre
Apr. 1 to Sept. 15	Apr. 15 to Aug. 1	May 1 to Aug. 1	Oats*, barley*	2 lbs.	3 bu.
June-July	June-July	Not. rec.	Sudangrass	1 lb.	30-40 lbs.
Aug. 1 to Oct. 15	Aug. 1 to Oct. 10	Aug. 1 to Oct. 1	Rye*	3 lbs.	2-3 bu.
Sept. 20 to Oct. 15	Sept. 10 to Oct. 10	Sept. 1 to Oct. 1	Wheat	3 lbs.	2-3 bu.

* Indicates species best suited for wildlife food.

Immediately after seeding, mulch:
-all slopes
-unstable soils, and
-heavy clay soils
with unweathered small grain straw or hay spread uniformly at a rate of 1.5 to 2 tons per acre, or 100 pounds (2-3 bales) per 1,000 square feet. Other suitable materials may be used, according to specifications in the Mulching BMP.

Source: USDA Soil Conservation Service Technical Guide #342

Exhibit 3

Determining Appropriate Seeding Mixture Numbers Based on Site Conditions.

Site	Rough Areas	Steep Areas Ditch Banks Cuts Fills	Utility Rights-of way	Pond Edges[b]	Grassed Waterways Diversions[b]
Well and moderately well drained sand and loamy sand (coarse textured soils)	sunny-1, shady-2 or 4	4 or 6	15	4	4
Well and moderately well drained, moderately coarse to moderately fine textured soils (sand loam, loam, silt loam, and clay loam)	sunny-1, shady-2 or 5	4, 7, 8, 9, or 19	15	11 or 14	11, 13 17, 20
Well and moderately well drained clay and or 5 silty clay (fine texture soils)	sunny-1 shady-2	7, 8, 9, 13 or 19	15	11, 12 or 14	11, 13, 17, 20
Somewhat poorly drained or poorly drained soils without artificial drainage[a]	3 or 5	8, 10, 13 or 16	15	12 or 13	17, 18
Organic soils[a]	3	10, 16 or 18	16	11 or 12	

[a] With artificial drainage, use the appropriate site condition in the well-drained groups above.

[b] Mixtures one and two can be used on grassed waterways that are to be given care and management as lawn.

Source: USDA Soil Conservation Service Technical Guide #342

Exhibit 4

Seeding Mixtures (in pounds per acre) Corresponding with Seeding Mixture Number

Under the seed mixture number selected in Exhibit 3, use all species shown in that column. For example: for Exhibit 3, seeding no. 6, the correct seeding mixture is 25 lbs. of creeping red fescue plus 5 lbs. of perennial ryegrass and 20 lbs. of tall fescue. These are minimum rates for ideal conditions. Use judgement to increase rates for less than ideal conditions.

Seeds Per Pound	Species	Seed Mixtures From Exhibit 3*																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
615000	Creeping red fescue**	20	30	10	40		25		20						20	20					
227000	Perennial ryegrass	(a)	(a)		(a)		5					5	5			5		5	5		
2177000	Kentucky bluegrass	20	10	25					5						15						
4990000	Redtop**								1							1	1	2	2		
533000	Reed canarygrass**										10						10				
8700000	Seaside bentgrass											1	1	1	1						
136000	Smooth bromegrass**											30		15		10		25			20
227000	Tall fescue					50	20		20	10			40	15		15			30	15	20
1230000	Timothy**							3	2								4				
375000	Birdsroot trefoil (b)**							10	10											10	
110000	Crownvetch (b)**									15											
TOTAL POUNDS		40	40	35	40	50	50	13	58	25	10	36	46	31	36	51	15	32	37	25	40

Seed per square foot at the recommended seeding rate

(a) Five pounds of ryegrass may be added to this mixture on erodible sites or other areas where quick cover is essential

(b) Inoculate all legume seeds with correct inoculant.

* Seeding rates have been rounded off.

** Indicates species best suited for wildlife cover.

Source: USDA Soil Conservation Service Technical Guide #342

Exhibit 5

Appropriate Seeding Mixtures (in pounds/sq. ft.) Corresponding with Seeding Mixture Number

Under the seed mixture number selected in Exhibit 3, use all species shown in that column. For example, for Exhibit 3, seeding no. 6, the correct seeding mixture is .6 lbs. of creeping red fescue plus .2 lbs. of perennial ryegrass and .5 lbs. of tall fescue. These are minimum rates for ideal conditions. Use judgement to increase rates for less than ideal conditions.

Seeds Per Pound	Species	Seed Mixture From Exhibit 3*																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
515000	Creeping red fescue**	.5	.7	.3	1.0		.6		.5						.75	.75					
227000	Perennial ryegrass	(a)			(a)		.2					.2	.2			.2		.2	.2		
2177000	Kentucky bluegrass	.5	.3	.6					.2						.4						
4990000	Redtop**								.03						.03	.03	.05	.05			
533000	Reed canarygrass**										.3						.3				
8700000	Seaside bentgrass											.03	.03	.03	.03						
136000	Smooth bromegrass**											.7		.4		.3		.6			.5
227000	Tall fescue					1.2	.5		.5	.3			1	.4		.4			.7	.4	.5
1230000	Timothy**							.1	.05								.1				
375000	Birdsroot trefoil[b] **							.3	.3											.3	
110000	Crownvetch[b] **									.4											

[a] 0.15 pounds of cereal ryegrass may be added to this mixture on erodible sites or other areas where quick cover is essential.

[b] Inoculate all legume seeds with correct inoculant.

*Seeding rates have been rounded off.

**Indicates species best suited for wildlife cover.

Source: USDA Soil Conservation Service Technical Guide #342

Appendix G

Impermeable Surface Inspection Plan

Plan

Kennecott
Eagle Minerals

Humboldt Mill

Impermeable Surface Inspection and Surface Repair Plan

Project I.D.: 06W003

Kennecott Eagle Minerals Company
Marquette, Michigan

December 2007

Foth

Humboldt Mill

Impermeable Surface Inspection and Surface Repair Plan

Project ID: 06W003

Prepared for

Kennecott Eagle Minerals Company

ISO 14001:2004 Registered System

Prepared by

Foth Infrastructure & Environment, LLC

December 2007

Foth Infrastructure & Environment, LLC 2007

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Humboldt Mill
Impermeable Surface Inspection and Surface Repair Plan

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     - 1.1.1 The COSA 1
     - 1.1.2 Concentrate Load-Out Building 1
   - 1.2 Site Inspections and Monitoring 2
   - 1.3 Repair Methods 2
     - 1.3.1 Concrete Areas 2

Figures

Figure 1 Impermeable Surface Area Locations

Appendices

Appendix A Impermeable Surface Inspection Log

1. Impermeable Surface Inspection and Surface Repair Plan

1.1 Introduction

This Impermeable Surface Inspection and Surface Repair Plan has been prepared to address integrity monitoring of all newly constructed concrete surfaces that will be exposed to contact water. This plan is not applicable to existing site buildings. The monitoring plan includes frequency of inspection and action plans for surface repair, along with a sample inspection log documenting the date of inspection, identification of the inspector, results, and required follow-up action. Inspection documents will be kept on site for 5 years. Kennecott Eagle Minerals Company (KEMC) Director of Maintenance will be responsible for overseeing the plan and supervising personnel.

Figure 1 (Appendix A) indicates impermeable surface areas with potential for exposure of reactive materials to the environment. Areas covered under this plan include:

- The coarse ore storage area (COSA).
- Concentrate Load-Out Area

1.1.1 The COSA

The COSA will be constructed to contain mined ore awaiting processing. The COSA building will measure approximately 20,000 ft^2 having a storage capacity of 5,000 tonnes of crushed ore. This building will be enclosed on three sides and constructed of steel framing with steel siding. A clear plastic drop door(s) or roll-up door(s) will be installed across the open side to minimize precipitation contact with the ore and reduce fugitive dust release. The floor of the COSA will be constructed of reinforced concrete sloping to a catch basin for collection of contact water. To minimize potential steel corrosion, the reinforcement rod will be epoxy-coated. Any collected contact water will be pumped to the WWTP for treatment or routed to the main mill and used as process water. A vapor barrier will be installed below the concrete floor to provide additional moisture retention.

Due to the operational activities, minor cracking and separation of the floor slab from the foundation wall may occur over time. In order to prevent liquid release through cracks in the concrete floor slab, KEMC personnel will conduct periodic inspections of the COSA floor and foundation wall to identify and repair concrete cracks that may occur.

1.1.2 Concentrate Load-Out Building

Concentrate load-out will either be by direct front-end loader to railcar or via discharge spouts. In either case load-out activities will occur within a covered structure to contain any concentrate spillage. The floor of the load-out structure will be constructed of reinforced concrete sloping towards a water collection system installed in the floor to collect liquids that may be present during load-out operations. To minimize potential reinforcement steel corrosion, the reinforcement will be epoxy-coated. Any collected contact liquid will be pumped to the mill and used as process water. A vapor barrier will be installed below the concrete floor to provide additional moisture retention.

Due to the operational activities, minor cracking and separation of the floor slab from the foundation wall may occur over time. In order to prevent liquid release from the building, KEMC

personnel will conduct periodic inspections of the floor and foundation wall to identify and repair concrete cracks that may occur.

1.2 Site Inspections and Monitoring

KEMC personnel will perform monthly inspections of the COSA and the concentrate lout-out building during operations to check for possible pavement/floor cracks.

COSA
Areas of the COSA which do not contain ore will be inspected and repaired as necessary. Then, ore will be moved to these previously inspected/repaired areas and the exposed portion of the COSA floor inspected and repaired as necessary. Staging of inspections as described herein will be performed until the entire COSA floor area is evaluated. To evaluate the catch basins in the COSA, any standing liquid will be discharged to the mill, and the catch basins inspected for any potential areas of leakage or cracking. KEMC personnel will complete monthly inspection logs outlining dates of inspection, identification of the inspector, results, and required follow-up action. A sample inspection log is included in Appendix B.

Concentrate Load-Out Building
KEMC personnel will provide monthly inspections of the concentrate load-out building concrete pavement during mining operations. Catch basins will be evaluated as described above for the COSA. Monthly inspection logs will be completed during the inspections.

1.3 Repair Methods

1.3.1 Concrete Areas

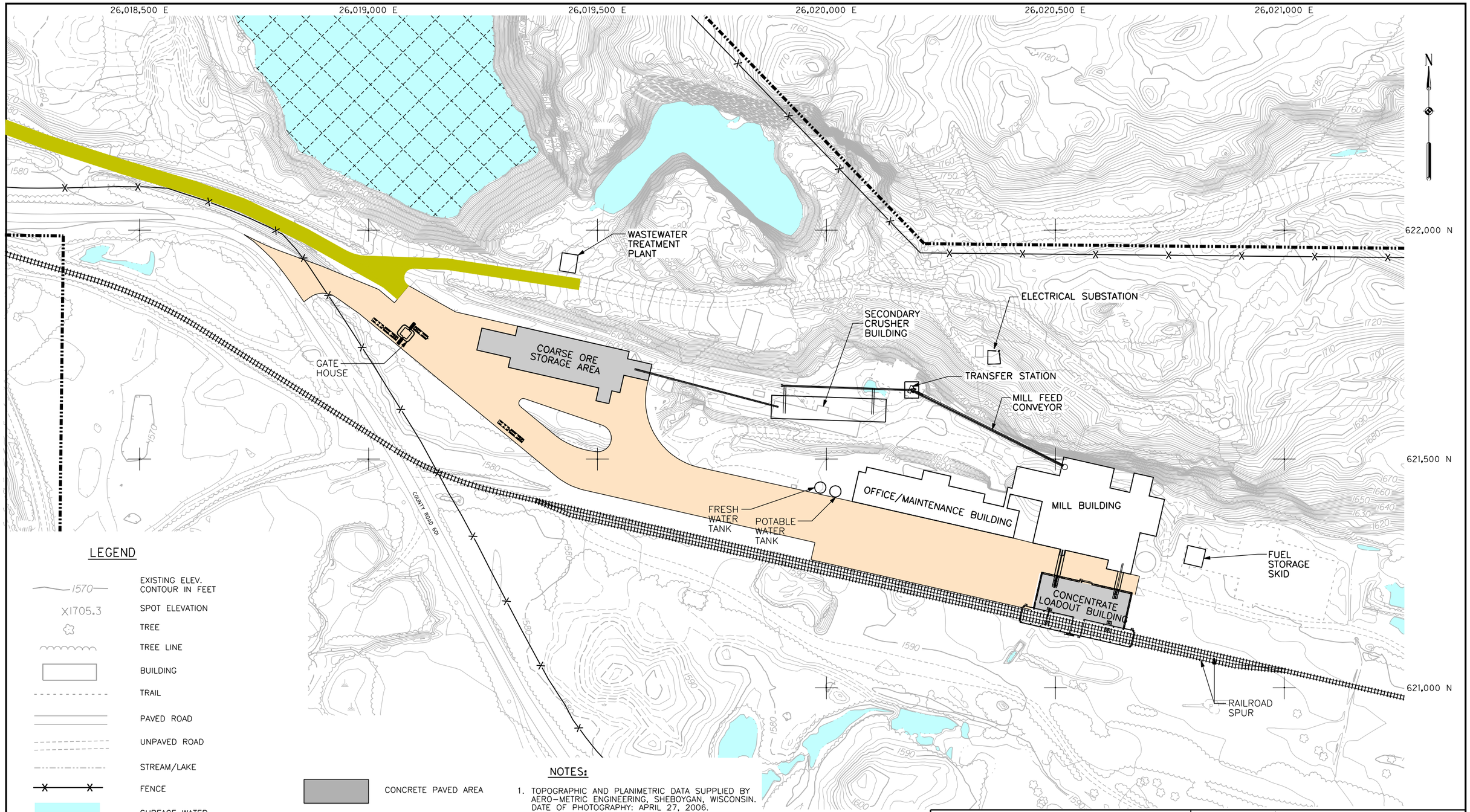
Once identified, cracks that have the potential to provide a conduit for contact water to seep into the environment. The cracks will be sealed by methods appropriate to their size. Based on the size of the crack to be repaired, repairs will be conducted by one of two methods: routing and epoxy troweling, and epoxy grouting. Cracks that are less than 1/8-inch in width will be considered class 1 cracks; cracks greater than 1/8-inch in width will be considered class 2 cracks.

Class 1 Cracks
Class 1 cracks will be repaired by routing and epoxy troweling. Routing of the crack consists of following along the crack with a concrete saw or other hand or pneumatic tool, opening the crack sufficiently to receive the sealant. A minimum routed width of ¼ - inch is desirable since smaller openings are difficult to fill. The surface of the routed crack will be cleaned and allowed to dry. Epoxy sealing will then be troweled into the crack. Separation of the floor slab from the perimeter wall/foundation will generally be filled by epoxy troweling.

Class 2 Cracks
Class 2 cracks will be repaired by epoxy injection. This method generally consists of drilling holes at close intervals along the crack and injecting epoxy under pressure.

Larger areas where mechanical damage has occurred may require removal and replacement with new concrete when weather permits. In these areas, the damaged area will be cut out and removed, new reinforcement bars drilled and grouted into the existing concrete, and a new section of concrete placed.

Figure



LEGEND

- 1570 — EXISTING ELEV. CONTOUR IN FEET
- X1705.3 — SPOT ELEVATION
- TREE
- TREE LINE
- BUILDING
- TRAIL
- PAVED ROAD
- UNPAVED ROAD
- STREAM/LAKE
- FENCE
- SURFACE WATER
- HUMBOLDT TAILINGS DISPOSAL FACILITY (HTDF)
- BITUMINOUS PAVED AREA
- GRAVEL SURFACE
- CONCRETE PAVED AREA
- RAILROAD SPUR

NOTES:

1. TOPOGRAPHIC AND PLANIMETRIC DATA SUPPLIED BY AERO-METRIC ENGINEERING, SHEBOYGAN, WISCONSIN. DATE OF PHOTOGRAPHY: APRIL 27, 2006.
2. CONTOUR INTERVAL BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988. HORIZONTAL DATUM BASED ON NAD 83/96. HORIZONTAL COORDINATES BASED ON MICHIGAN STATE PLANE.

Foth Infrastructure & Environment, LLC

REVISED	DATE	BY	DESCRIPTION

CHECKED BY:	JOS1	DATE: AUG. '08
APPROVED BY:	AKM	DATE: AUG. '08
APPROVED BY:		DATE:

Kennecott Eagle Minerals

FIGURE 1

HUMBOLDT MILL PROJECT
IMPERMEABLE SURFACE AREA LOCATIONS

Scale: 0 100' 200'
Date: AUGUST, 2008
Prepared By: BLK
Project No. 06W003

L:\06w003\MPA\TIA\impermeable-surface-area-plan.dgn
12/15/2008 jow

Appendix A

Impermeable Surface Inspection Log

Impermeable Surface Inspection Form
Kennecott Eagle Minerals Company

Inspector: _____	**Concrete Pavement**
Date: _____	Inspection Area: _____

Inspection Results

Recommended Actions

Follow-up of Previous Recommendations

Date of Next Inspection: _____

Archive Inspection Form Until: _____ (5 yrs from date of inspection)