Noranda’s Bell Mine

Then and Now

Bell Mine

- Located on a peninsula extending into Babine Lake, near Granisle, British Columbia.
- Operated from 1971 to 1992, with some shutdown periods.
- Generated roughly 70 millions tonnes of tailings and 70 million tonnes of waste rock in various dumps and dams.

Bell Mine

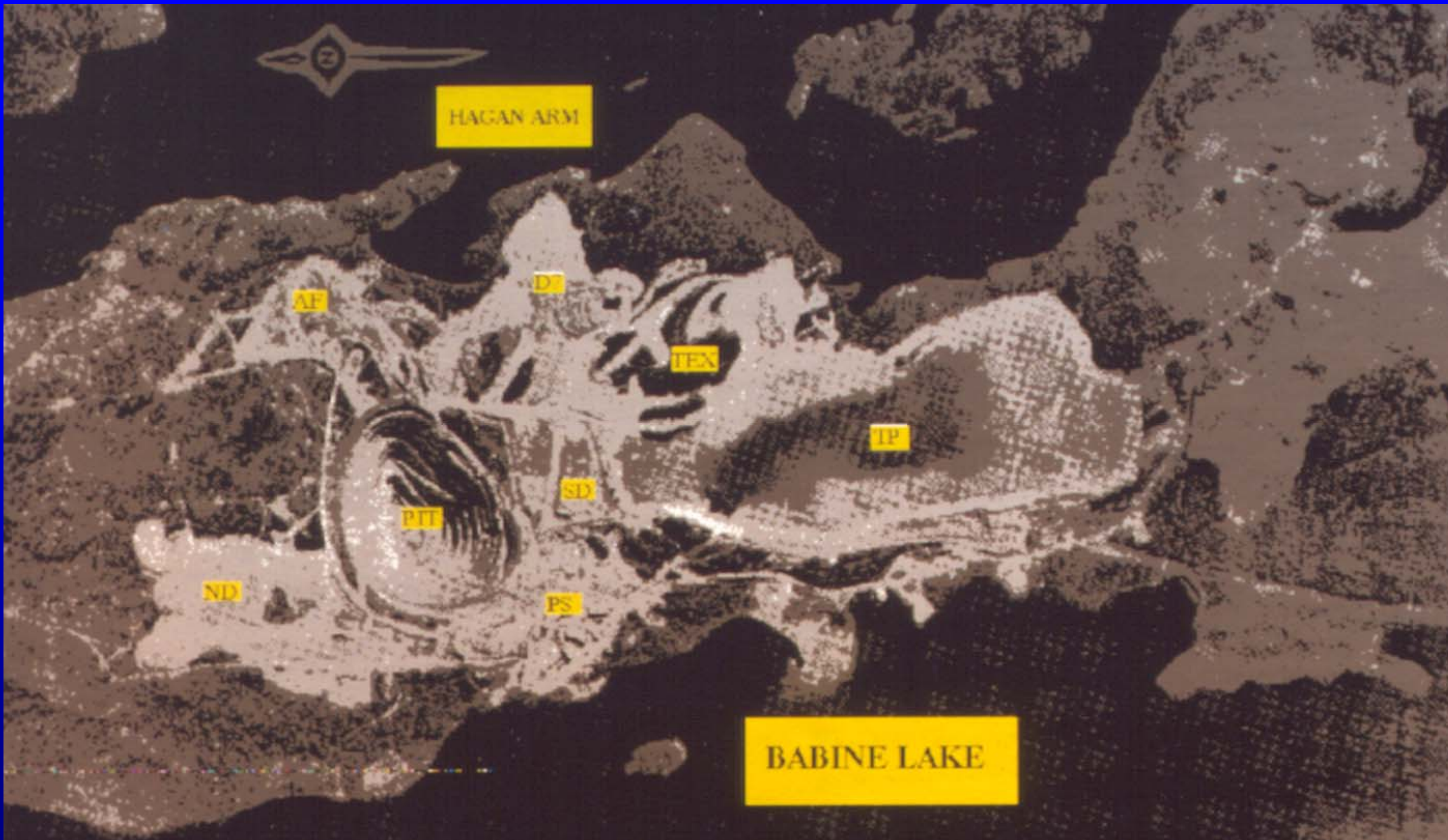
- In 1990, Maurice Ethier (Mine Manager) and Ross Gallinger (Environmental Coordinator) decided to create an “encyclopedia” for the closure plan, explaining the past and current conditions and predicting future conditions upon proper closure. This included detailed studies of Babine Lake, which has a major salmon fishery.

- The Closure Plan (*Bell ’92*) was comprised of 10 volumes with one summary document. Geocon was responsible for geotechnical issues, engineering, and overall project management. Rescan handled biological issues. MDAG (Kevin and Nora) examined solid and aqueous geochemistry using the Wheel approach.

Bell Mine - Then

BELL '92
CLOSURE PLAN

"Exit with Excellence"



HAGAN ARM
AF
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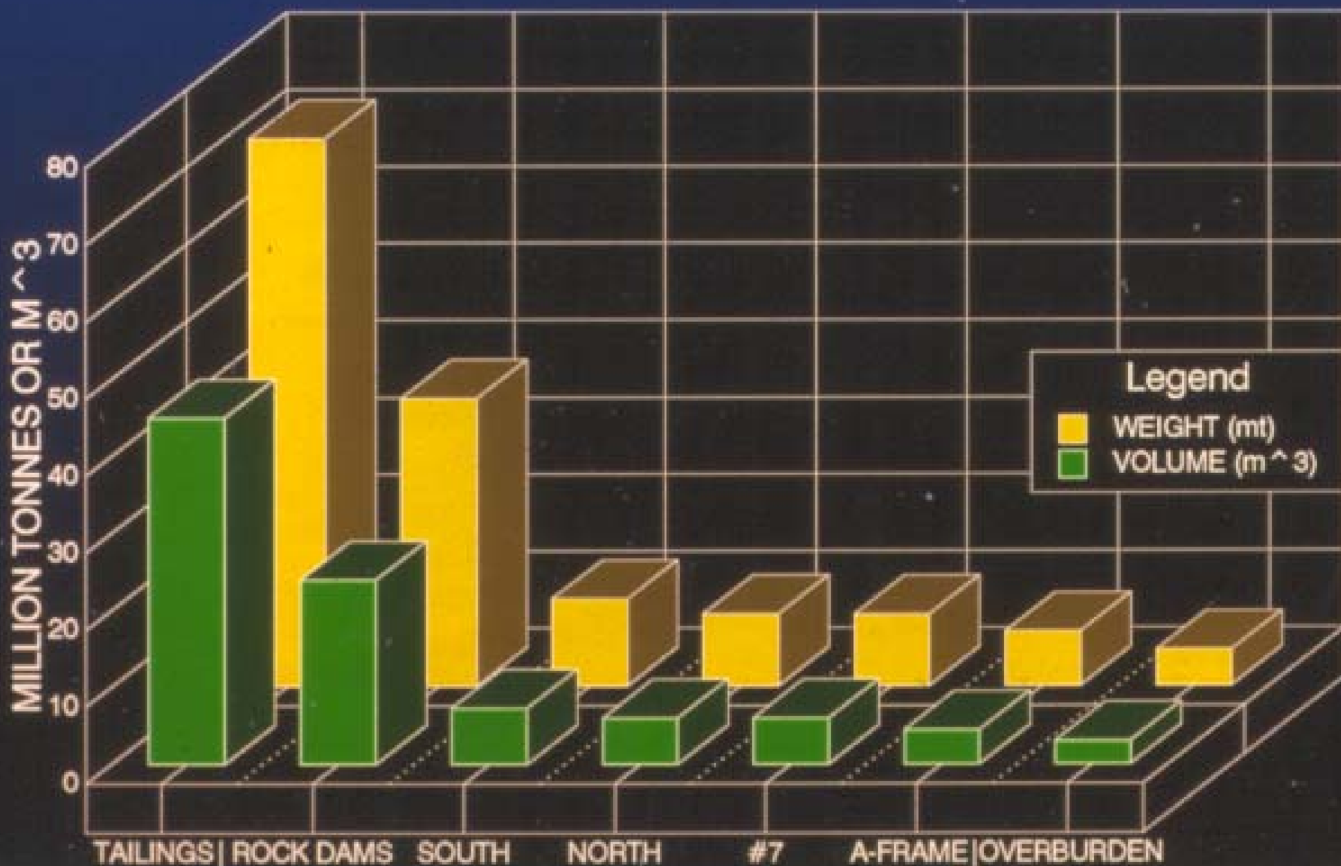
BABINE LAKE

INVENTORY OF MINE ROCK AND TAILINGS AT BELL MINE



ROCK TYPES AT BELL MINE

	TONNAGE (mt)	REACTIVITY
BFP	6.3	2
BBFP	6.3	1
RHYODACITE	15.7	3
QFP	6.3	1
SEDIMENTARY	15.7	2
TUFF	12.5	3
ANDESITE	MINOR	
16 ZONE	MINOR	

VISUAL REACTIVITY: 1=NONE; 2=SOMEWHAT; 3=REACTIVE

ACID-BASE ACCOUNTING FOR MINE ROCK

	NO.		NNP			PASTE	-pH
		LOW	MEAN	HIGH	LOW	MEAN	HIGH
BULK	134	-239	-56	47	3.5	7.3	8.6
BFP	3	-78	-20	16	7.7	7.9	8.3
BBFP	6	-21	17	84	8.0	8.2	8.4
RHYO	4	-60	-20	17	7.7	8.0	8.2
TUFF	3	-132	-31	25	6.6	7.5	8.2
QFP	3	-19	39	73	7.9	8.3	8.3
SED'S	5	-181	-33	126	4.2	7.1	8.1
AND	1		2			8.0	
16 Z	5	-4	14	25	7.5	7.7	7.8

ACID-BASE ACCOUNTING FOR MINE-ROCK DUMPS AND TAILINGS

	NO.		NNP			PASTE	-pH
		LOW	MEAN	HIGH	LOW	MEAN	HIGH
NORTH	14	-44	-13	69	7.3	7.6	7.9
A-FRAM	8	-87	-42	-6	2.4	4.6	7.3
SOUTH	1		-48				
NO. 7	7	-64	11	61	5.5	7.5	8.0
LW GRD	2	-50	-28	-5		4.4	
TAILS	56	-388	-53	42	1.8	7.0	8.1

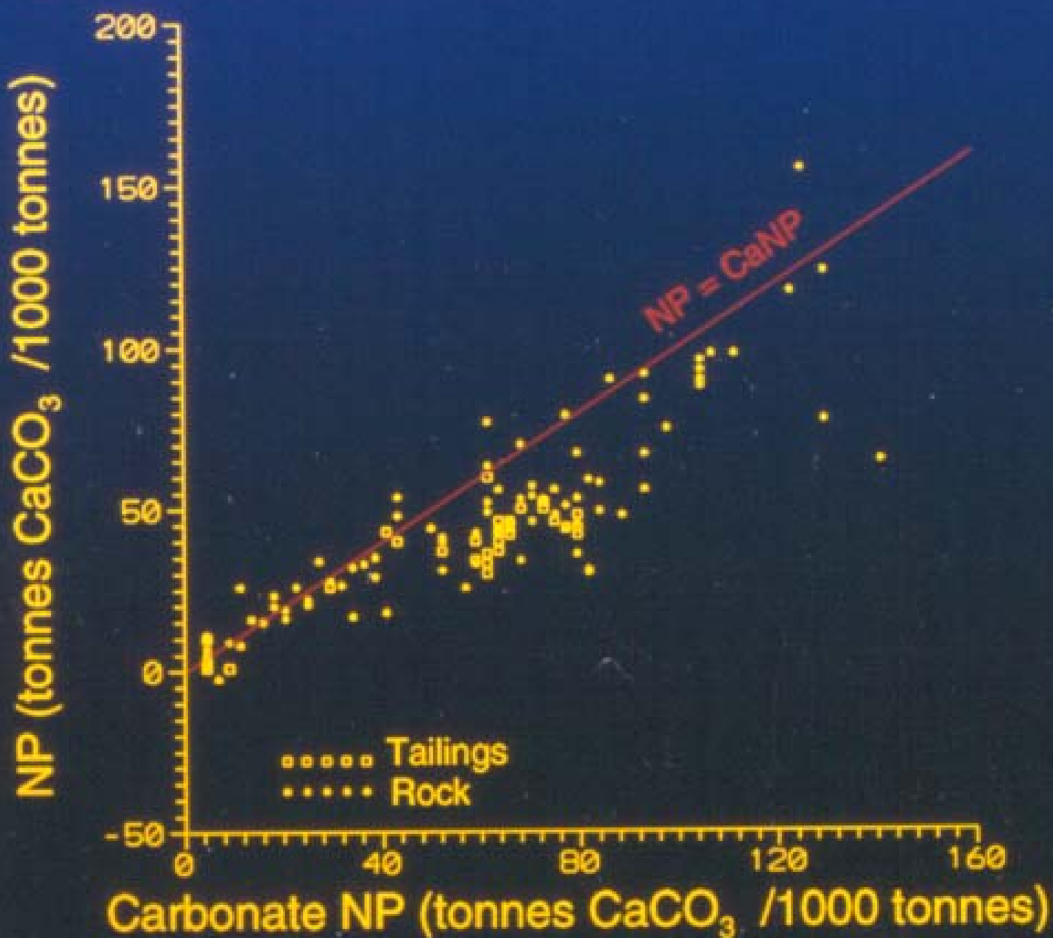
COMPARISON OF SULFIDE VALUES FROM VARIOUS SOURCES

	NORTH	A-FRAME	SOUTH	LW GRD
RK TYPE	2.15	2.02	1.23	1.93
HL PULP	2.39	1.06	2.36	0.61
HL COLS	1.78	1.25		1.13
HL COLS	2.18	1.38		
DRILL	1.69	0.56		
VISUAL	1.2	1.1	1.3	1.5

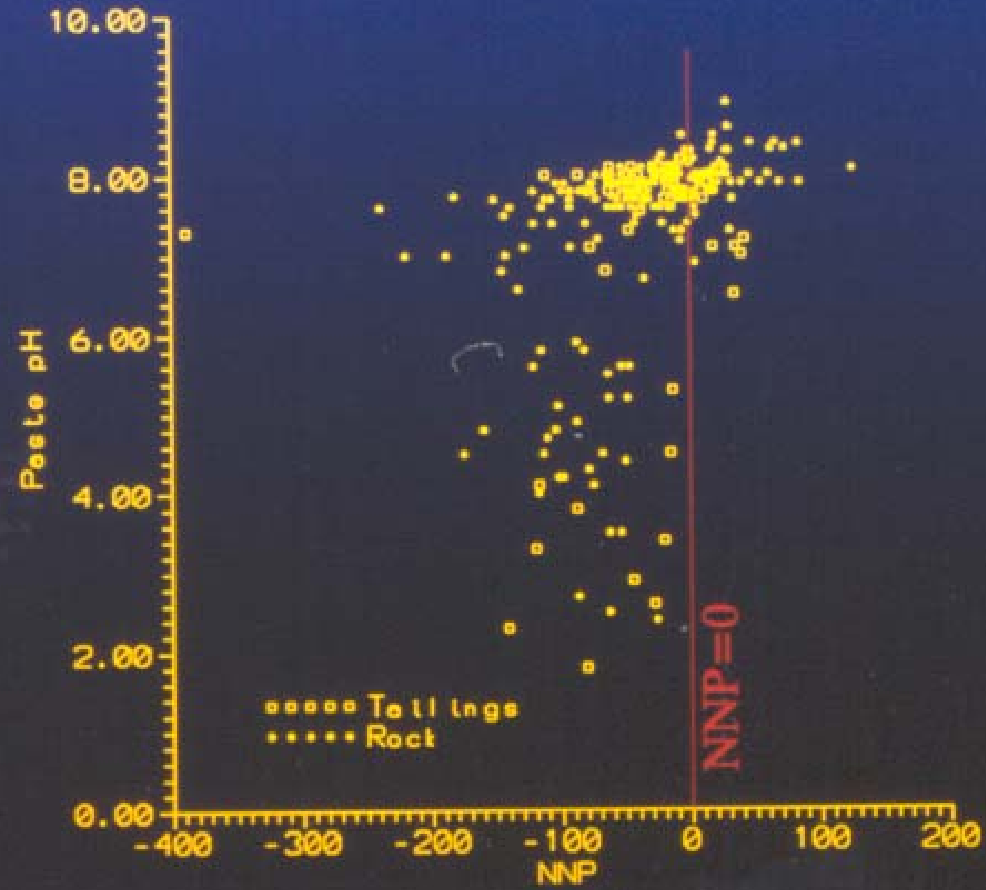
AVERAGE TAILINGS MINERALOGY

MINERAL	PERCENTAGE
PYRITE	4.5
PYRRHOTITE	-
CHALCOPYRITE	0.3
SPHALERITE	-
ARSENOPYRITE	0.002
GYPSUM	0.085
NEUT. POT.	4.2
SIDERITE	2.1
FERRIC OXIDES	0.8
PHOSPHATE	0.154

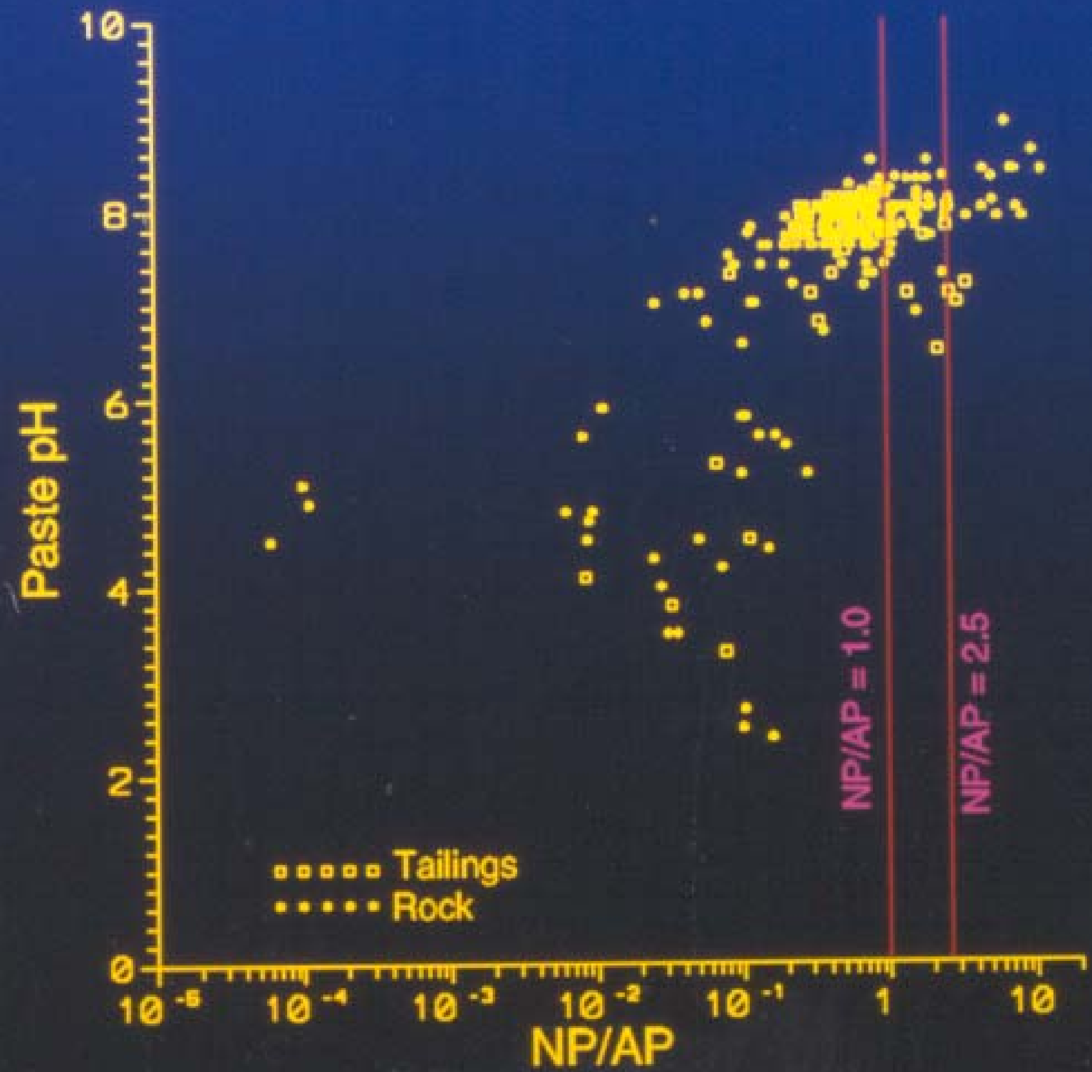
Neutralization Potential vs Carbonate Neutralization Potential



Paste pH vs Net Neutralization Potential

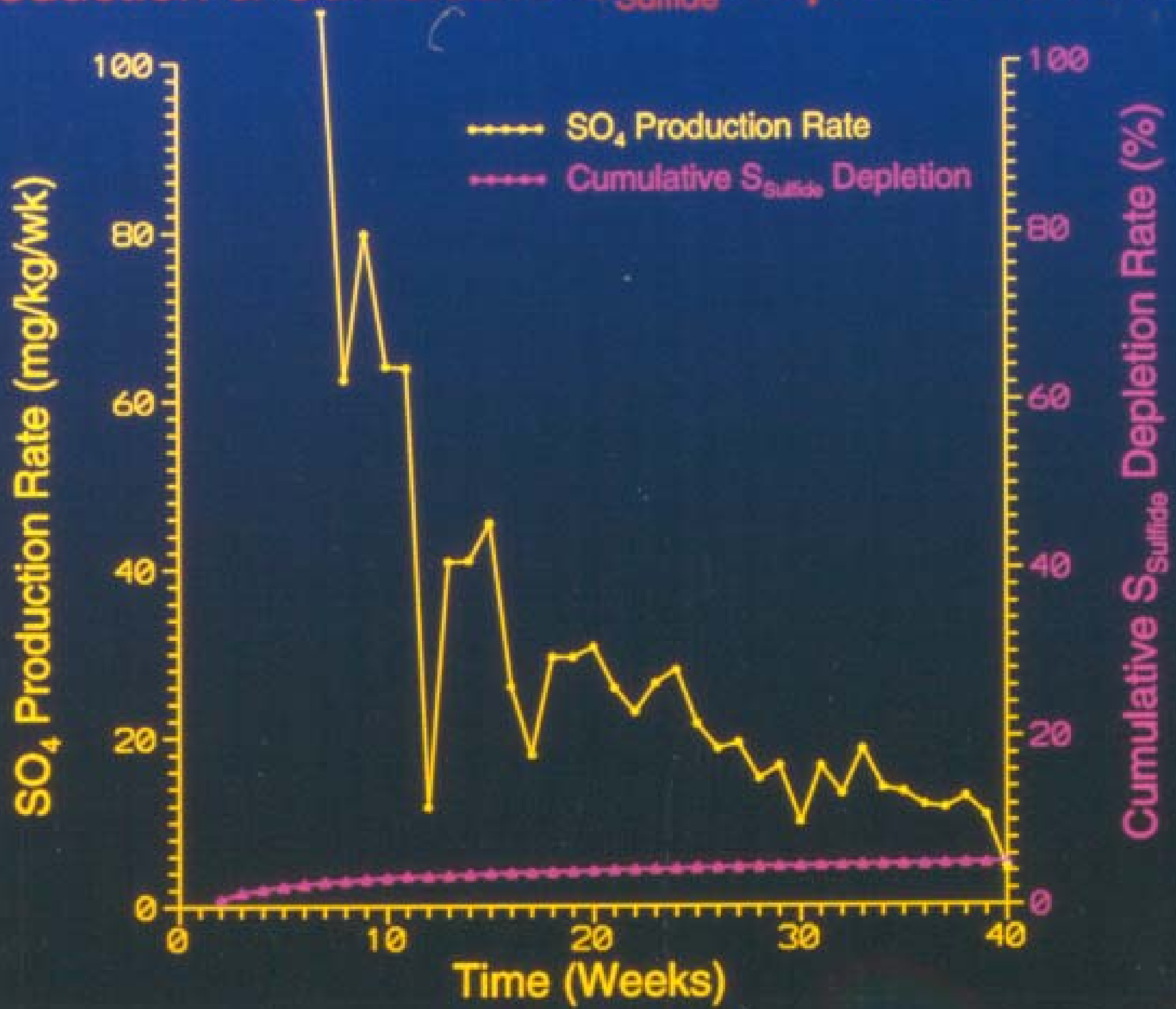


Paste pH vs NP/AP Ratio



A-Frame Dump Mine Rock

SO_4 Production & Cumulative $S_{Sulfide}$ Depletion Rate vs Time

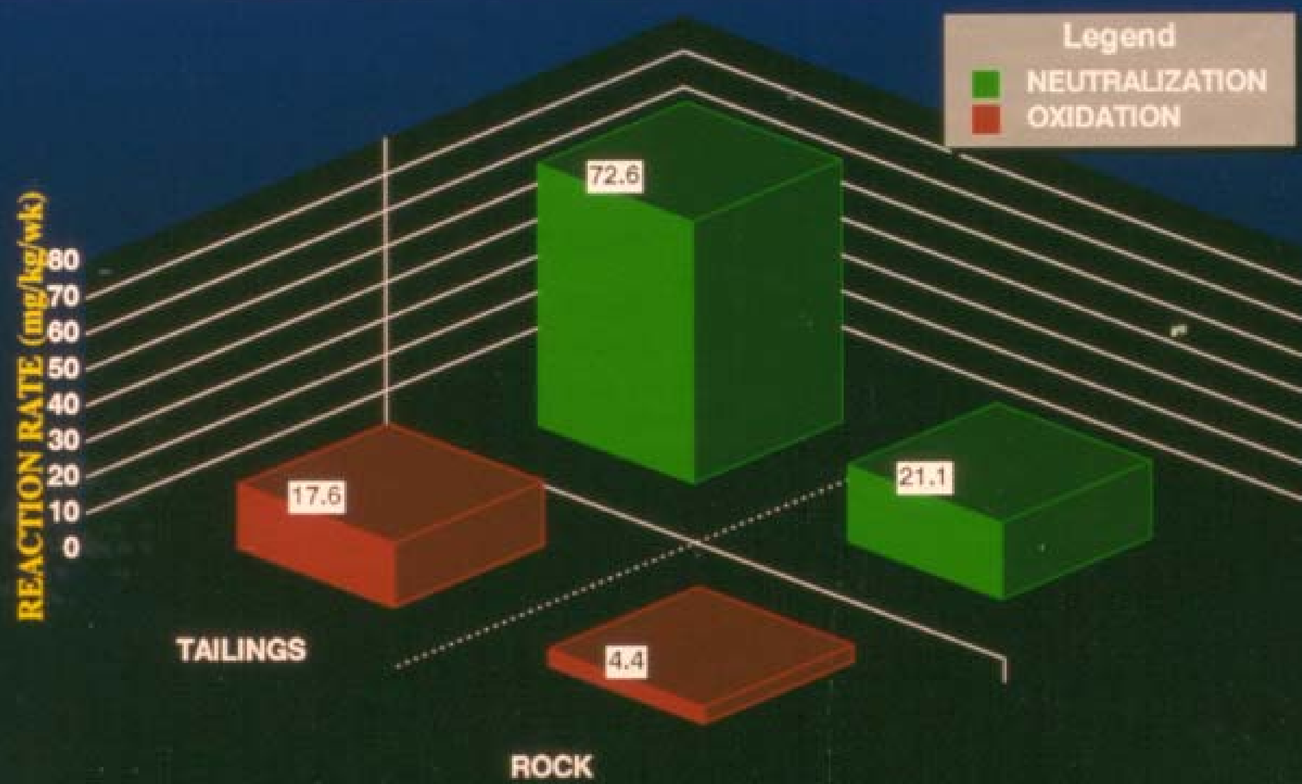


MEAN VALUES OF KINETIC RATES

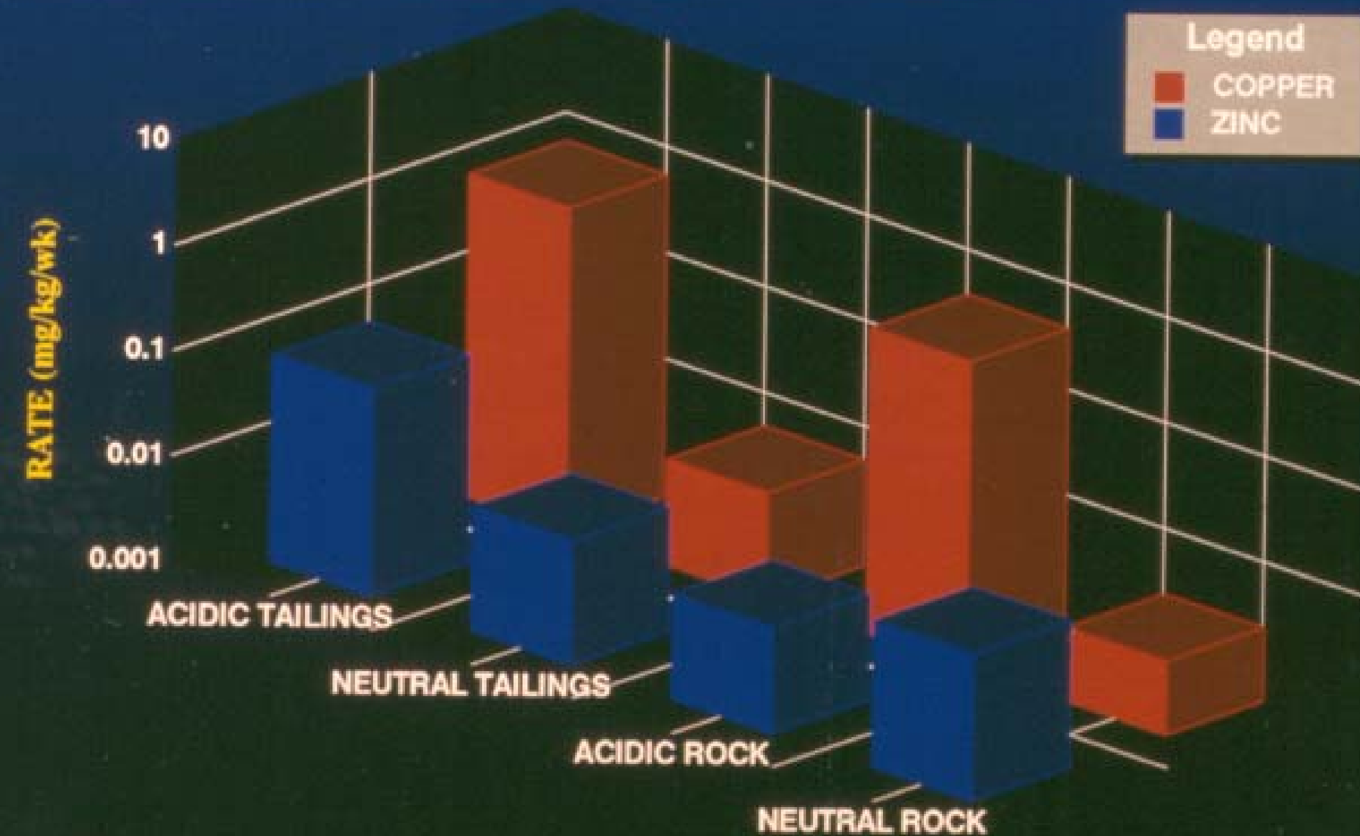
A-FRAME DUMP

mg/kg/wk	H. CELL	4" COLS	24" COLS	30t CRIBS
SULFATE	10.3	-	33.9	10.1?
COPPER	1.1	1.7	3.1	0.4
NICKEL	0.011	0.038	0.032	0.002
ZINC	0.015	0.32	0.051	0.004

RATES OF OXIDATION AND NEUTRALIZATION IN TAILINGS AND ROCK



RATES OF METAL LEACHING FROM MINE ROCK AND TAILINGS



MEAN PREDICTED CONCENTRATIONS IN NEUTRAL BELL MINE WATERS

mg/L	MODEL, pH 7.0	NEUTRAL CELLS
pH	7	~7
ALKALINITY	56	-
COPPER	0.2	2.0*
NICKEL	0.02	0.01
ZINC	0.06	1.1
SULFATE	2000	1730*

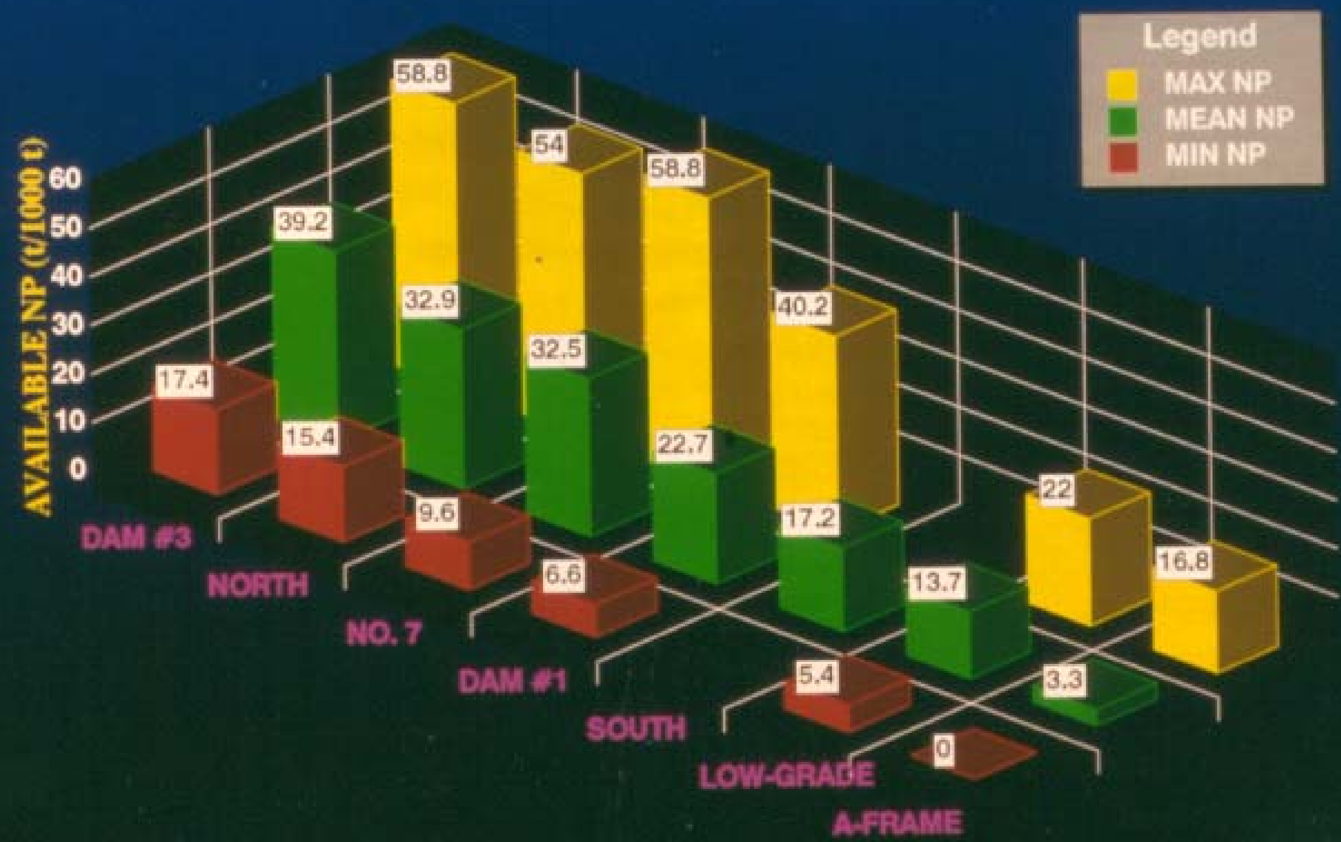
MEAN PREDICTED CONCENTRATIONS IN ACIDIC BELL MINE WATERS

mg/L	MODEL, pH 2.5	ACIDIC CELL
pH	2.5	2.4
ACIDITY	3420	4250
COPPER	781	308
NICKEL	0.84	1.58
ZINC	5.4	4
SULFATE*	10,000	4,080

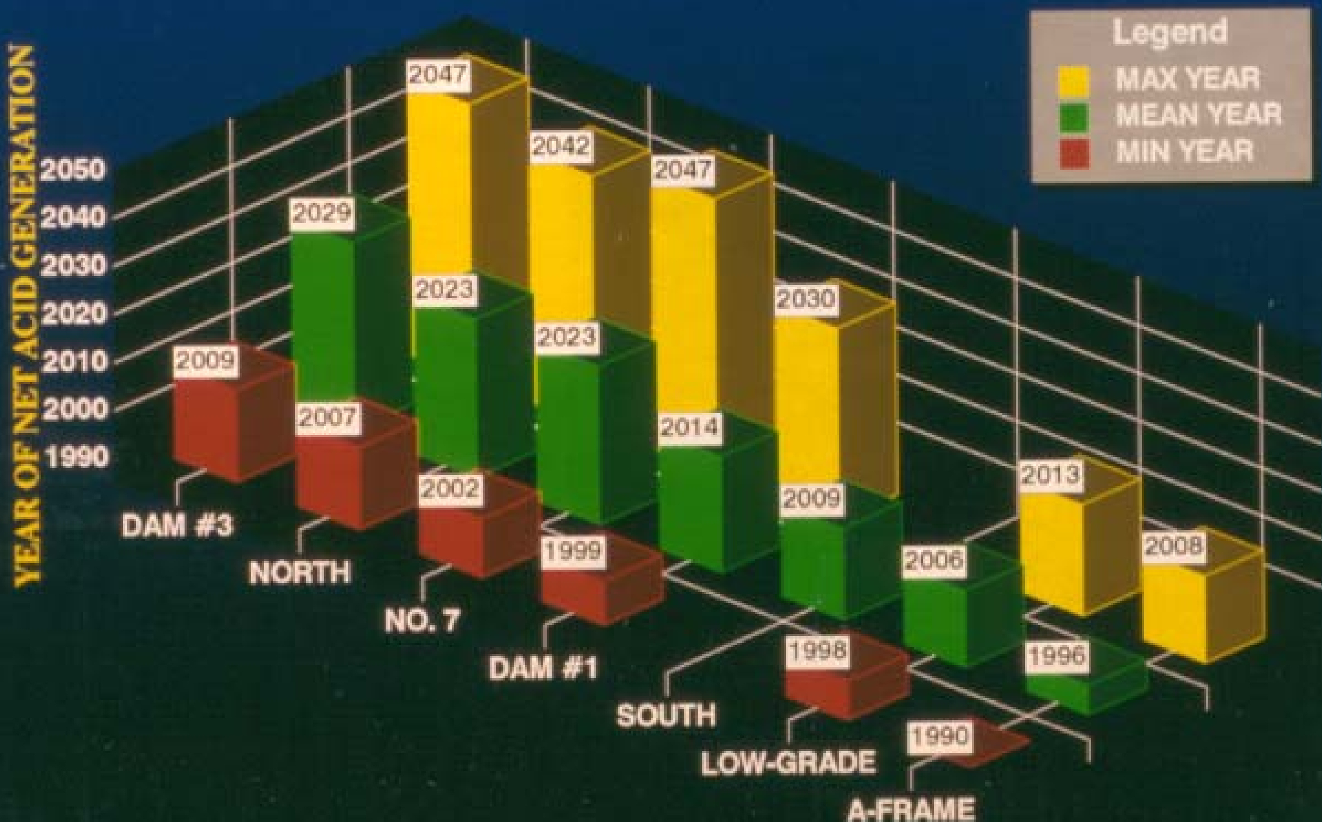
"WORST-CASE" WATER CHEMISTRY AT BELL MINE

mg/L	ON-SITE	4"&24" COLS	30t CRIBS
ALUMINUM	528	2600	632
COPPER	600	>1000/590	1600
IRON	1000	4100	2320
NICKEL	2.1	11.5	6.3
ZINC	28	115	44
ACIDITY	8230	-	-

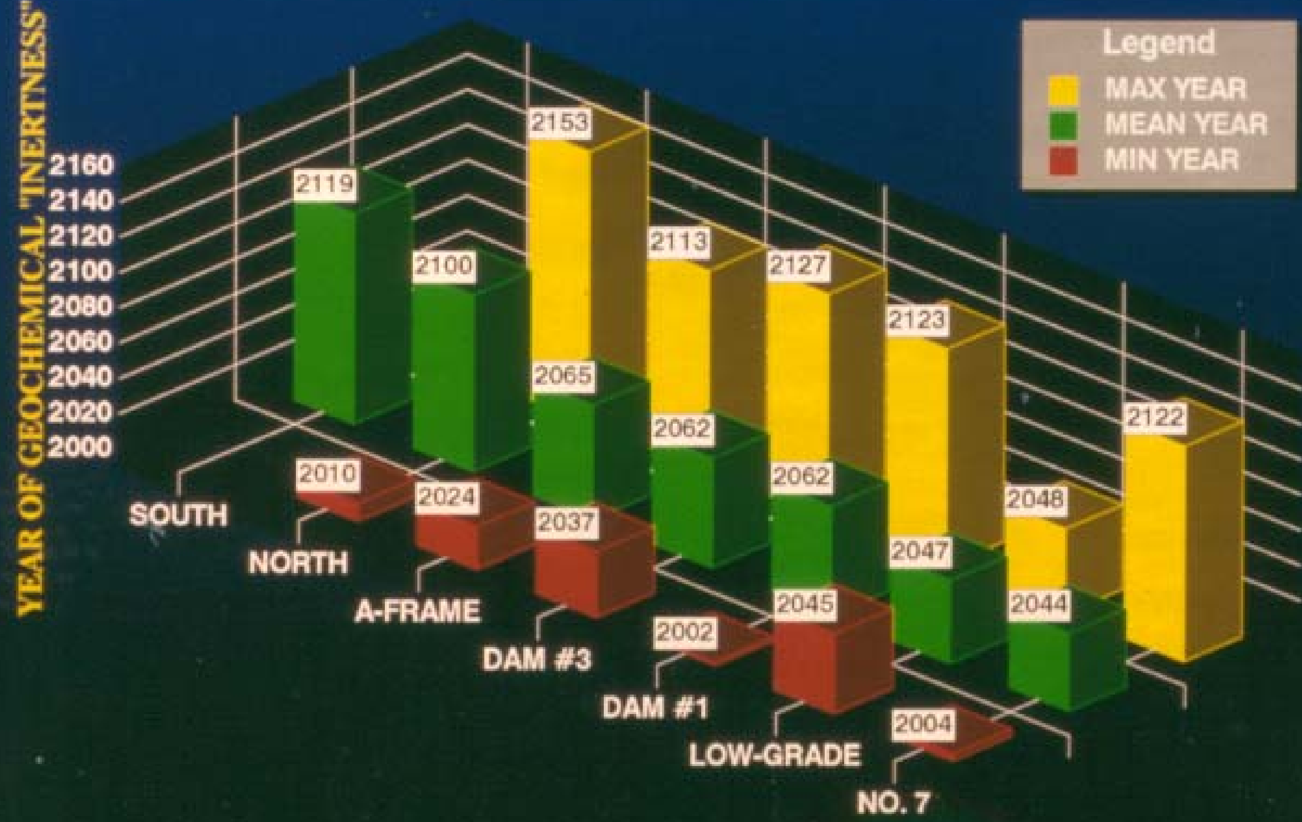
AVAILABLE NEUTRALIZATION POTENTIAL IN DUMPS AND DAMS



YEAR OF PREDICTED ONSET OF NET ACID GENERATION



YEAR OF DEPLETION FOR ALL REACTIVE MINERALS



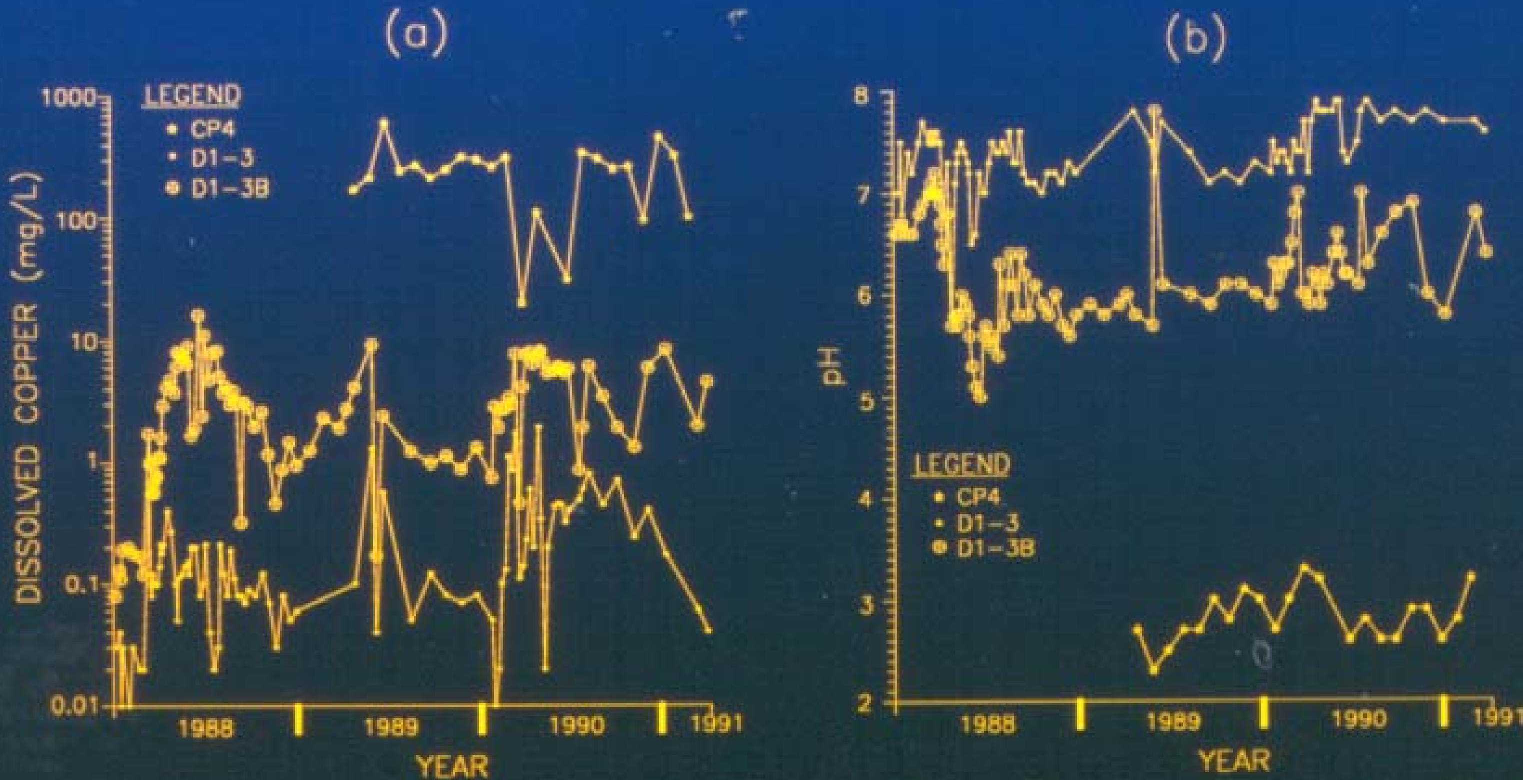
PREDICTIONS OF WATER CHEMISTRY THROUGH TIME AT BELL MINE

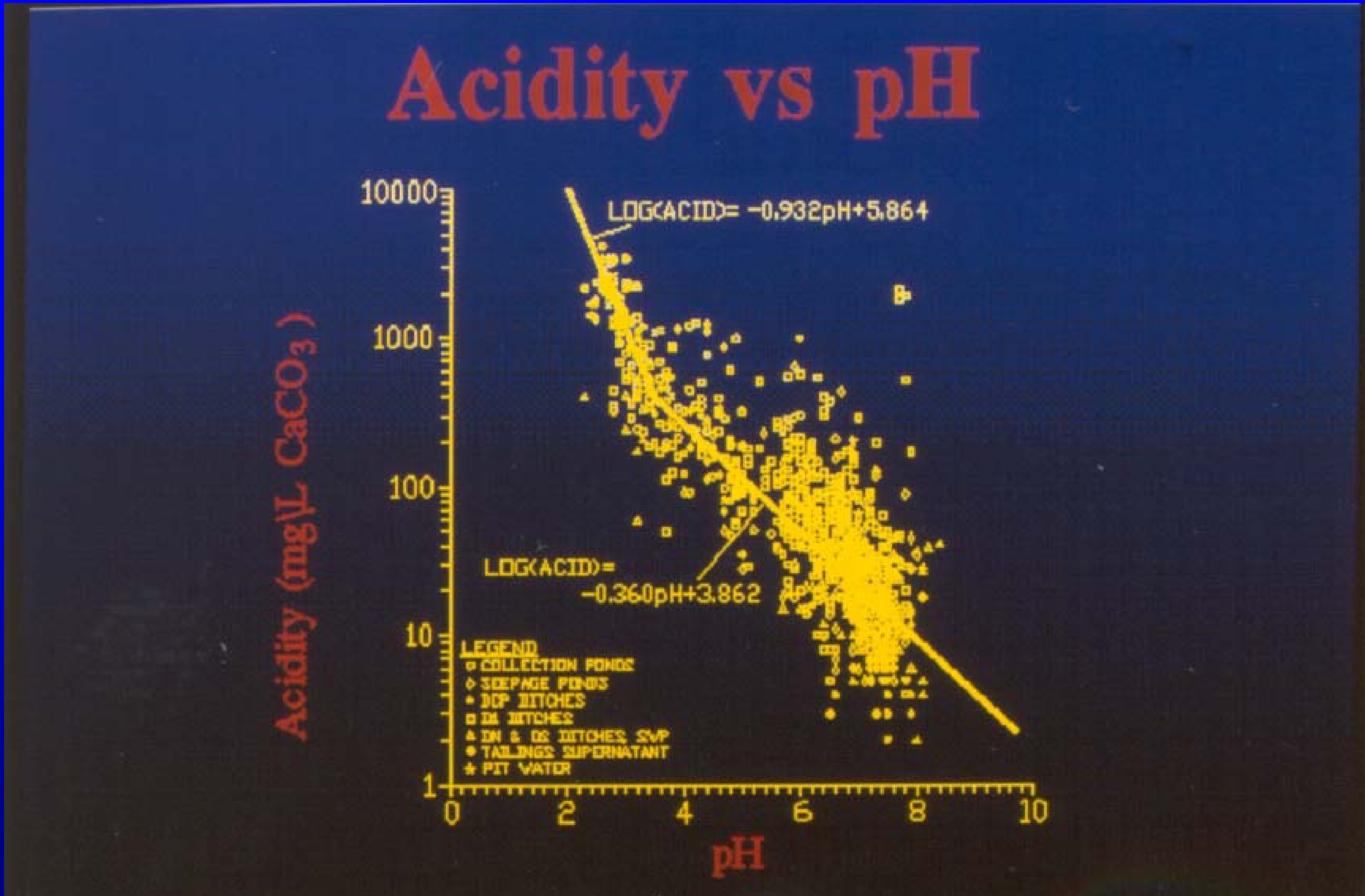
- 1. DETERMINE YEAR WHEN NEUTRAL (pH 7.0) CONDITIONS DISAPPEAR AND ACIDIC (pH 2.5) CONDITIONS APPEAR IN EACH WATERSHED
- 2. DETERMINE YEAR WHEN GEOCHEMICAL "INERTNESS" WILL APPEAR IN EACH WATERSHED
- 3. ENSURE SURFACE RUNOFF ON THE TAILINGS REMAINS GEOCHEMICALLY ISOLATED FROM THE SHALLOW ACIDIC TAILINGS

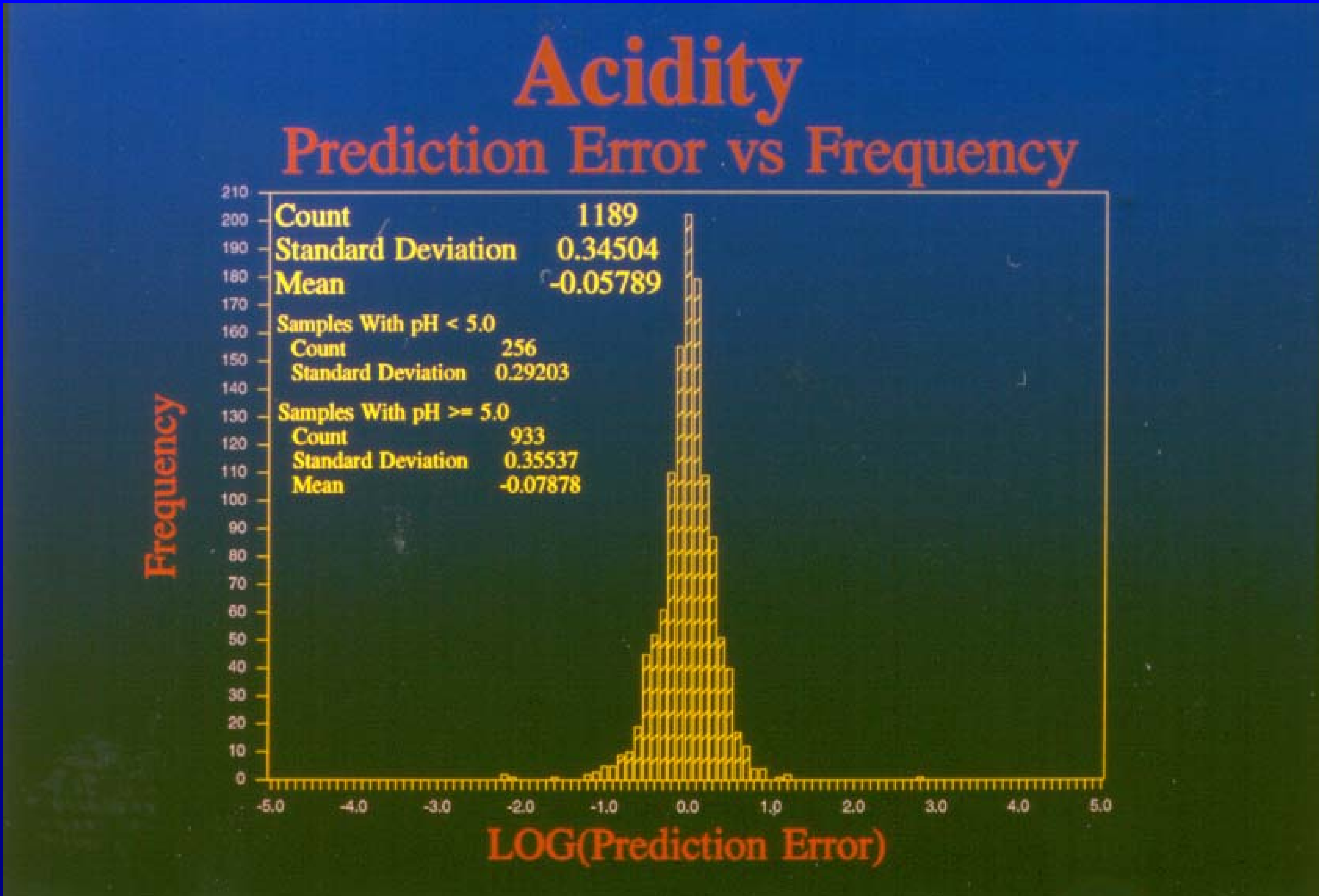
PREDICTIONS OF WATER CHEMISTRY THROUGH TIME AT BELL MINE

- 4. PUMP WATER FROM EACH WATERSHED WHEN IT BECOMES ACIDIC TO THE PIT
- 5. DETERMINE WATER-CHEMISTRY IMPACTS FROM THE PIT WALLS
- 6. PREDICT PIT CHEMISTRY THROUGH TIME, PARTICULARLY AFTER THE PIT IS FULL AND TREATMENT IS REQUIRED

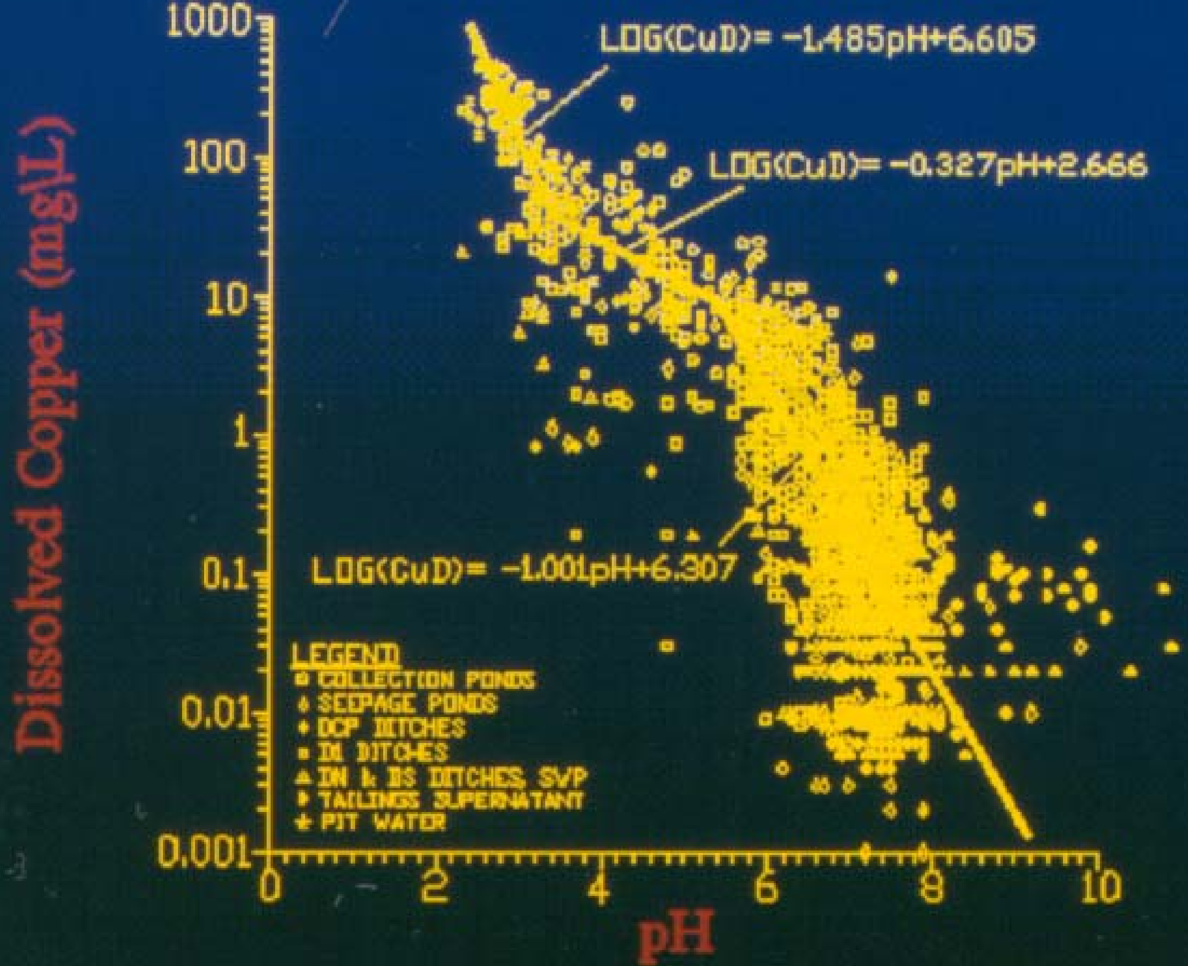
RELATIONSHIP OF WATER CHEMISTRY TO TIME

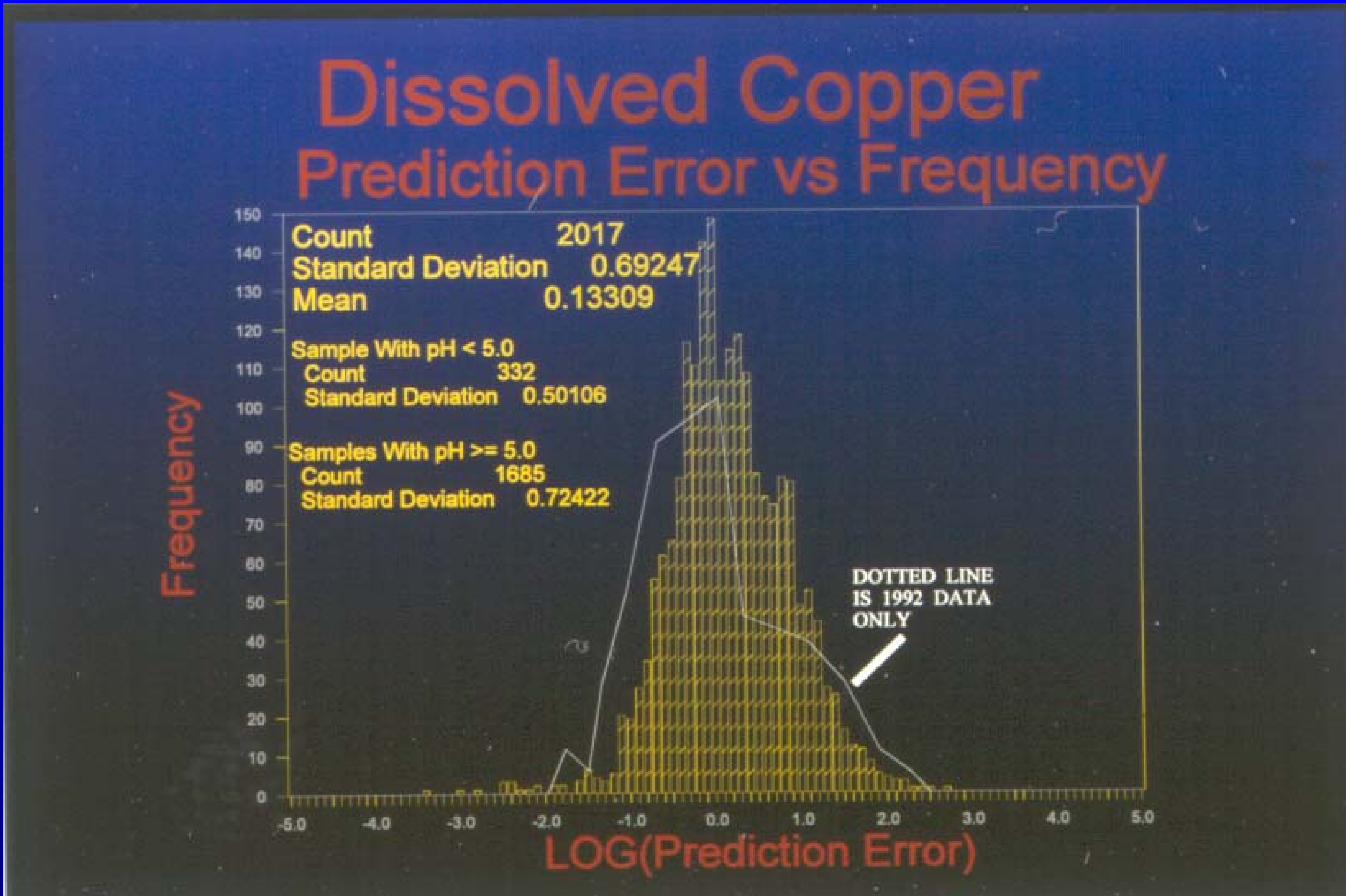


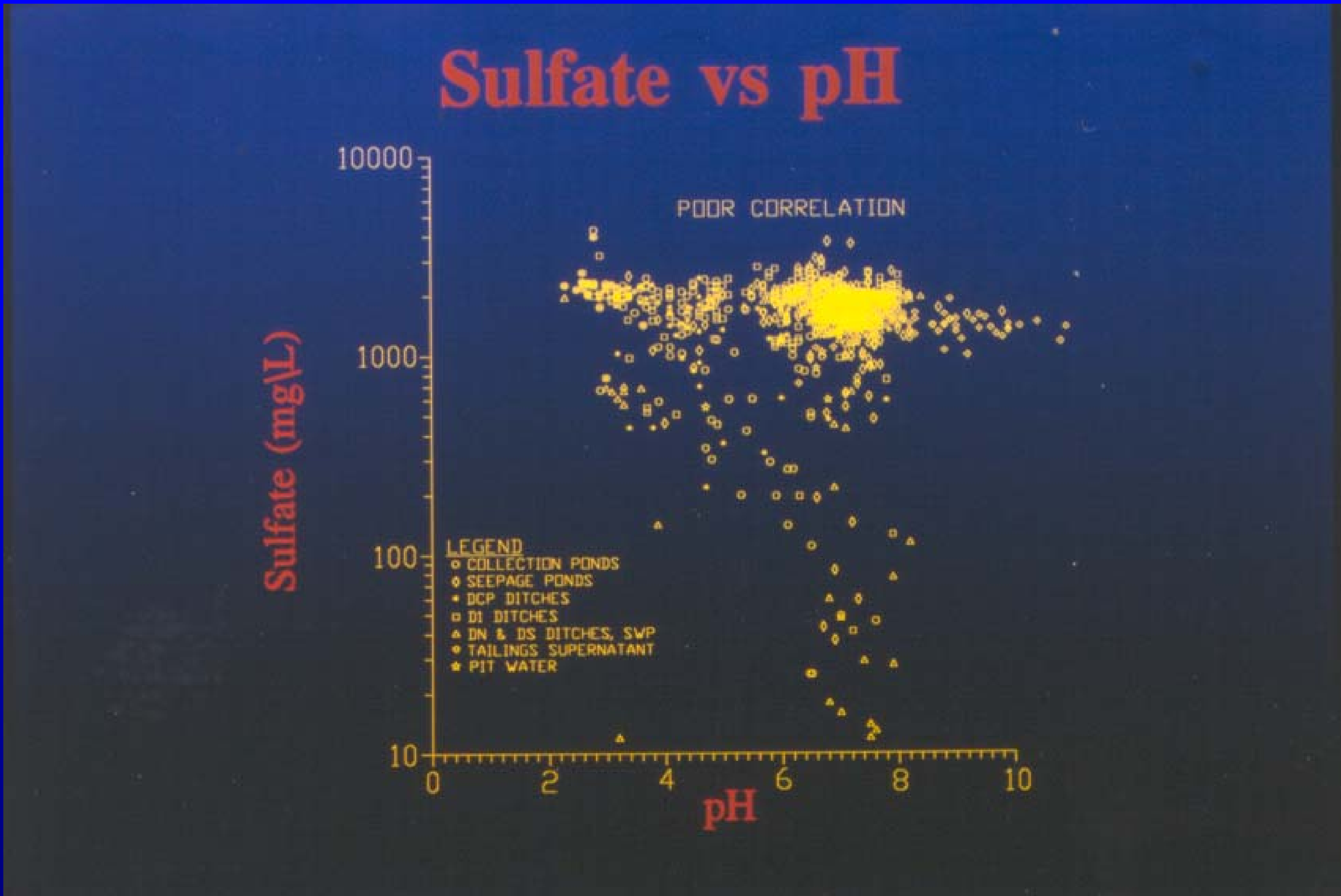

Acidity vs pH
LOG(ACID)= -0.932pH+5.864
LOG(ACID)=
-0.360pH+3.862
Acidity (mg\L CaCO3)
10000
1000
100
10
1
0
2
4
6
8
10
pH
LEGEND
COLLECTION PONDS
SEEPAGE PONDS
DCP DITCHES
DS DITCHES
DN & DS DITCHES SVP
TAILINGS SUPERNATANT
PIT WATER


Acidity
Prediction Error vs Frequency
Count 1189
Standard Deviation 0.34504
Mean -0.05789
Samples With pH < 5.0
Count 256
Standard Deviation 0.29203
Samples With pH >= 5.0
Count 933
Standard Deviation 0.35537
Mean -0.07878
Frequency
LOG(Prediction Error)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0

Dissolved Copper vs pH

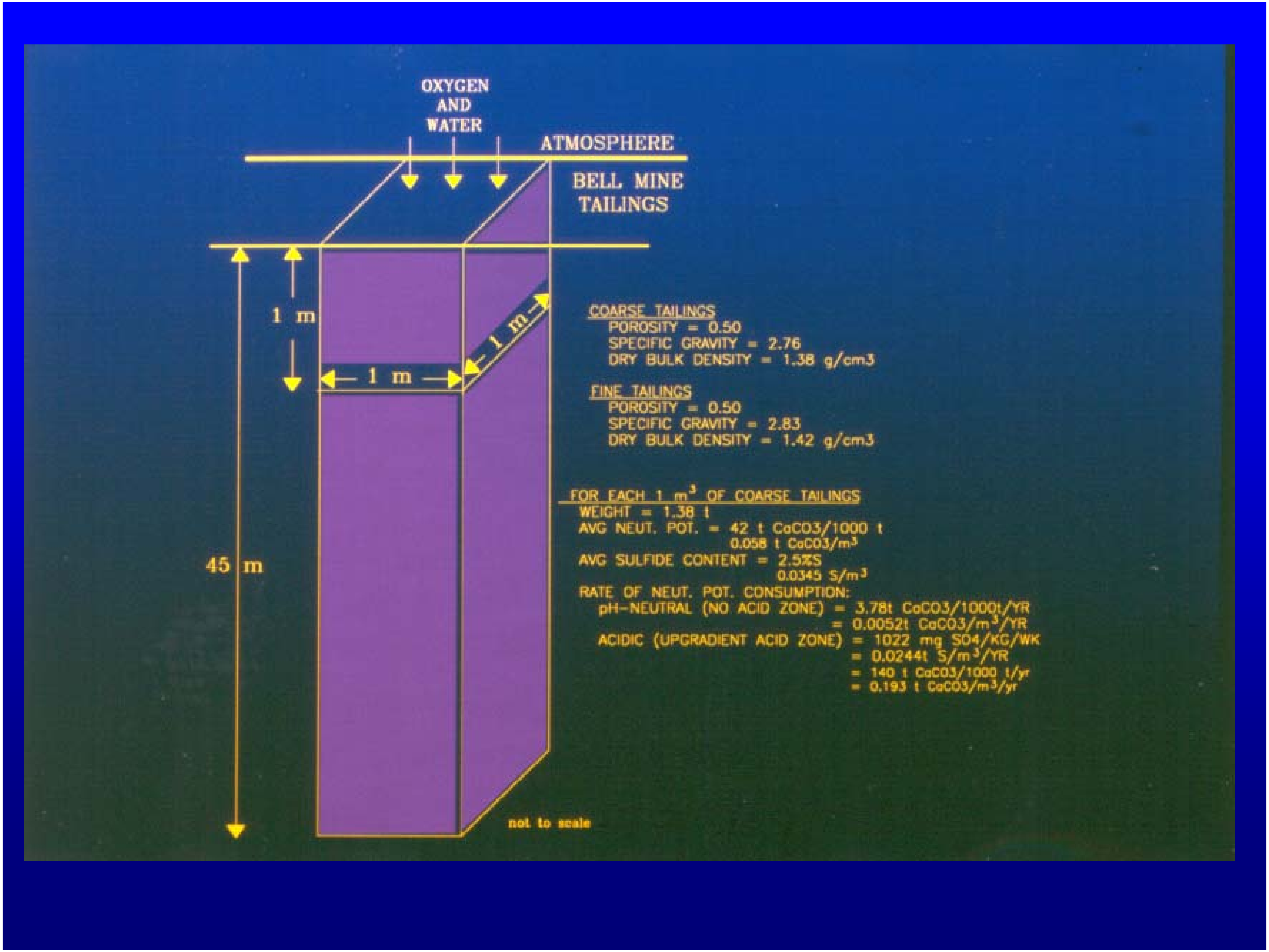



Dissolved Copper
Prediction Error vs Frequency
Count 2017
Standard Deviation 0.69247
Mean 0.13309
Sample With pH < 5.0
Count 332
Standard Deviation 0.50106
Samples With pH >= 5.0
Count 1685
Standard Deviation 0.72422
DOTTED LINE IS 1992 DATA ONLY
Frequency
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
LOG(Prediction Error)


Sulfate vs pH
POOR CORRELATION
Sulfate (mg\L)
10000
1000
100
10
0
2
4
6
8
10
pH
LEGEND
COLLECTION PONDS
SEEPAGE PONDS
DCP DITCHES
DI DITCHES
DN & DS DITCHES, SWP
TAILINGS SUPERNATANT
PIT WATER

EMPIRICAL WATER-CHEMISTRY MODEL

- DISSOLVED COPPER
  - $pH<3.4$ - $\log(Cu) = -1.485pH + 6.605$
  - $3.4<pH<5.4$ - $\log(Cu) = -0.327pH + 2.666$
  - $pH>5.4$ - $\log(Cu) = -1.001pH + 6.307$
  - standard deviation = 0.692 log cycles
- DISSOLVED ZINC
  - $\log(Zn) = -0.441pH + 1.838$
  - standard deviation = 0.667


OXYGEN
AND
WATER
ATMOSPHERE
BELL MINE
TAILINGS
1 m
1 m
1 m
45 m
COARSE TAILINGS
POROSITY = 0.50
SPECIFIC GRAVITY = 2.76
DRY BULK DENSITY = 1.38 g/cm3
FINE TAILINGS
POROSITY = 0.50
SPECIFIC GRAVITY = 2.83
DRY BULK DENSITY = 1.42 g/cm3
FOR EACH 1 m³ OF COARSE TAILINGS
WEIGHT = 1.38 t
AVG NEUT. POT. = 42 t CaCO3/1000 t
0.058 t CaCO3/m³
AVG SULFIDE CONTENT = 2.5%S
0.0345 S/m³
RATE OF NEUT. POT. CONSUMPTION:
pH-NEUTRAL (NO ACID ZONE) = 3.78t CaCO3/1000t/YR
= 0.0052t CaCO3/m³/YR
ACIDIC (UPGRADIENT ACID ZONE) = 1022 mg SO4/KG/WK
= 0.0244t S/m³/YR
= 140 t CaCO3/1000 t/yr
= 0.193 t CaCO3/m³/yr
not to scale

OXIDATION AND ACID GENERATION IN THE TAILINGS

- **STEP 1: INITIAL ZONE OF OXIDATION**
  - OXYGEN WILL DIFFUSE INTO THE UPPER 2 METERS
    - CAUSES ACID GENERATION
    - CAUSES NP CONSUMPTION
  - UPPER NP WILL BE CONSUMED AROUND YEAR 2004
  - RATES OF ACID GENERATION WILL THEN ACCELERATE ~60x
  - STRONGLY ACIDIC WATER WILL BE CARRIED DOWNWARD

OXIDATION AND ACID GENERATION IN THE TAILINGS

- **STEP 2: DOWNWARD MIGRATING ACID FRONT**
  - WATER PASSING THROUGH THE INITIAL ZONE (ACID ZONE) WILL ACCUMULATE ACIDITY AS IT MOVES DOWNWARD
  - NP IN THE DEEPER TAILINGS WILL BE PROGRESSIVELY CONSUMED, CREATING A MIGRATING ACID FRONT
  - THE ACID FRONT WILL MOVE DOWNWARD 3.3 METERS A YEAR
  - THE SULFIDE-DEPLETION FRONT WILL FOLLOW AT 0.70 METERS A YEAR

OXIDATION AND ACID GENERATION IN THE TAILINGS

- **STEP 3: SLOWING OF THE MIGRATING ACID FRONT**
  - AS THE ACTIVELY OXIDIZING ZONE MOVES DEEPER INTO THE TAILINGS AND UPPER SULFIDE DEPLETED, OXYGEN GRADIENTS WILL DECREASE
  - DECREASED OXYGEN GRADIENTS WILL PROVIDE LESS OXYGEN AND OXIDATION RATES WILL DECREASE
  - MIGRATION RATES OF THE ACID FRONT AND SULFIDE-DEPLETION FRONT WILL DECREASE TO NEGLIGIBLE LEVELS

OXIDATION AND ACID GENERATION IN THE TAILINGS

- **CONCLUSION: ACIDIC WATER WILL NOT CONSUME ALL NP ALONG THE HUNDREDS OF METERS OF FLOWPATH**
- **CONCLUSION: TAILINGS SEEPAGE WILL NOT BE ACIDIC**
- **OBSERVATION: BECAUSE TAILINGS DAMS ARE PREDICTED TO BE ACIDIC, THE TAILINGS SEEPAGE WILL BECOME ACIDIC AS IT FLOWS THROUGH THE DAMS**

IMPACTS OF MINE WALLS ON MINEWATER CHEMISTRY

- EXPOSED WALLS UNDERGO OXIDATION, LEACH METALS, AND CAN RELEASE ACIDITY
- ROCK SURFACES ON FRACTURES BEHIND THE WALLS CAN ALSO BE GEOCHEMICALLY ACTIVE
- FRACTURE SURFACES CAN REPRESENT A SOURCE OF METALS AND ACIDITY THAT IS 10x GREATER THAN THE EXPOSED PIT WALLS

IMPACTS OF MINE WALLS ON MINEWATER CHEMISTRY

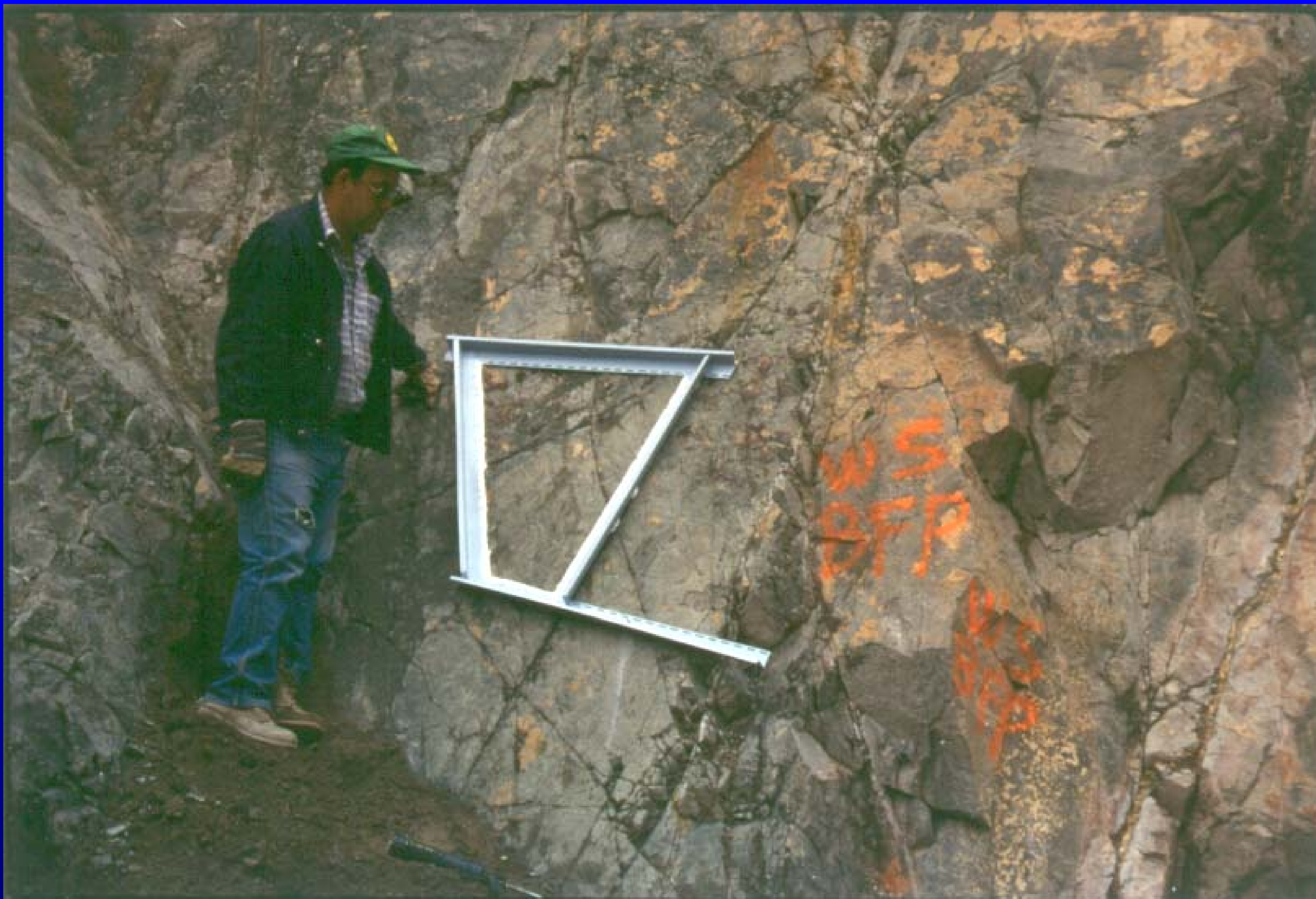
- UPON INITIATION OF FLOODING, THE UNFLUSHED SURFACES RELEASE THEIR ACCUMULATED PRODUCTS TO THE WATER AND COULD SIGNIFICANTLY DEGRADE WATER QUALITY

- ANY SURFACES REMAINING ABOVE THE FINAL WATER LEVEL WILL CONTINUE TO RELEASE METALS AND ACIDITY

IMPACTS OF MINE WALLS ON MINEWATER CHEMISTRY

- FRACTURE SURFACES ARE EITHER (1) FLUSHED REGULARLY, (2) FLUSHED OCCASIONALLY SUCH AS ONCE YEARLY, OR (3) NOT AT ALL DURING OPERATION

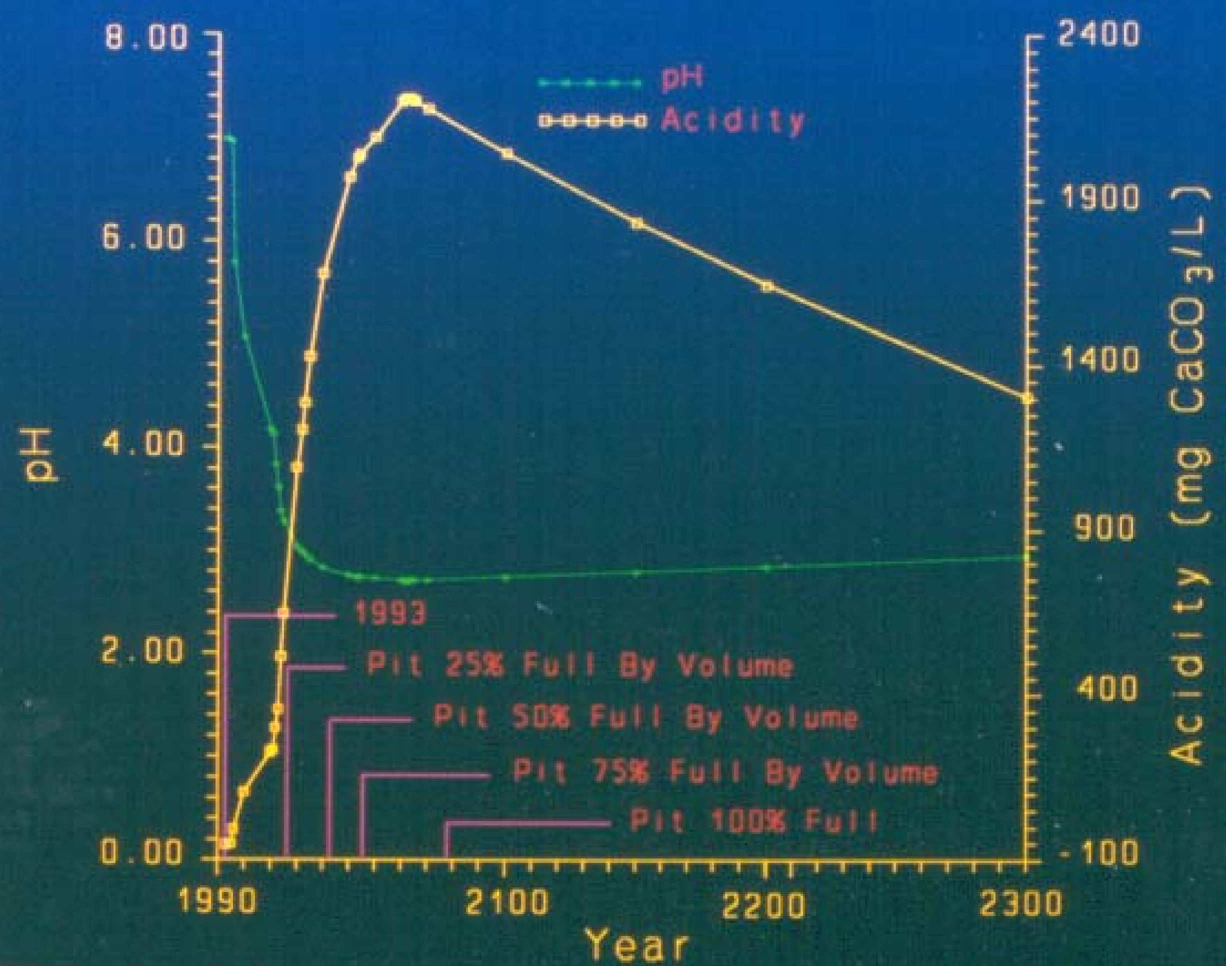
- FRACTURE SURFACES WHICH ARE NOT FLUSHED DURING OPERATION CAN ACCUMULATE IMPRESSIVE AMOUNTS OF METALS AND ACIDITY


WS
BFP
WS
BFP

YEARLY PRODUCTION OF METALS AND NON-METALS IN/ON PIT WALLS AT BELL MINE

kg/yr	ACIDIC	NEUTRAL
ACIDITY	32,800	~0
SULFATE	31,500	13,300
COPPER	2,380	15
NICKEL	12	32
ZINC	31	75

Pit Water Quality Prediction Through Time
pH & Acidity vs Year



AVERAGE PREDICTED CONCENTRATIONS DISSOLVED IN PIT WATER AT STEADY STATE

PARAMETER (mg/L)	PREDICTED PIT CONC
pH	2.7
ACIDITY	2230
ALUMINUM	230
CADMIUM	0.07
CALCIUM	370
CHROMIUM	0.08
COPPER	390
IRON	270
NICKEL	0.7
SELENIUM	<0.2
ZINC	4.4
SULFATE*	2000

Bell Mine Now


TP6

Bell Tailings Update

- In 1999, test pits were excavated in the tailings to assess the original predictions for rapidly downward migrating fronts of net acidity and sulphide depletion. This work showed that there is significantly less acid generation and migration than predicted in the Closure Plan. Analyses of test-pit samples and the results of long-term humidity cells, which were not available for the Closure Plan, showed that the discrepancies can be attributed to three primary factors.

Bell Tailings Update

- First, the original prediction that rates would accelerate by a factor of 50, as acidic conditions developed, was based on one humidity cell that was acidic from the beginning of testing. This acceleration is not happening (within the factor-of-two resolution of our data) based on field observations after eight years of closure, and thus the generation of acidity and the depletion of sulphide is significantly less than predicted.

Bell Tailings Update

- Second, the ratio of neutralization-potential (NP) consumption to acid generation was relatively high at roughly 4:1 based on near-neutral cells from the Closure Plan. Two cells were continued for a few additional years and showed that the appropriate ratio was below 2.0:1 and likely around 1.5:1. Thus, NP is depleted at a proportionally much lower rate than originally expected.

Bell Tailings Update

- Third, published literature indicates the rate of sulphide oxidation is zero order (independent of oxygen level and depth in this case) to multi-order, with no detailed information on which order applies in any situation. The Closure Plan assumed zero order, which is now known not to be the case. Instead, sulphide oxidation and NP consumption are focussed into the shallowest tailings, leading to less NP consumption than expected at depths of 0.5-2 m.

Bell Tailings Update

- With the new information, the original predictions for the tailings have been updated and are now consistent with observations to date. The updated predictions call for much slower downward migration rates for the fronts of acidity and sulphide depletion. The updated new rates are 0.03 m/yr and less, compared with the original predictions of 3.3 m/yr and less. These migration rates of the acid and sulphide-depletion fronts will likely slow significantly with time and depth, due to the restriction of oxygen with depth as explained in the Closure Plan. Therefore, annual production of acidity and metal leaching has been significantly less than originally expected and will decrease further with time.

Bell Tailings Update

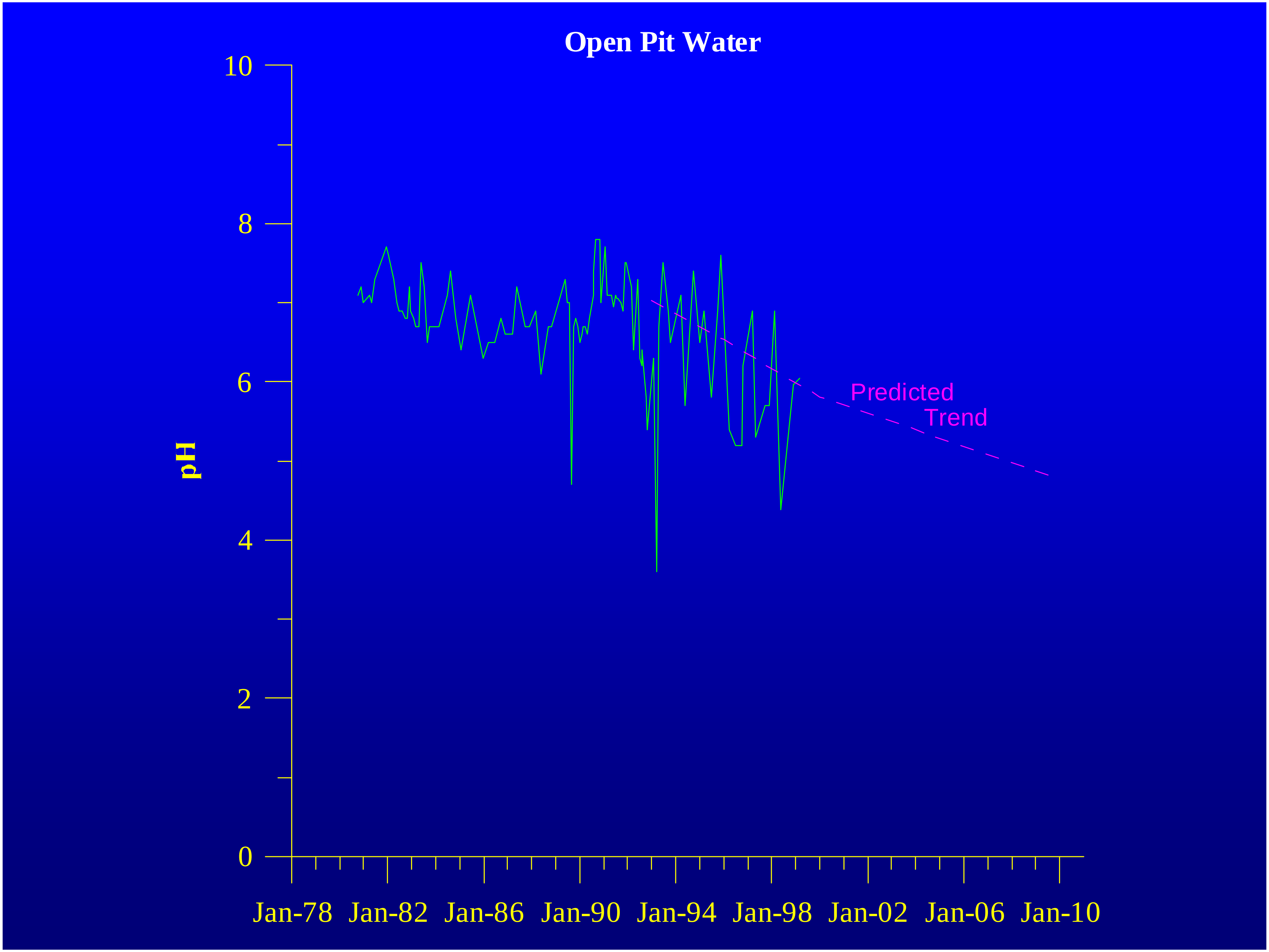
- The surficial tailings-pond water was predicted to be near-neutral to around 2003 and then become acidic. However, because the tailings are now known to generate less acidity and consume less NP than originally predicted (above), the revised predictions are for significantly less acidity and metal leaching into the pond.

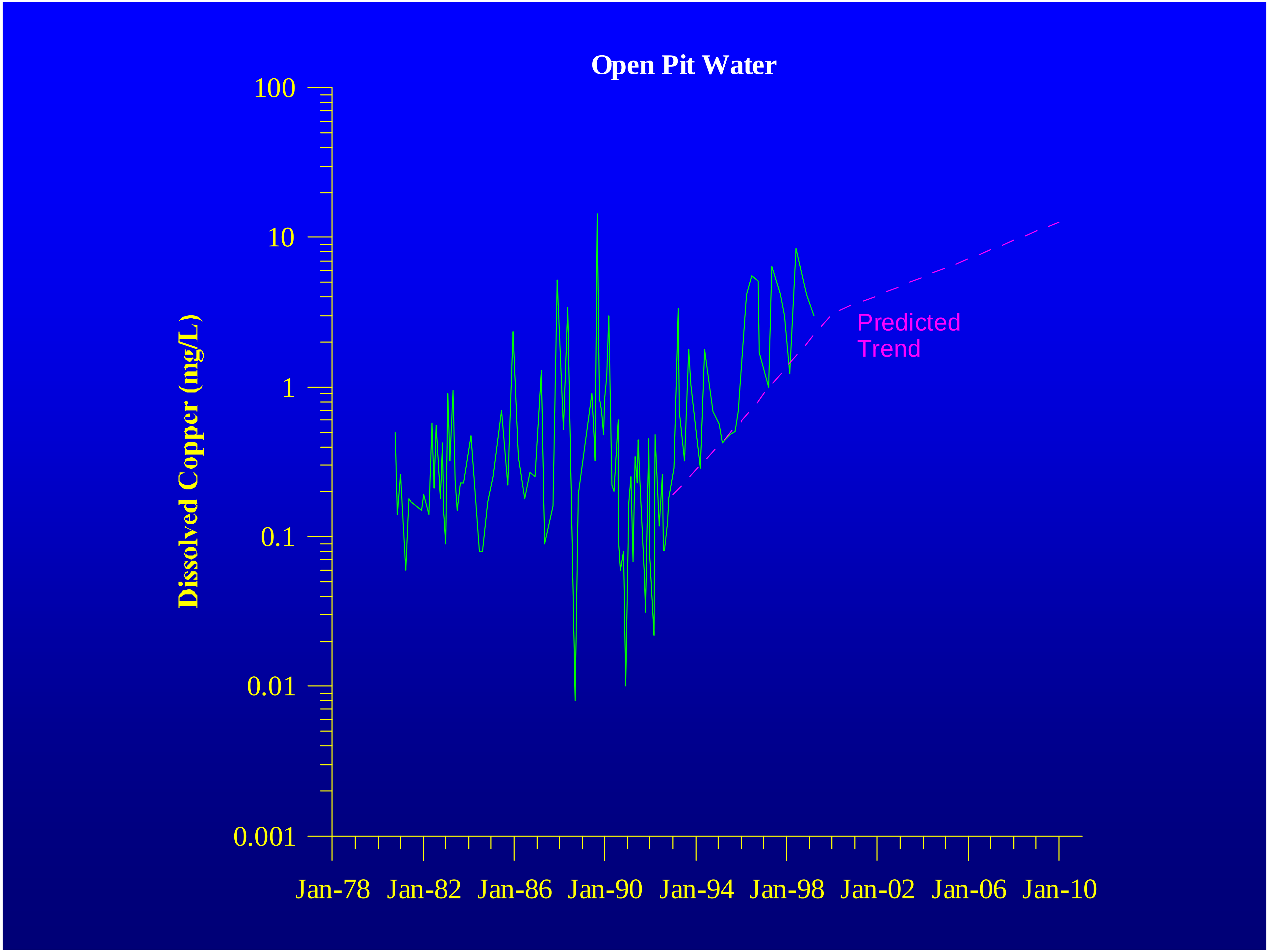
Bell Drainage-Chemistry Update

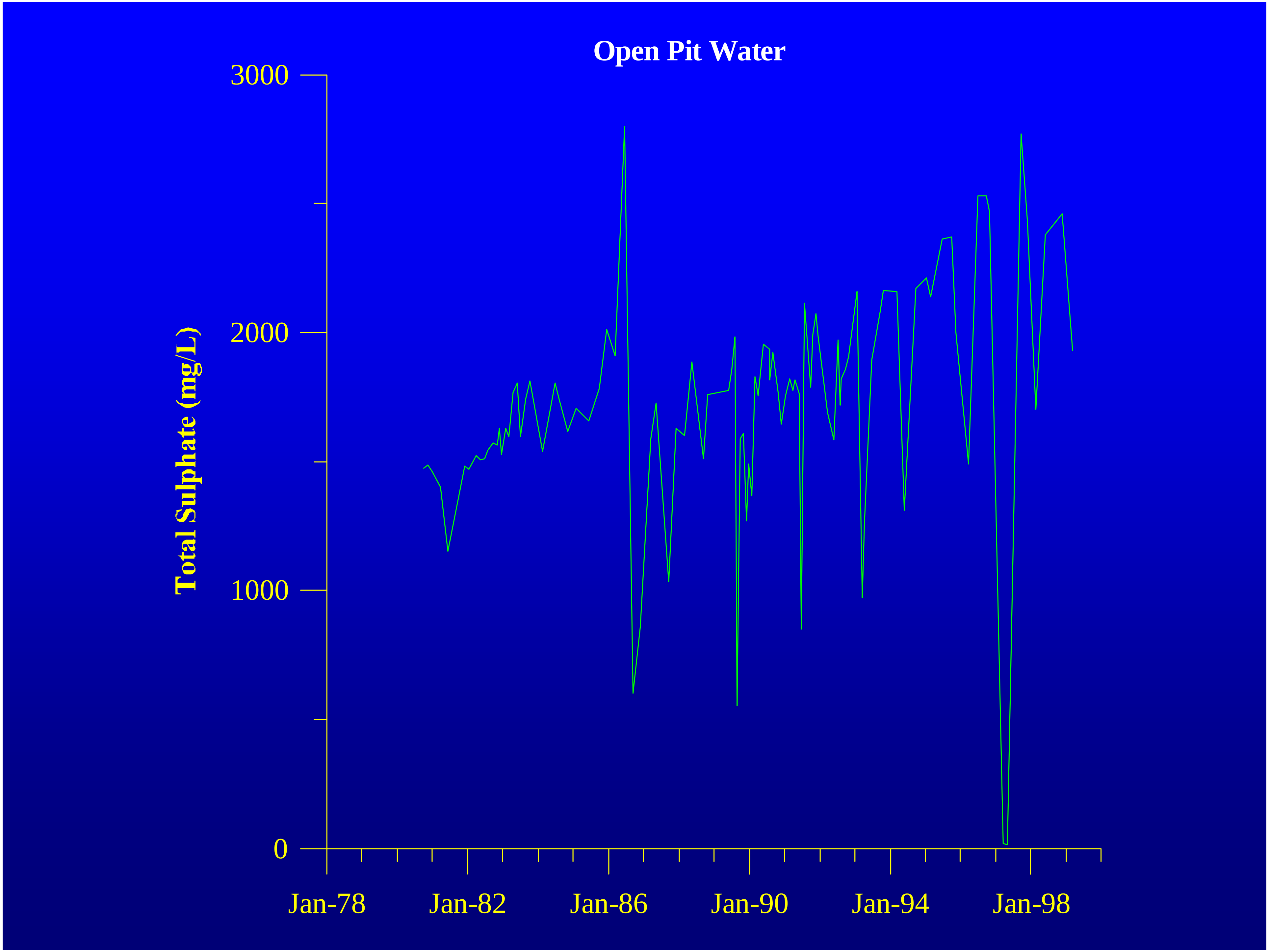
- As predicted, aqueous concentrations of parameters still regularly measured at Bell Mine have remained around the same seasonal range and average. Where adjustments were made to the best-fit equations for predicting concentrations, the adjustments were within a factor of two, which is a common resolution in this type of geochemical work. For example, dissolved copper around the minesite has generally been about one-half that observed during operation, but does not show a pattern of decreasing concentrations from year to year.

Bell Drainage-Chemistry Update

- The pit receives all drainage from around the minesite that is not acceptable for discharge, and detailed predictions were made for its cumulative chemistry through time in the Closure Plan. Samples are collected seasonally from the surface of the pit, but this surficial water may not always be representative of the entire pit-water column. In any case, the observed good agreement with predicted trends and concentrations, indicate the original predictions remain generally valid and that the pit water is evolving towards acidic conditions as predicted. No adjustments to the original predictions for the pit are needed at this time.


Open Pit Water
pH
10
8
6
4
2
0
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06
Jan-10
Predicted
Trend


Open Pit Water
Dissolved Copper (mg/L)
100
10
1
0.1
0.01
0.001
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98
Jan-02
Jan-06
Jan-10
Predicted
Trend


Open Pit Water
Total Sulphate (mg/L)
3000
2000
1000
0
Jan-78
Jan-82
Jan-86
Jan-90
Jan-94
Jan-98

Bell Drainage-Chemistry Update

- Many ponds were predicted to be acidic sometime between 2000 and 2030. A few ponds have become acidic, and several others show increasing concentrations of sulphate suggesting the buildup to eventual net acidity. In contrast, a few ponds show decreasing trends in concentrations, apparently due to remedial work. In any case, because predictions were for net acidity after 2000, it is too early to determine the accuracy of this prediction for each pond. Nevertheless, the predictions appear to be generally correct based on the few ponds that became acidic and on the increasing sulphate concentrations in some ponds.

BELL MINE
WATER MANAGEMENT MANUAL

Noranda Inc.
Bell Mine
Granisle, British Columbia

June 1999

AGRA
ENGINEERING GLOBAL SOLUTIONS


2

File

Last Reported Value		
CD7_RC	Wed Oct 06 15:48:15	1.00

Noranda Bell Mines SCADA System

Alarms

Reports

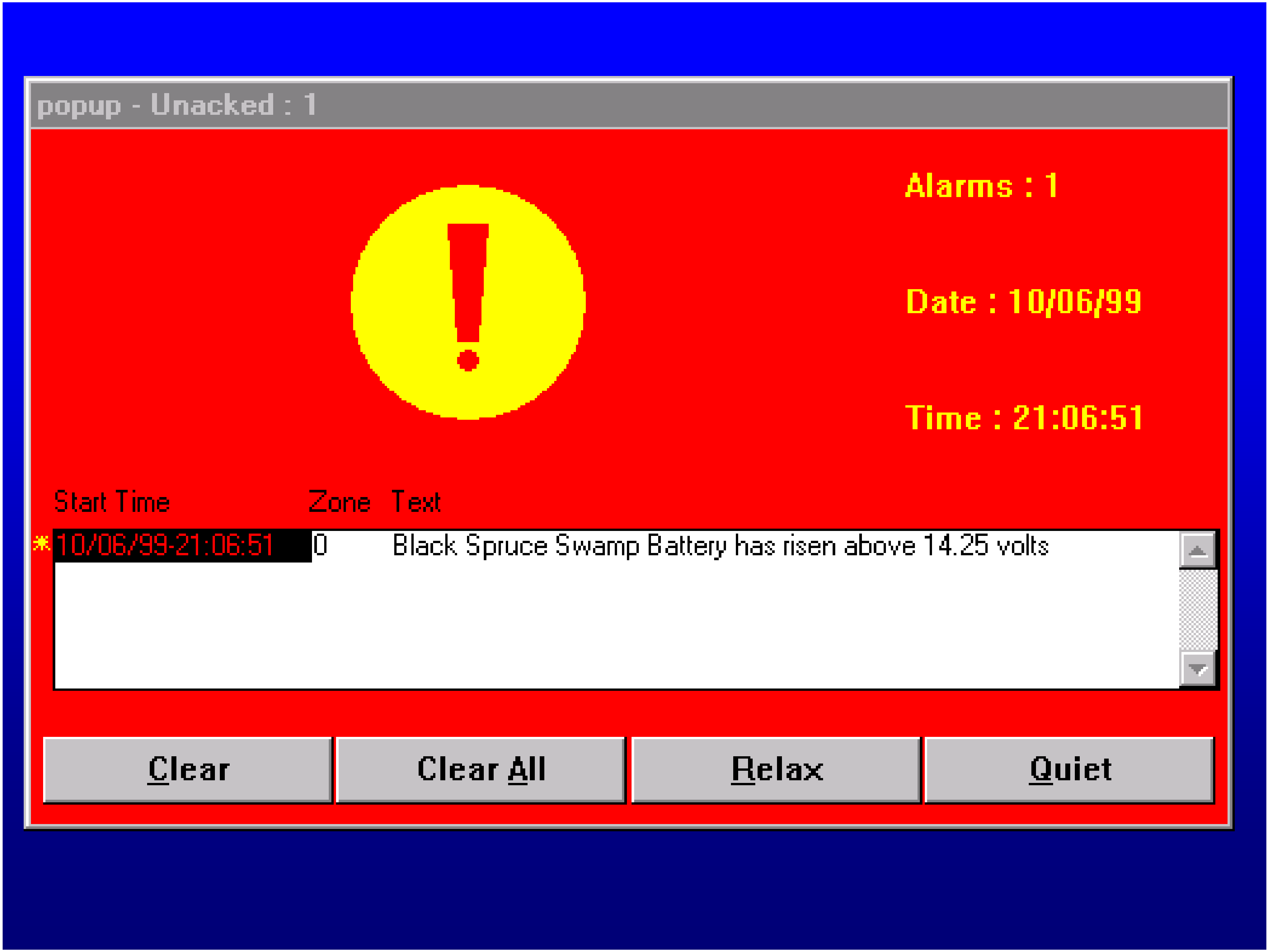
Login

Site	Pump 1	Pump 2	Level	Battery	Alarms
CP 2			4.77	13.20	
CP 4			5.17	12.44	
CP 5			6.75	12.00	
CP 8					
CP D7			2.35	12.38	
CP TEX			7.41	13.35	
SP 1-3			4.25	12.69	
SP 1-5			1.75	13.18	
SP 3-1			42.42	******	Reservoir Control is OFFLINE
SP 7-1			1.65	13.32	
GM 10			0.97	13.90	
Black Spruce Swamp					
SC 20 - Bear Island				13.80	
TEX Pond Repeater - #40				12.76	
Tailings Pond Repeater - #50				12.61	
18 Km Repeater - #60				13.63	
#2 Shop				13.76	
Townsite CTU #10				14.29	
Minesite CTU #20				13.38	

= Pump Off = Pump Running

= Active Alarm (Un-Acked) = Ended Alarm (Un-Acked)

Screen updated at: 15:48:57 06/10/99 Current Operator: Rosendab


popup - Unacked : 1
Alarms : 1
Date : 10/06/99
Time : 21:06:51
Start Time
Zone
Text
10/06/99-21:06:51
0
Black Spruce Swamp Battery has risen above 14.25 volts
Clear
Clear All
Relax
Quiet