# Geochemical Predictions of the Landusky Spent Ore Heap Leach Pads & Implications for Water Management.

By

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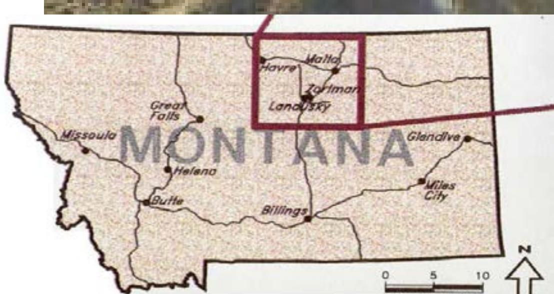
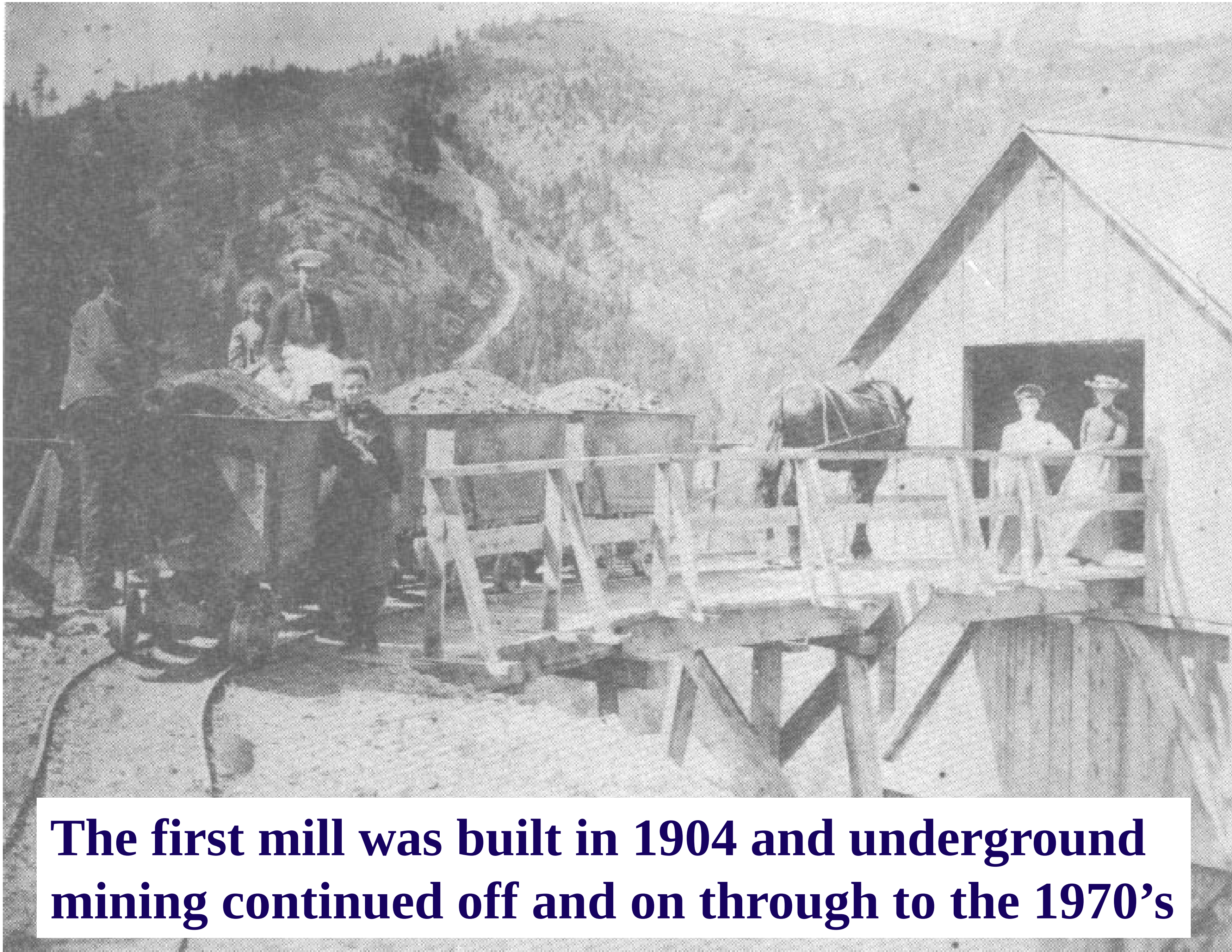
# Objectives

- Site description
- Leach pad history and geochemical characteristics
- Current water management
- Water quality & management changes over time

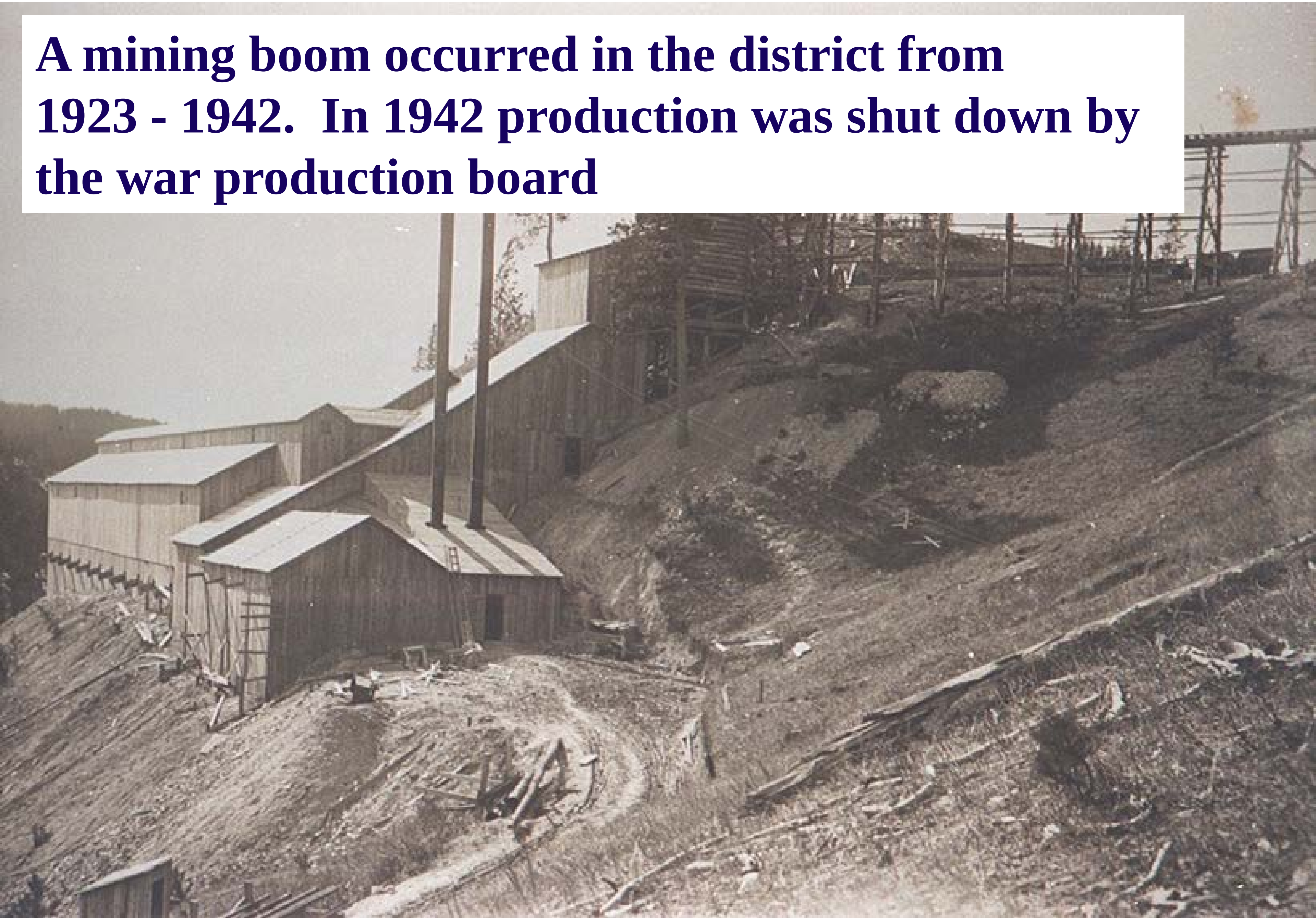
## The Landusky gold mine is located adjacent to the Zortman gold mine in the Little Rocky Mountains in Phillips County
## (~155 miles north of Billings)

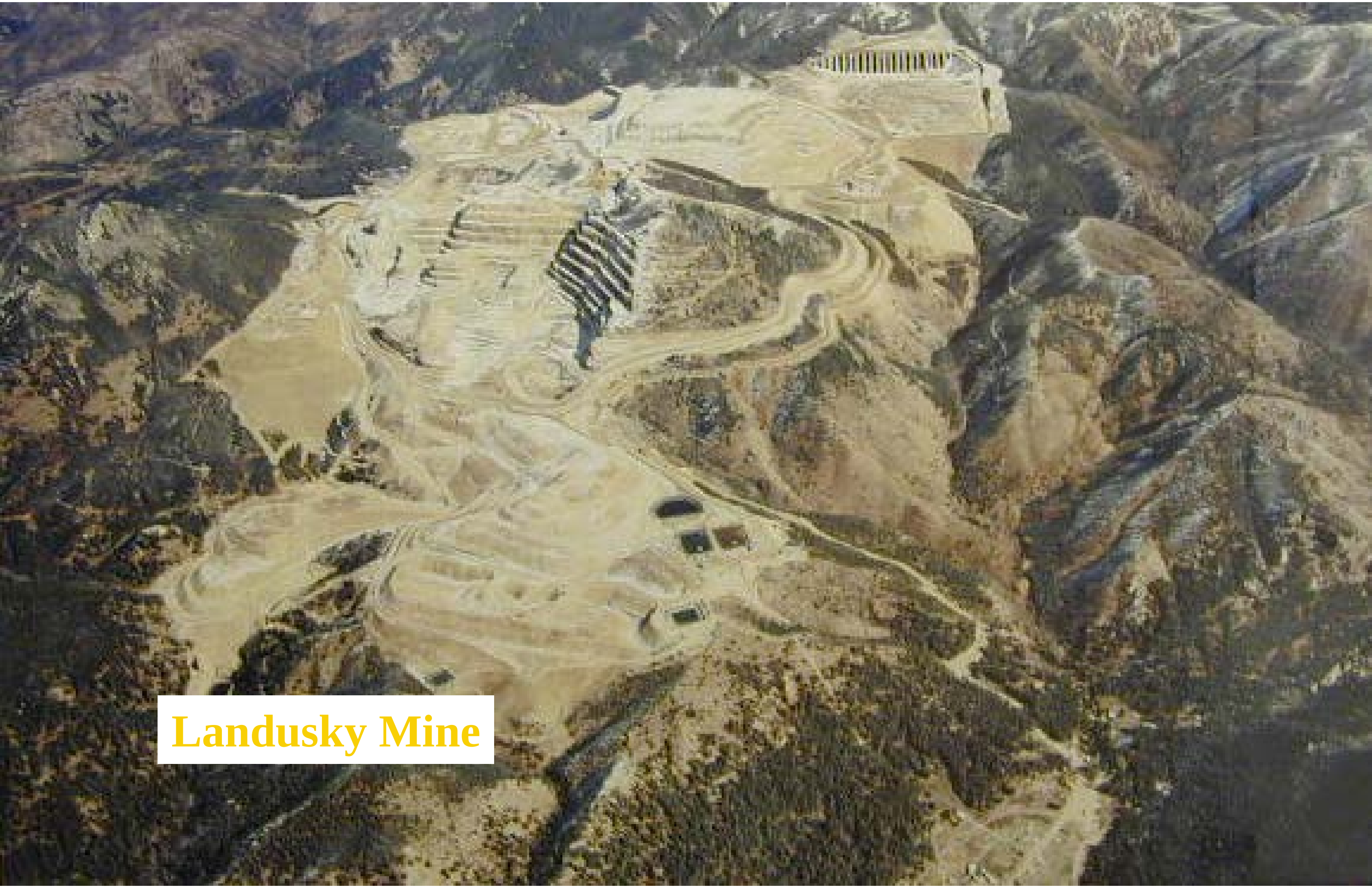


**The first mill was built in 1904 and underground mining continued off and on through to the 1970's**

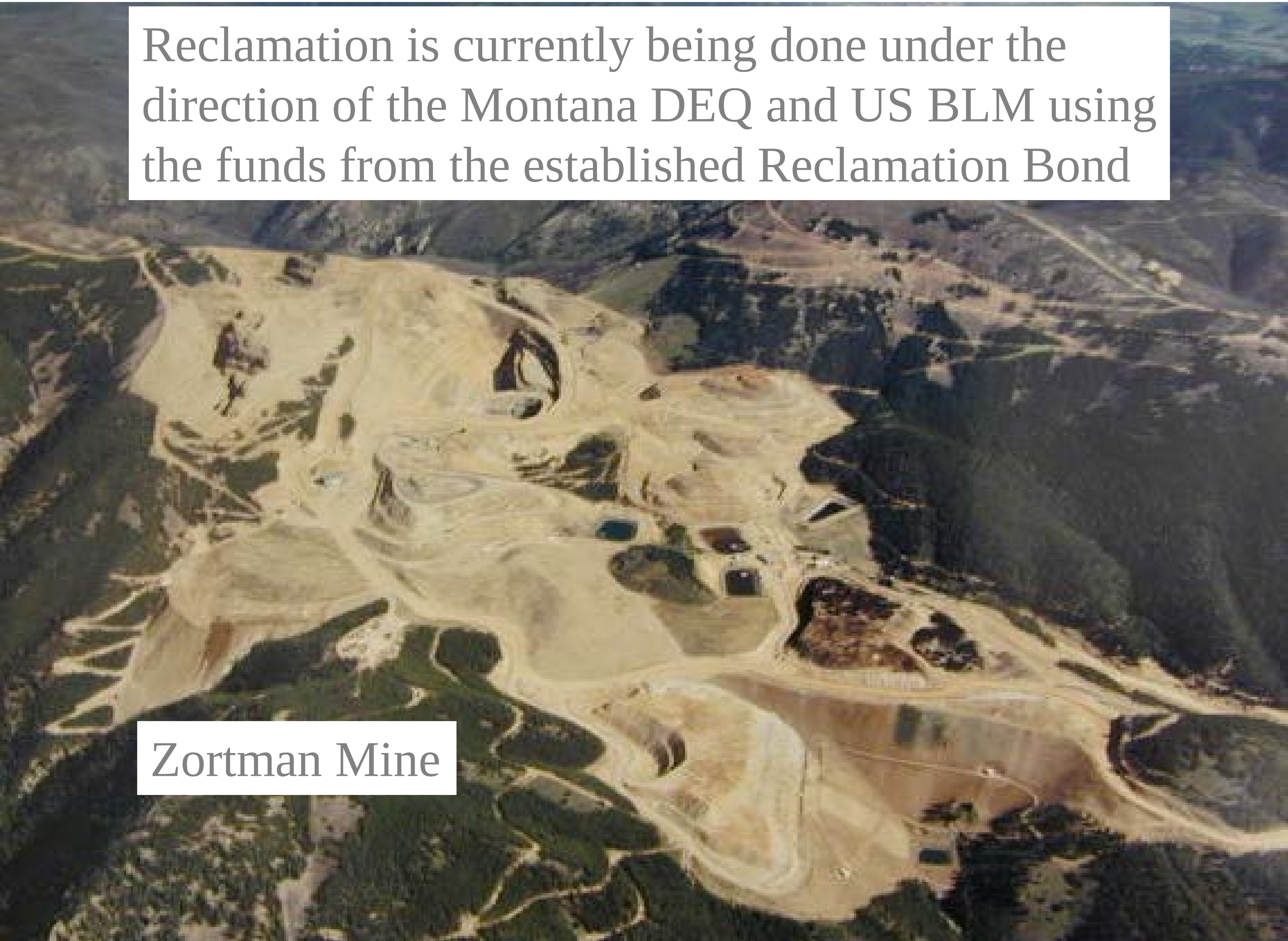
**A mining boom occurred in the district from 1923 - 1942.  In 1942 production was shut down by the war production board**



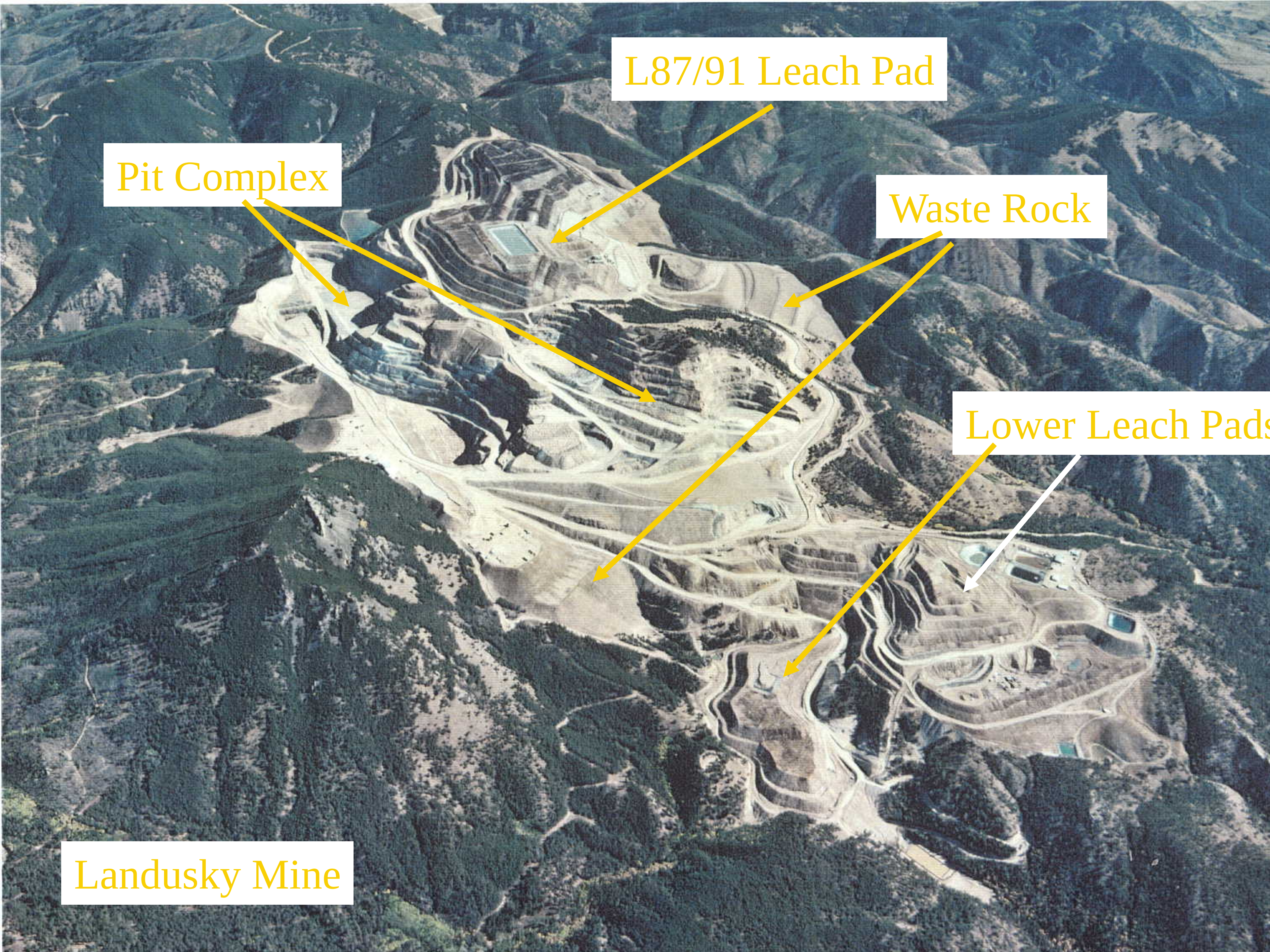
**Open pit heap leach operations began in 1979 and continued until 1996 when the proponent went bankrupt.**



Reclamation is currently being done under the direction of the Montana DEQ and US BLM using the funds from the established Reclamation Bond



Zortman Mine


L87/91 Leach Pad
Pit Complex
Waste Rock
Lower Leach Pads
Landusky Mine


L87/91 LP is one of the largest valley-filled leach pads holding ~120 million tonnes of spent ore

# Reclamation Issues

- The most significant reclamation issue is that of water management.
- There are essentially 3 water types on the site:
    1. Clean water discharge
    2. ARD - treated with HDS lime treatment
    3. Spent ore leachate - currently land applied

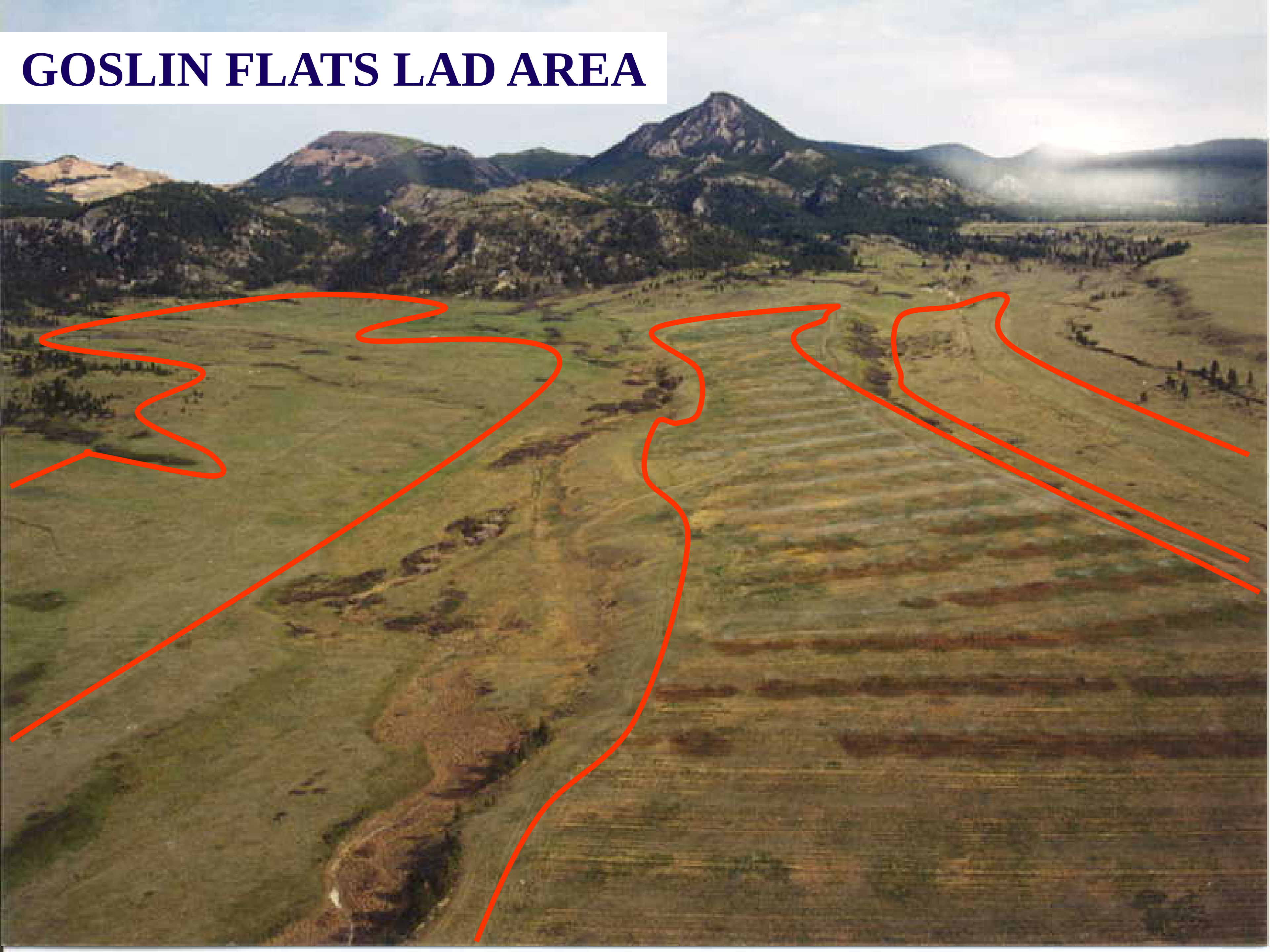
# Spent Ore Leachate

- Heap leach pads were operated at pH conditions of ~10.
- A significant amount of sulfidic ROM ore was placed on the leach pads - which is potentially acid generating
- After operations, the leach pads were rinsed to drop the pH to circum-neutral conditions and $H_2O_2$ was added to the leachate to break down CN
- The solutions were then land applied in a Land Application Disposal (or LAD) area - currently still in use

# Spent Ore Leachate

- The LAD relies on the cation exchange in the soils and plant uptake of constituents.
- Solutions are irrigated over the surface to enhance evaporation and minimize surface water discharge.

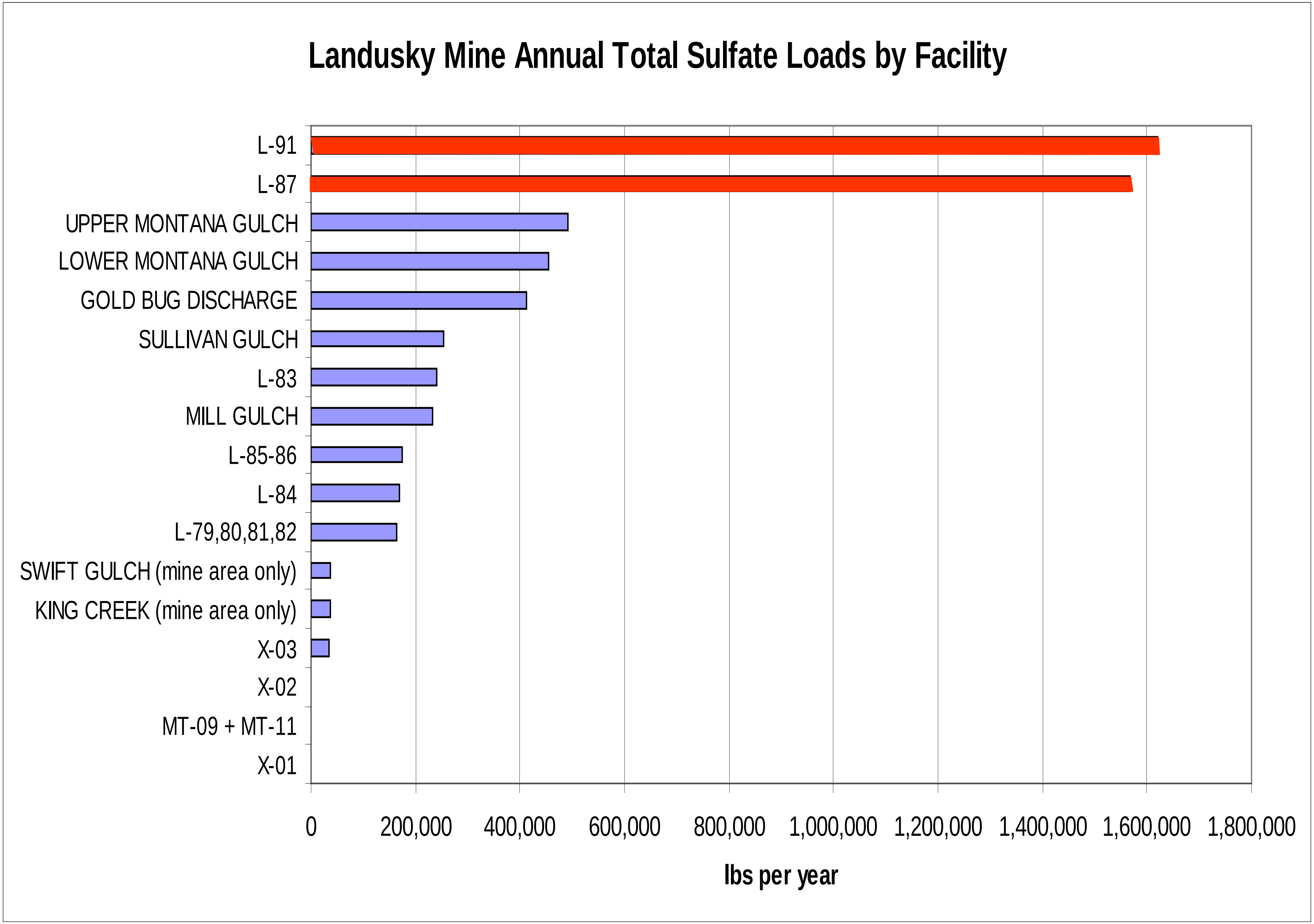
# GOSLIN FLATS LAD AREA



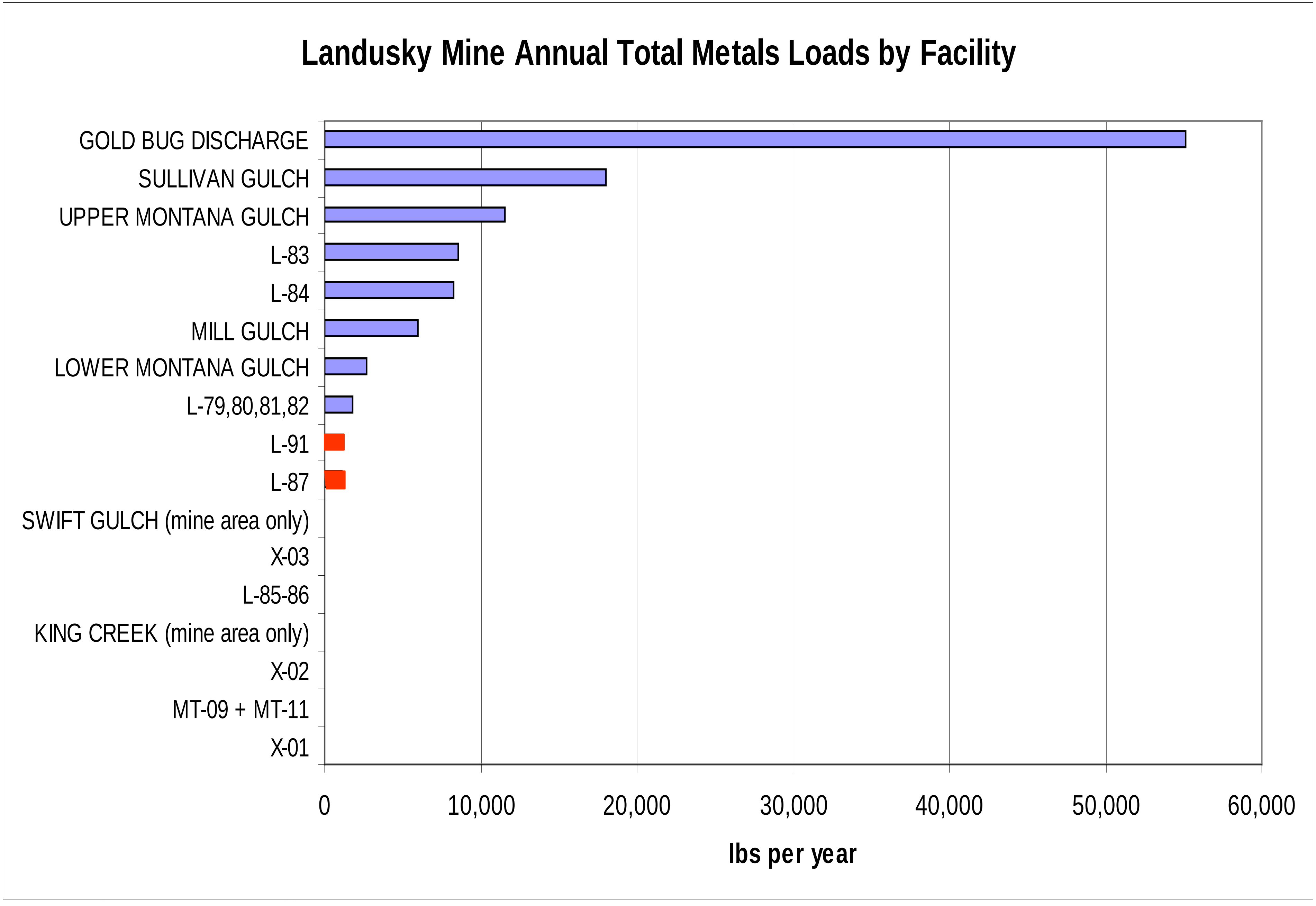
# GOSLIN FLATS LAD AREA, VIEW SOUTH

# LAD Issues

- Need to land apply close to 100 Million Gallons of water a year - on a seasonal basis (early spring to late fall),
- Approaching the agronomic limits for $NO_3$ and Na
- Issues related to increasing concentrations of Se, $SO_4$ and other constituents in the water have lead to the evaluation of potential pre-treatment technologies
- An ARD study implied that the leach pad is potentially acid generating, current water quality suggests sulphides are oxidizing (high $SO_4$) and solutions are being buffered (pH ~6.5) therefore the metal concentrations (other than Se) have remained low



Landusky Mine Annual Total Sulfate Loads by Facility
L-91
L-87
UPPER MONTANA GULCH
LOWER MONTANA GULCH
GOLD BUG DISCHARGE
SULLIVAN GULCH
L-83
MILL GULCH
L-85-86
L-84
L-79,80,81,82
SWIFT GULCH (mine area only)
KING CREEK (mine area only)
X-03
X-02
MT-09 + MT-11
X-01
0
200,000
400,000
600,000
800,000
1,000,000
1,200,000
1,400,000
1,600,000
1,800,000
lbs per year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10,000
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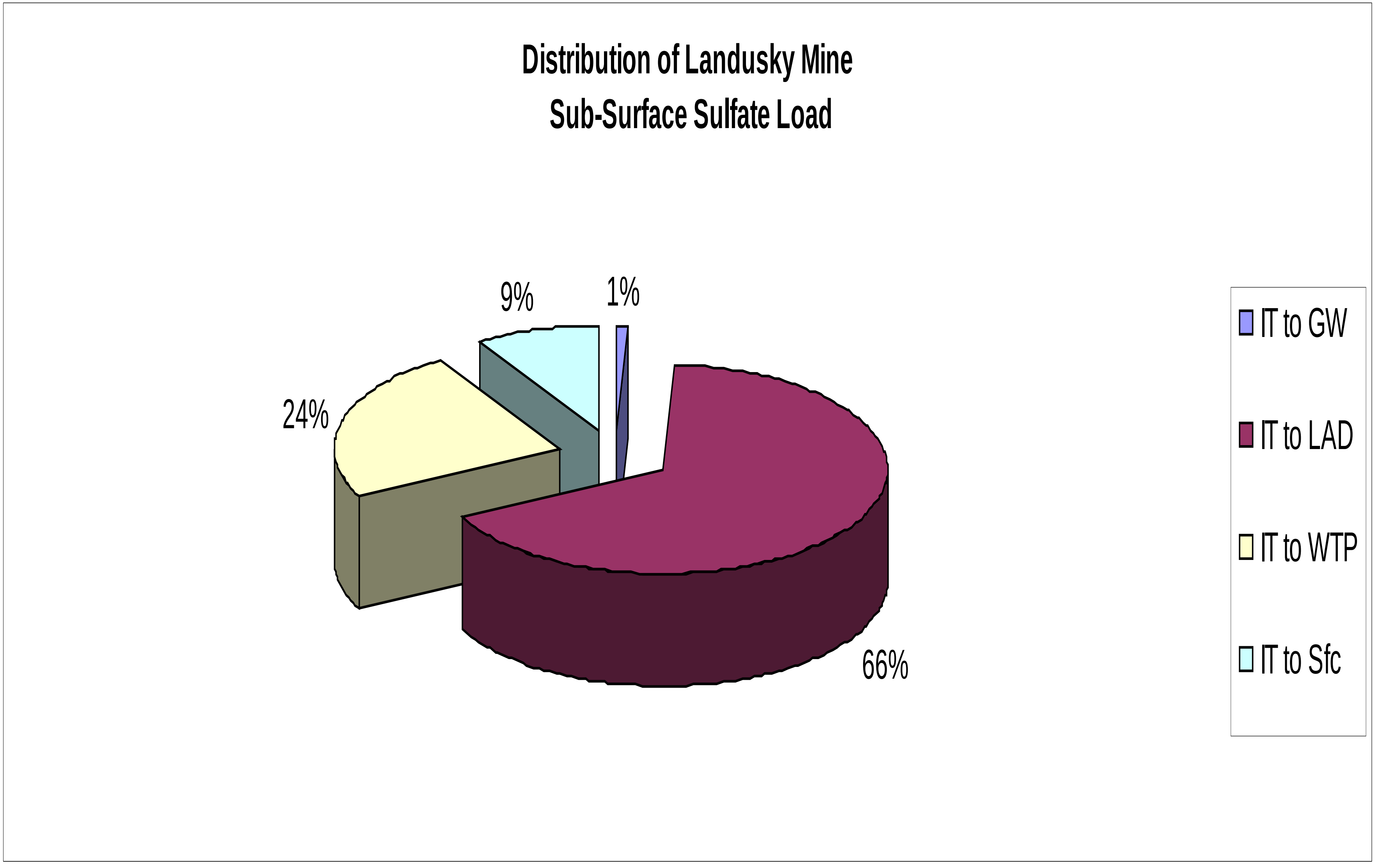
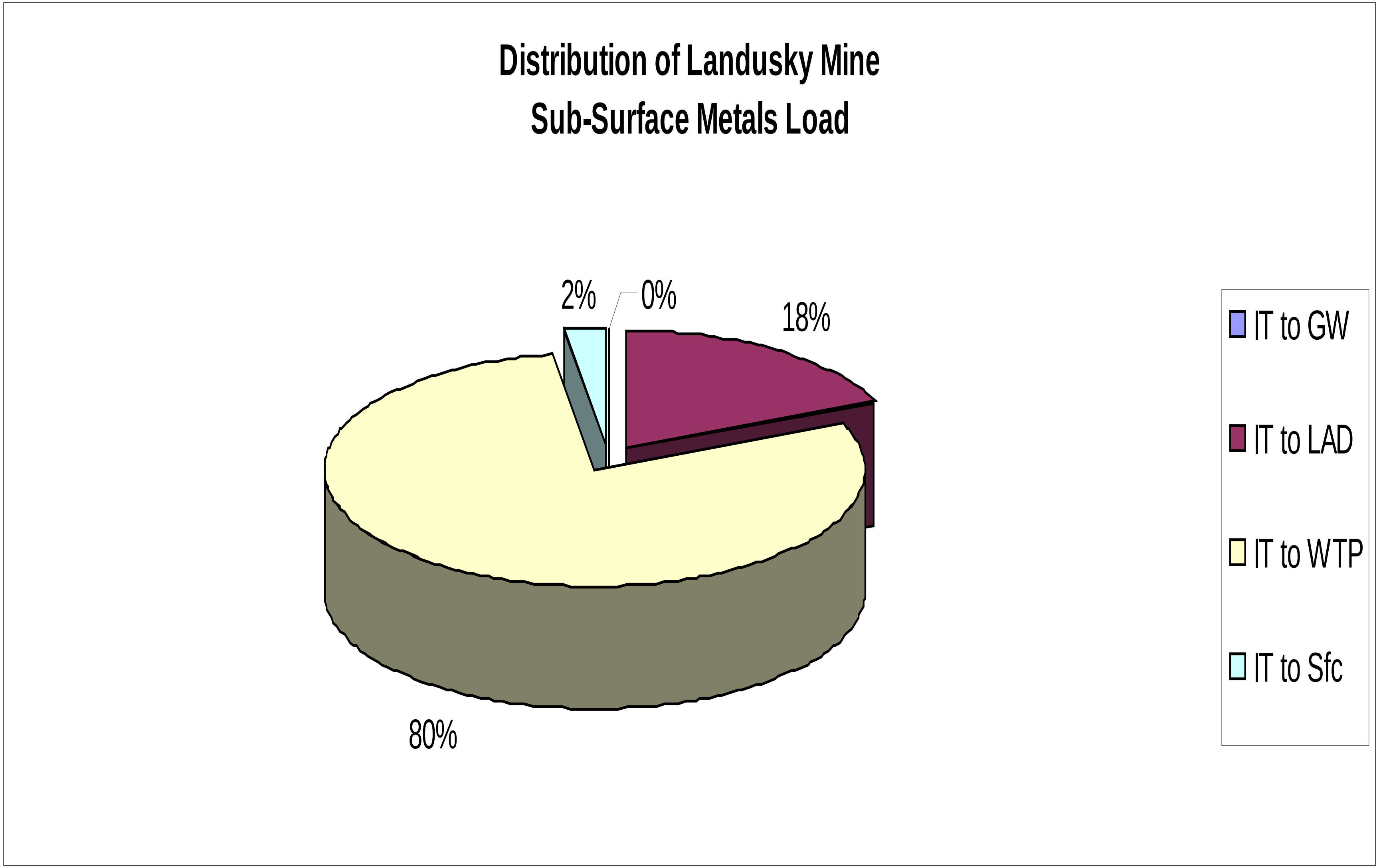
50,000
60,000
lbs per year


Distribution of Landusky Mine
Sub-Surface Sulfate Load
9%
1%
24%
66%
IT to GW
IT to LAD
IT to WTP
IT to Sfc

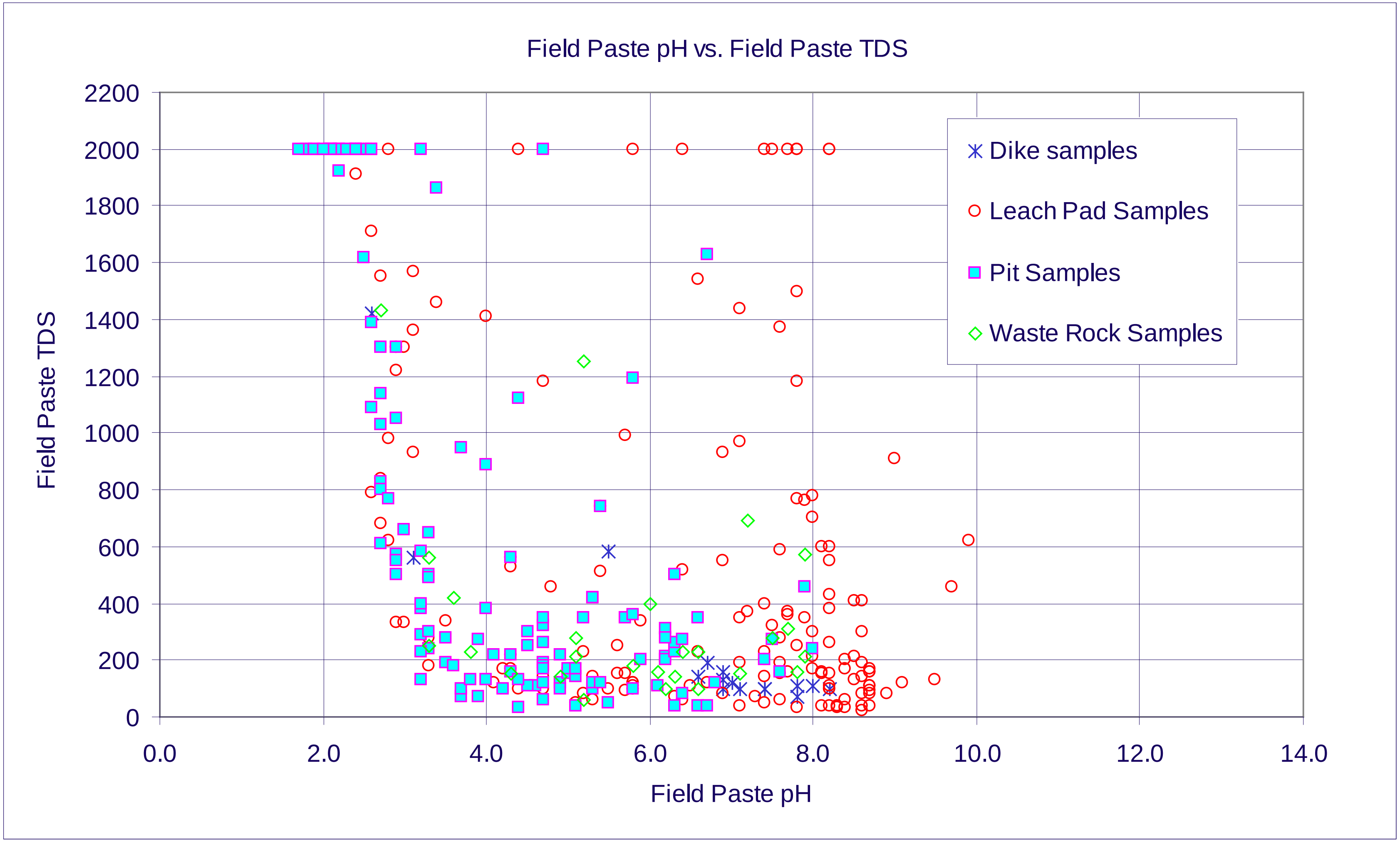

Distribution of Landusky Mine
Sub-Surface Metals Load
2%
0%
18%
80%
IT to GW
IT to LAD
IT to WTP
IT to Sfc

# Future Water Quality Changes?

- It is obvious that the water chemistry in the leach pad is changing
- An investigation was completed to help predict what the future changes may be in order select the best pre-treatment technology to accommodate the changes

# The Field Survey Consisted of:

- paste pH and paste TDS measurements
- visual identification of:
  - rock type
  - degree of oxidation
  - degree of alteration
  - surface precipitates and staining
  - presence of visible sulfides
  - any ‘unusual’ textures




In general, samples with low pH have high TDS values due to the presence of soluble minerals on the grain surfaces. The exception is the leach pad samples for which the added alkalinity (during leaching) is maintaining near neutral pH values and contributing to TDS.

# Surface ‘salts’

- Color on the leach pads was highly variable and in general not indicative of pH trends

# Surface 'salts' - Mineralogical Analysis

- Powder XRD analyses confirm the presence of:
  - Calcite ($CaCO_3$)
  - Huntite ($CaMg_3(CO_3)_4$)
  - Jarosite ($KFe3(SO_4)_2(OH)_6$
  - Copiapite ($Fe_5(SO_4)_6(OH)_2.20H_2O$
  - Akaganite (β-FeOOH)

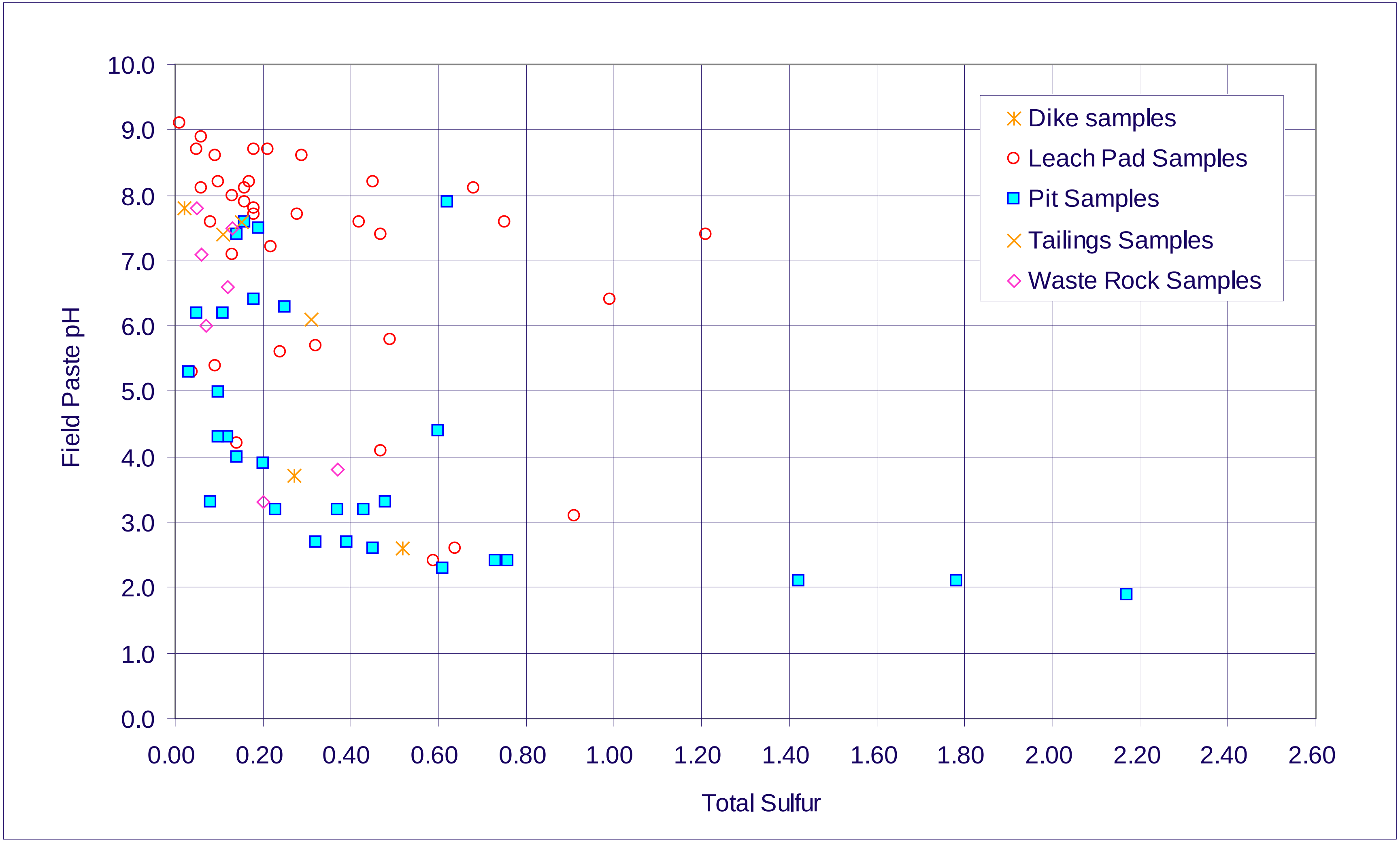
- Single crystal XRD analyses suggest:
  - Celadonite ($K(Mg,Fe)(Fe,Al)[Si_4O_{10}](OH)_2$)
  - Calcanthite ($CuSO_4.5H_2O$)
  - Melanterite ($(FeSO_4).7H_2O$
  - Dumortierite ($Al_7(BO_3)(SiO_4)_3O_3$)

mineralogical analysis being done by B. Sheriff and H. Jamieson at Queen's University

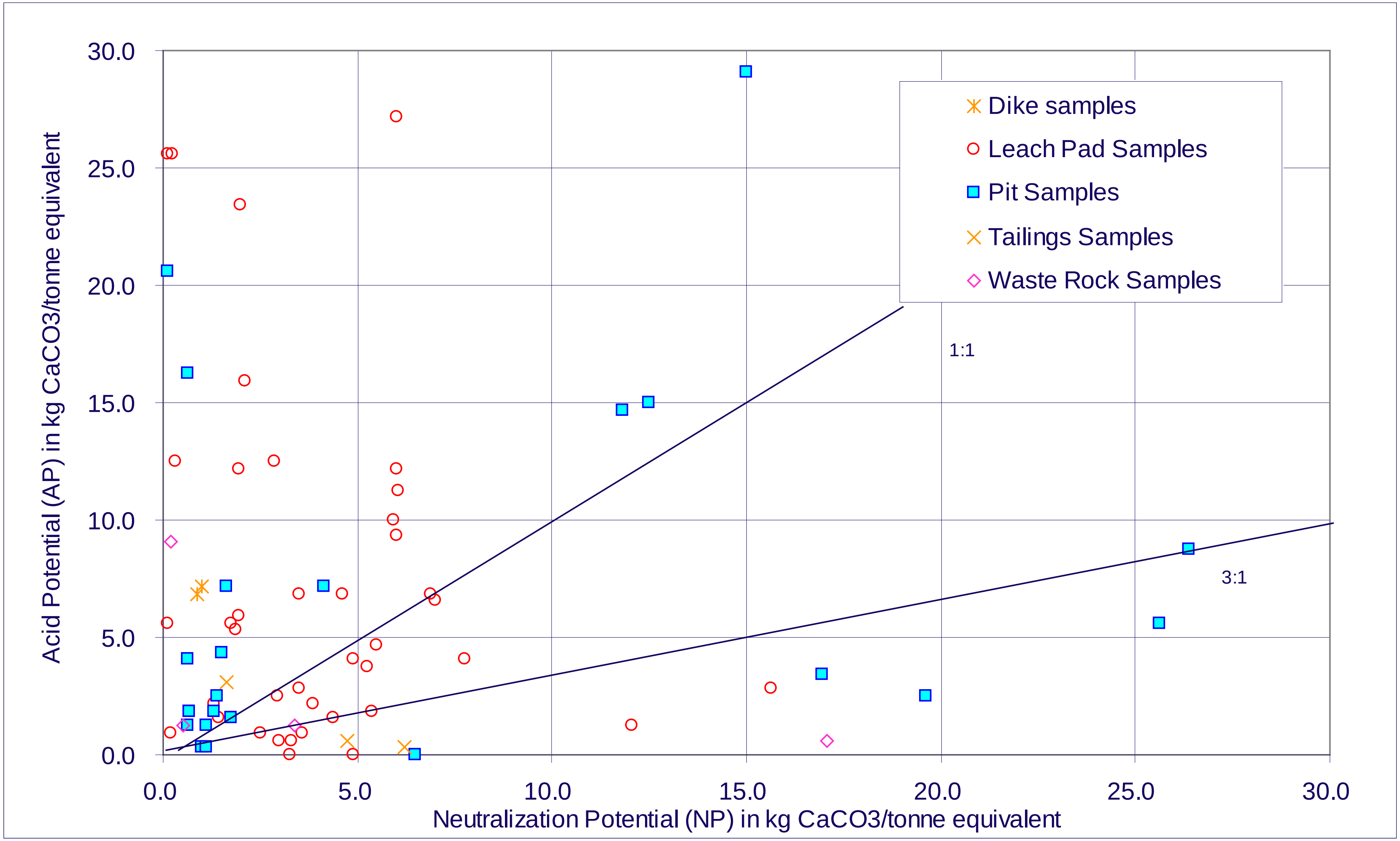
# Laboratory ARD Testing

- During the field reconnaissance survey, samples were collected for lab testing.  Lab tests included:
  - Paste pH and conductivity on the ‘as received’ fines
  - modified acid base accounting (ABA) tests
  - inorganic carbon analyses
  - leach extraction analyses
  - forward acid titration tests
  - multi-element ICP analyses
  - net acid generation (NAG) tests, and
  - seive analyses

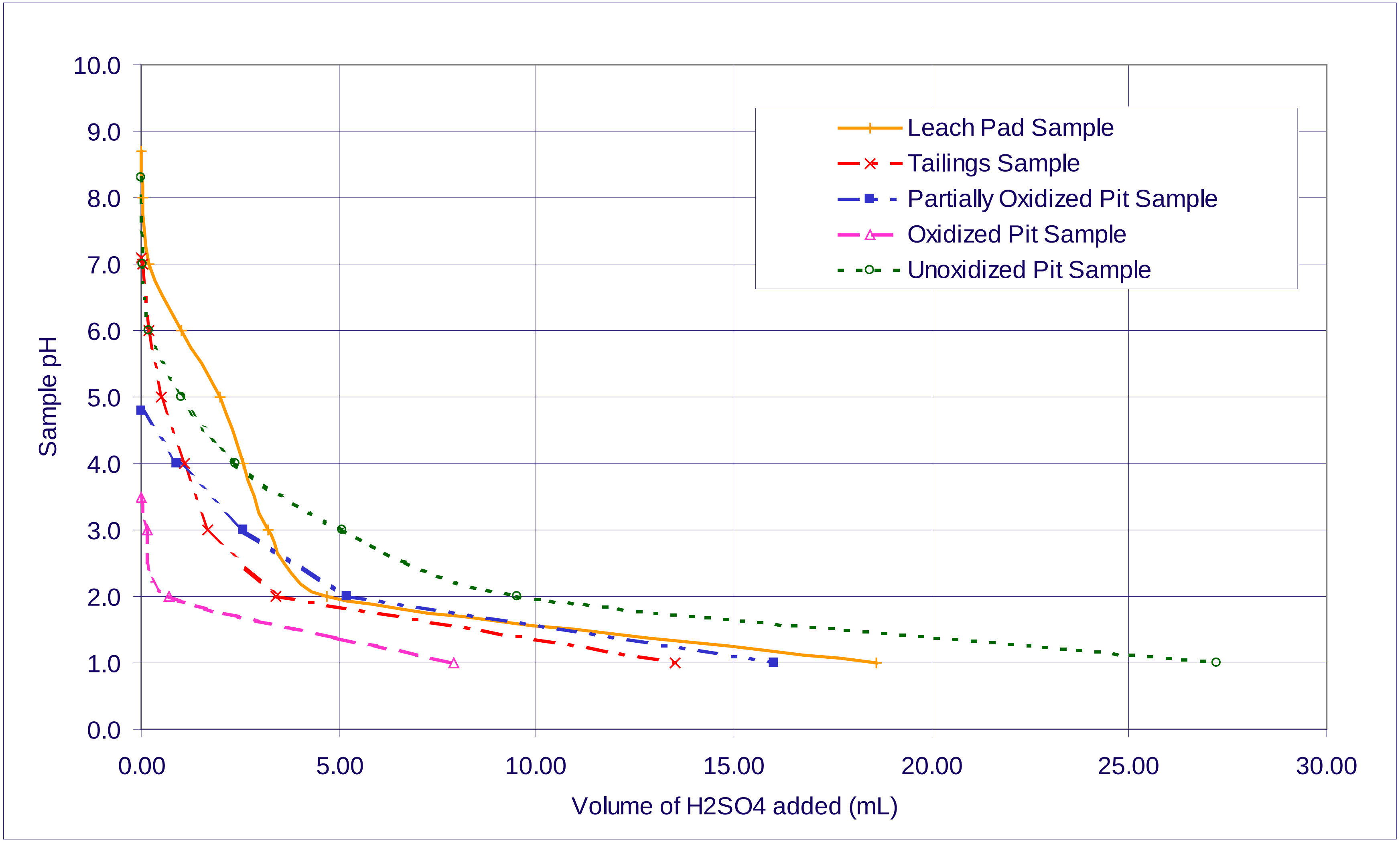
# Modified Acid Base Accounting



# Modified Acid Base Accounting



# Forward Acid Titration Tests

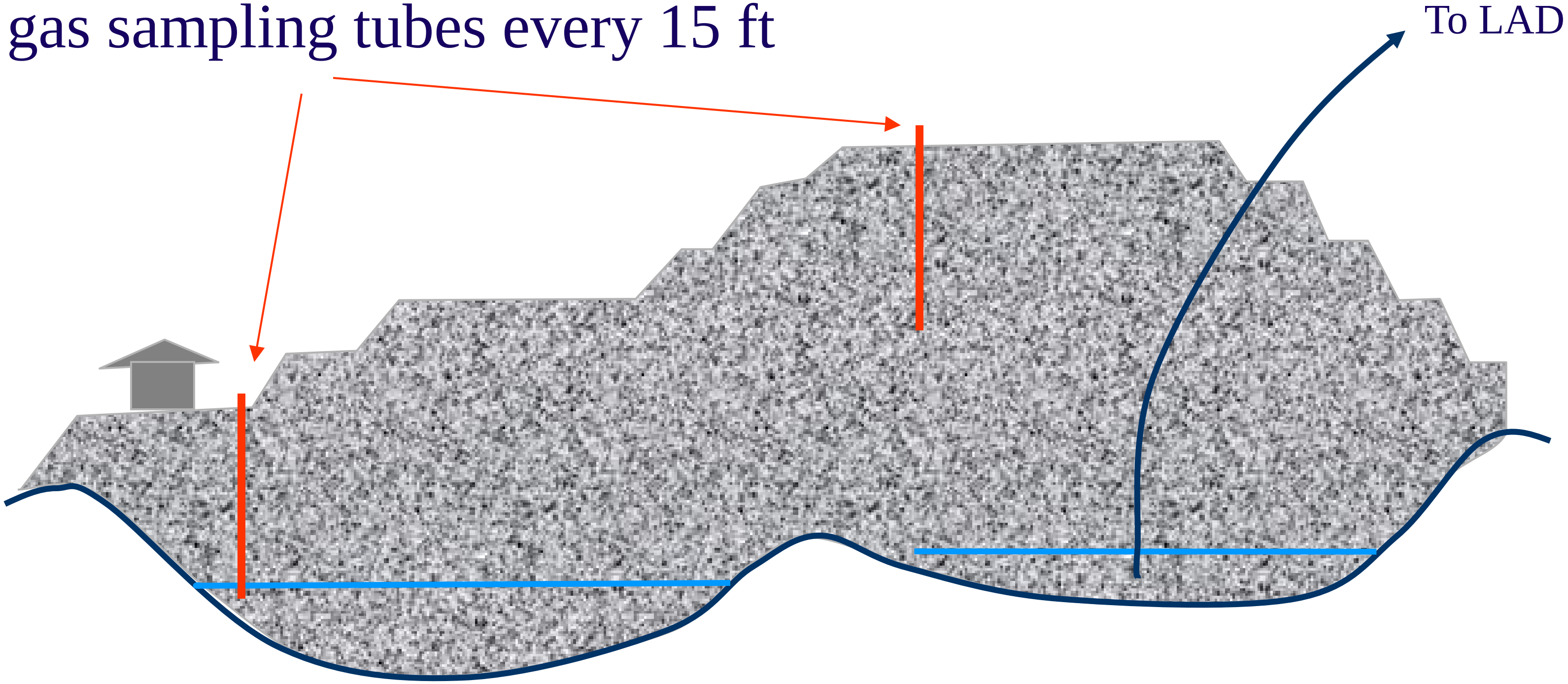


# Drilling Program

- A Becker hammer-type drill rig was used in order to minimize sample crushing and the geochemical disturbance of the samples

# Borehole Instrumentation

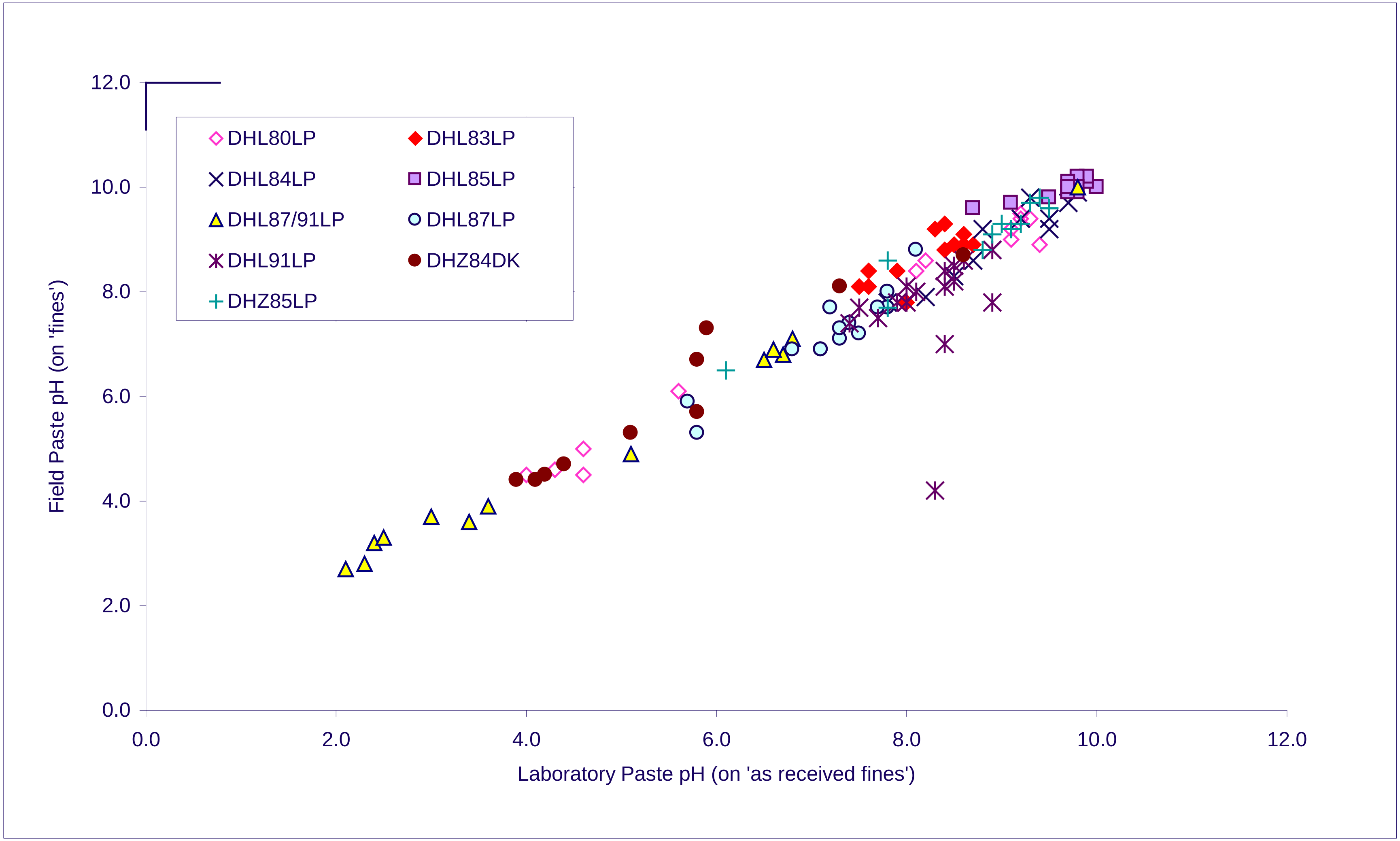
Instrumented boreholes installed with slotted PVC, thermistors every 15 ft & pore gas sampling tubes every 15 ft



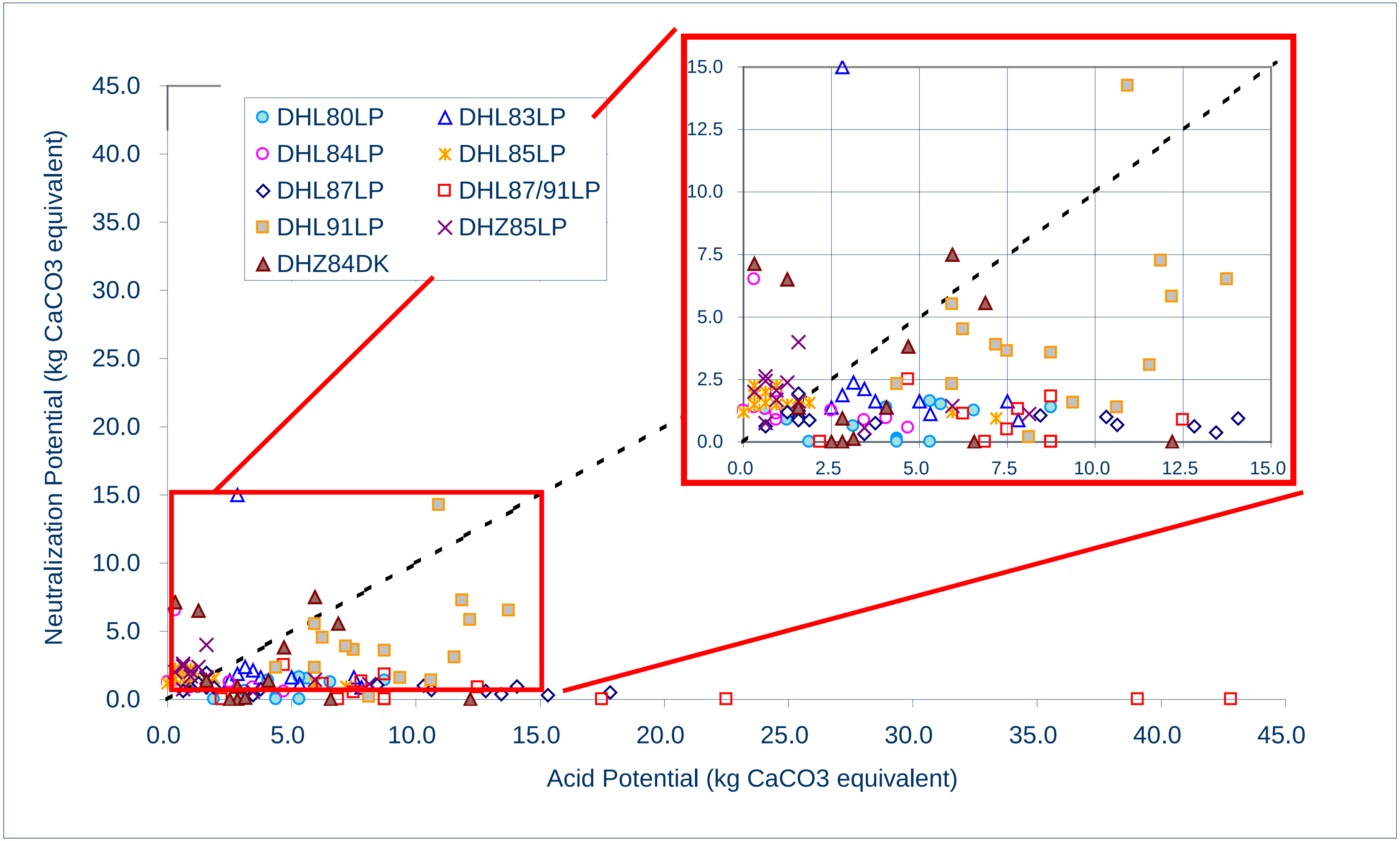
# Drill Cuttings Sampling

Samples were collected every 10 ft & paste pH and EC measured,
A sub-set of samples were submitted for laboratory testing

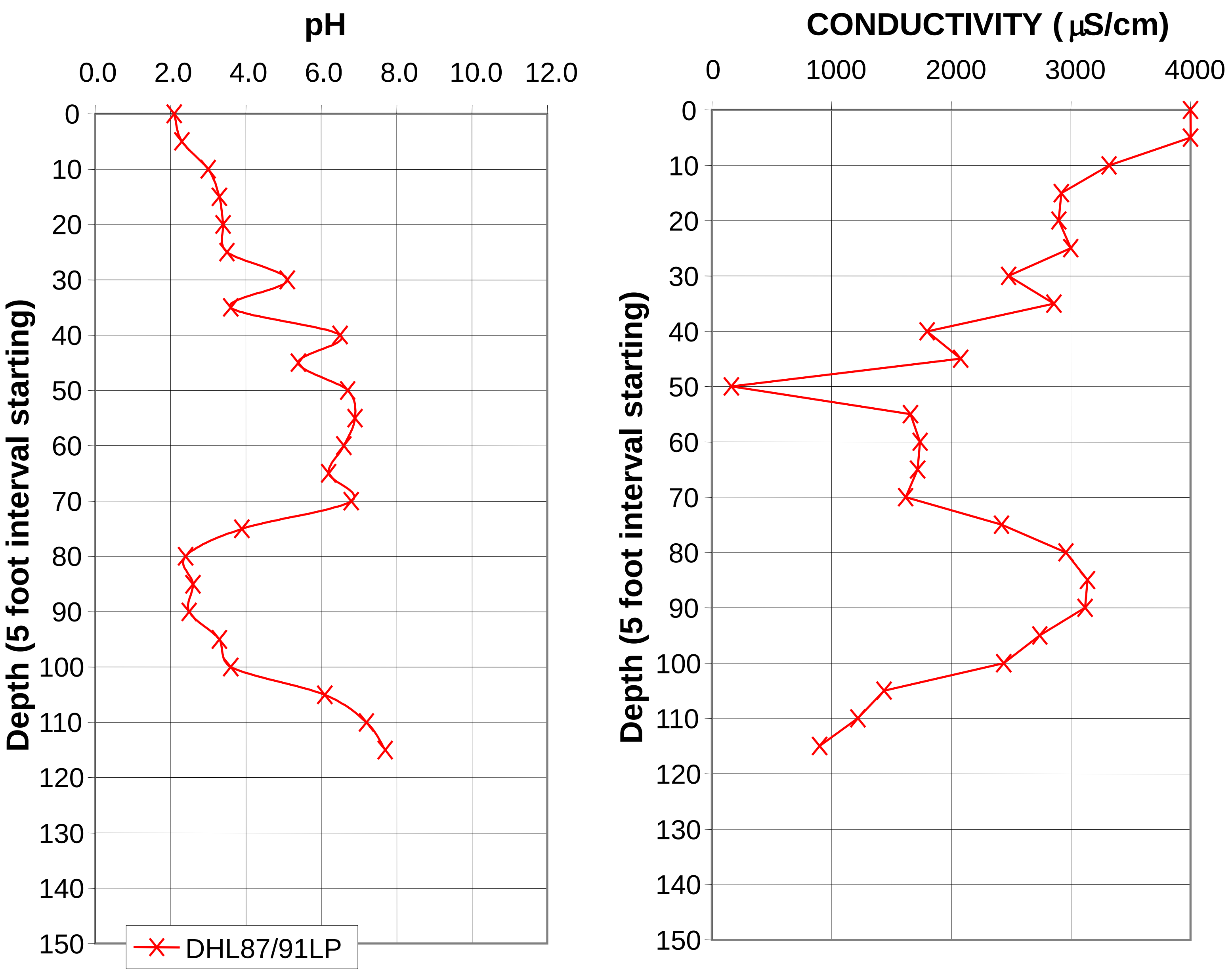
# Paste pH Results

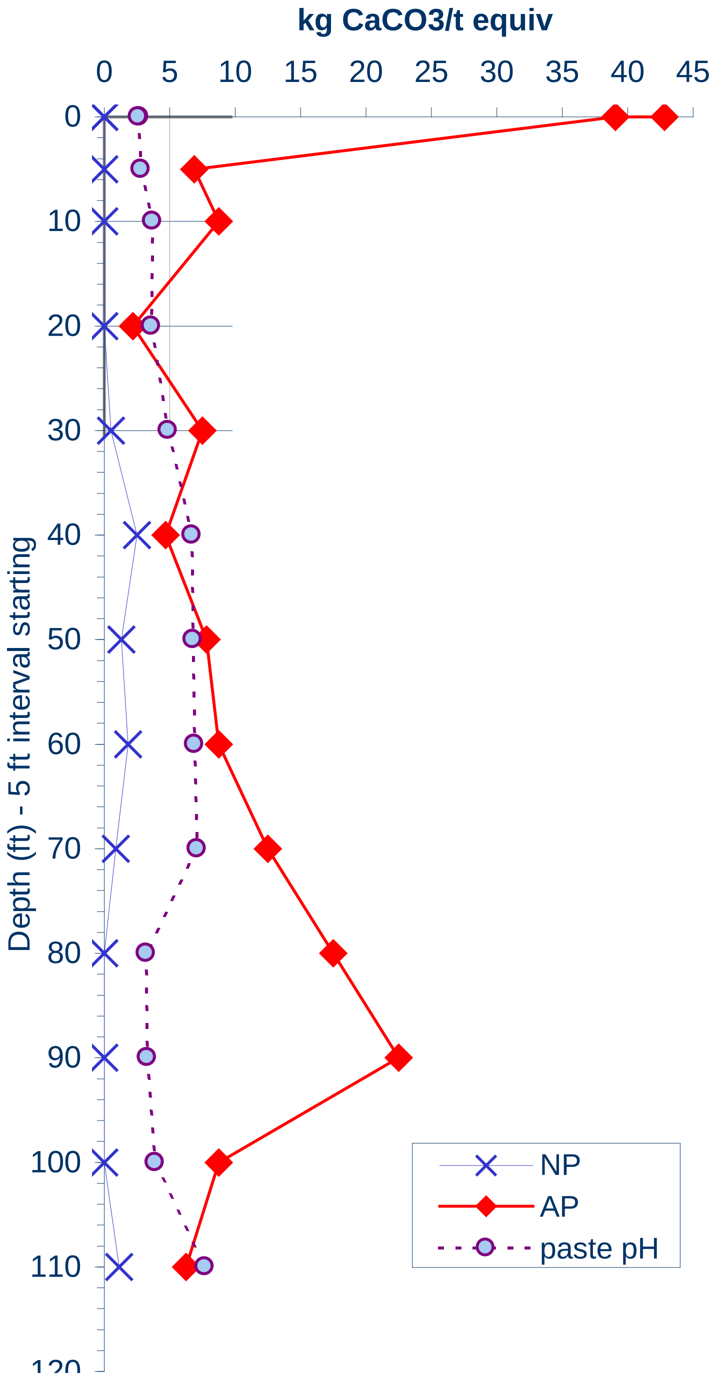


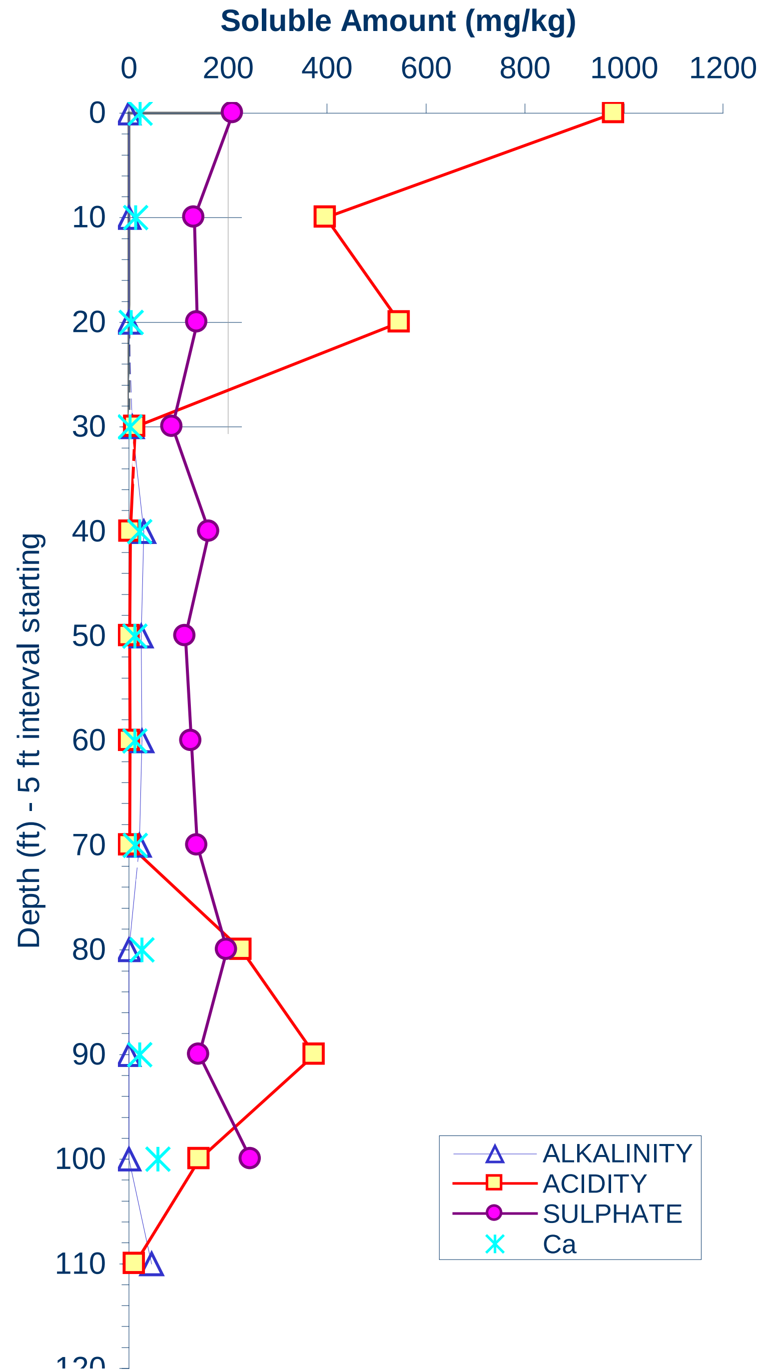
# Modified ABA Results

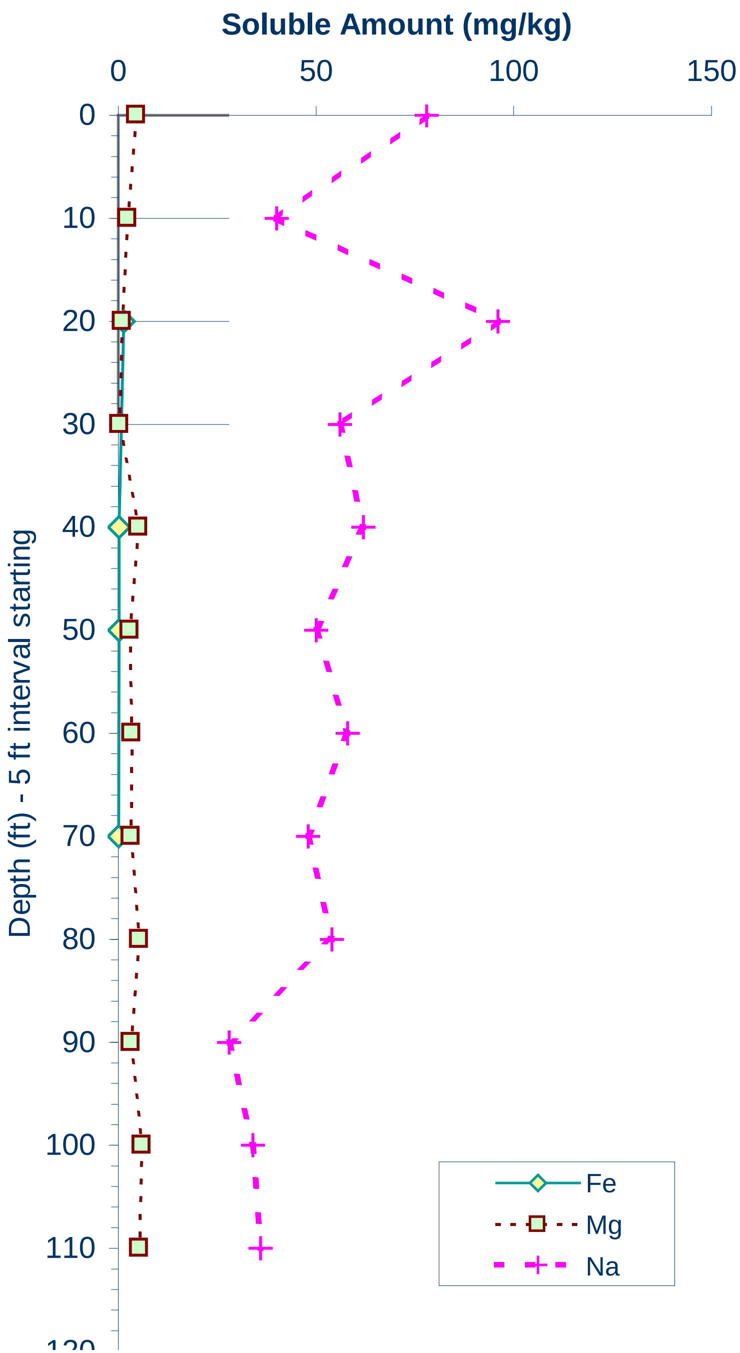


# Geochemical Characteristics With Depth

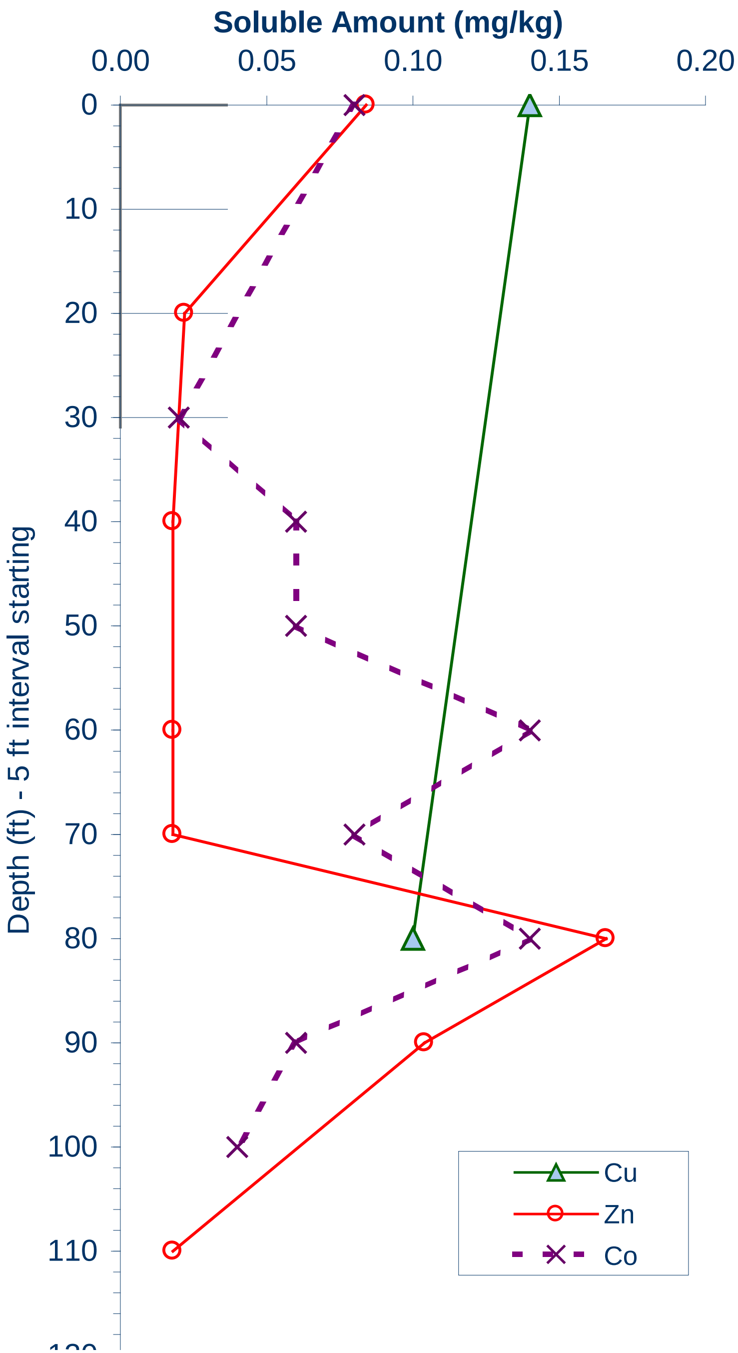



kg CaCO3/t equiv
0
5
10
15
20
25
30
35
40
45
Depth (ft) - 5 ft interval starting
0
10
20
30
40
50
60
70
80
90
100
110
NP
AP
paste pH


Soluble Amount (mg/kg)
0
200
400
600
800
1000
1200
Depth (ft) - 5 ft interval starting
0
10
20
30
40
50
60
70
80
90
100
110
ALKALINITY
ACIDITY
SULPHATE
Ca

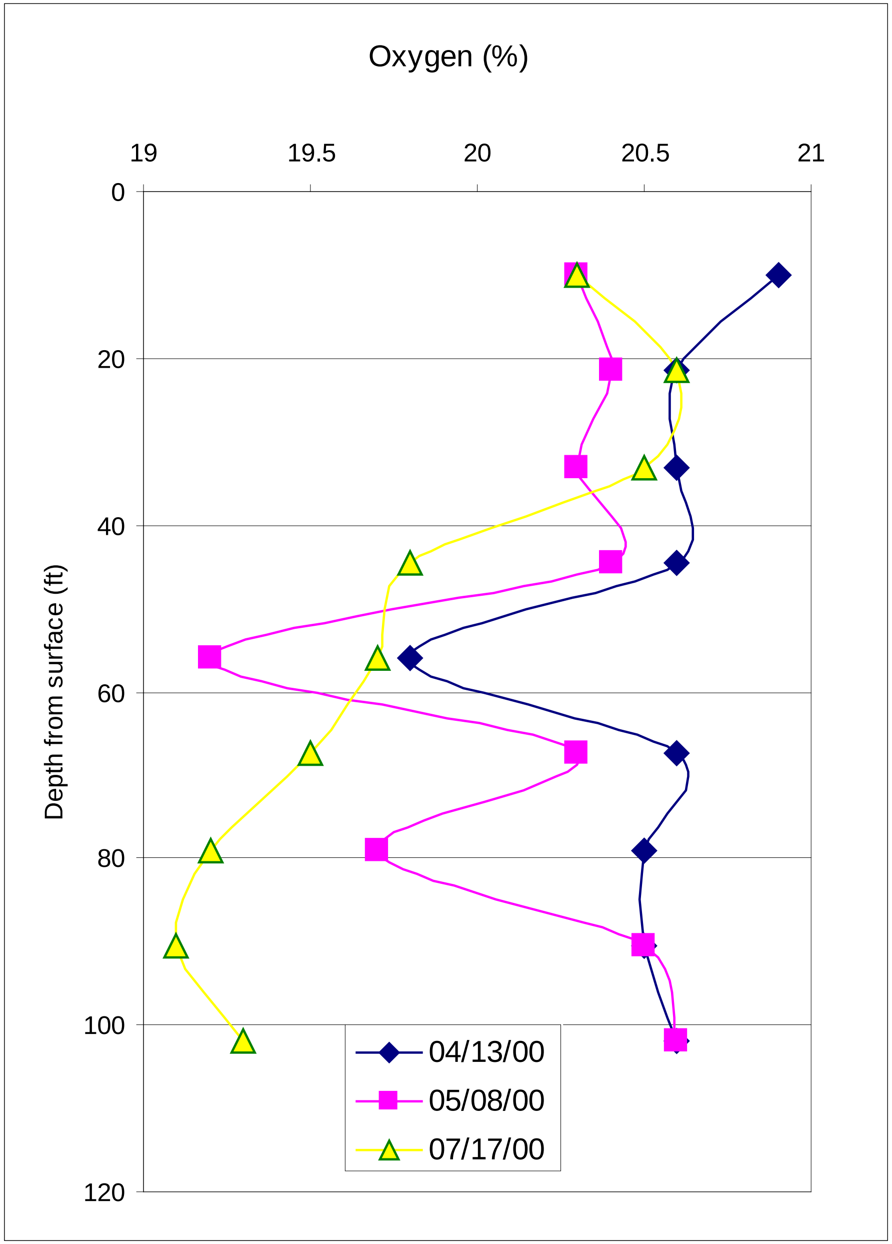


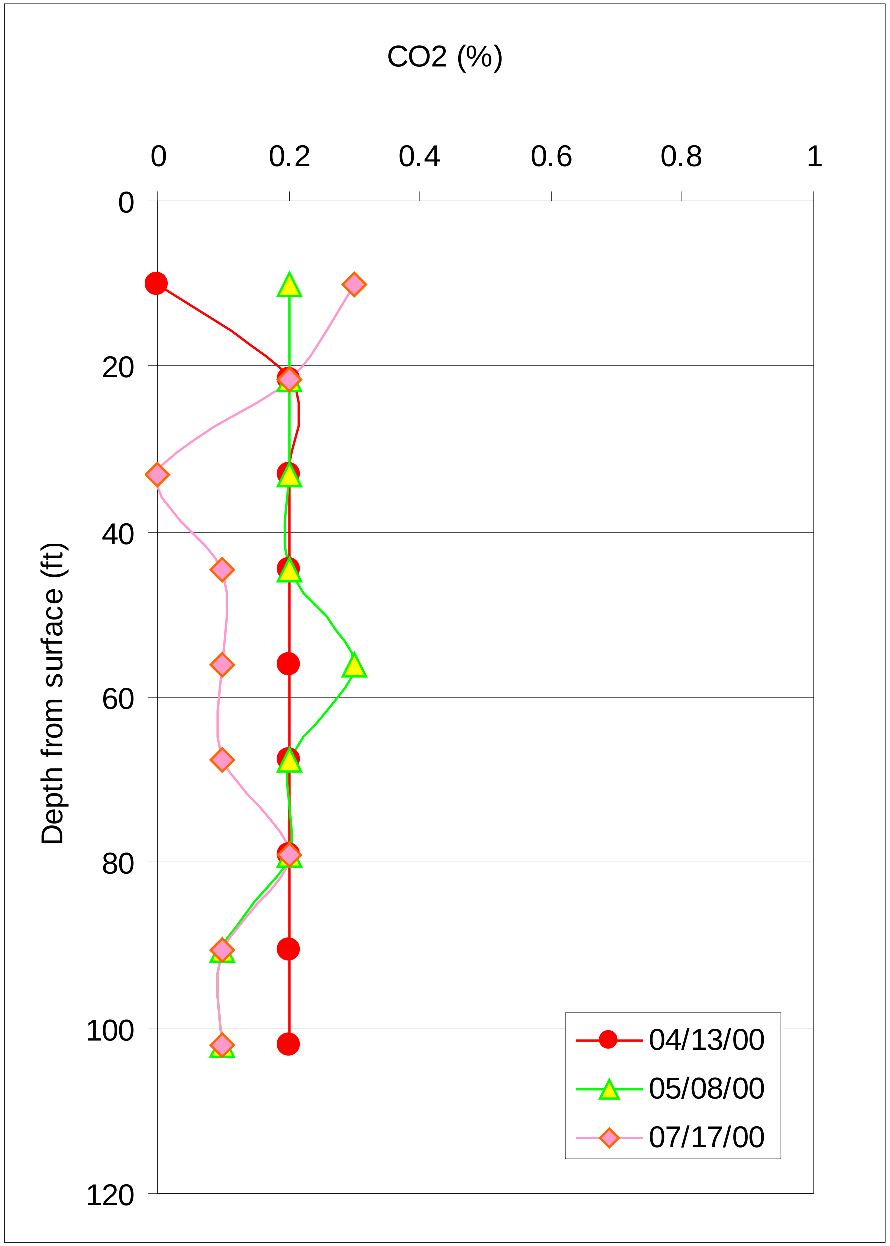
Soluble Amount (mg/kg)
0
50
100
150
Depth (ft) - 5 ft interval starting
0
10
20
30
40
50
60
70
80
90
100
110
Fe
Mg
Na

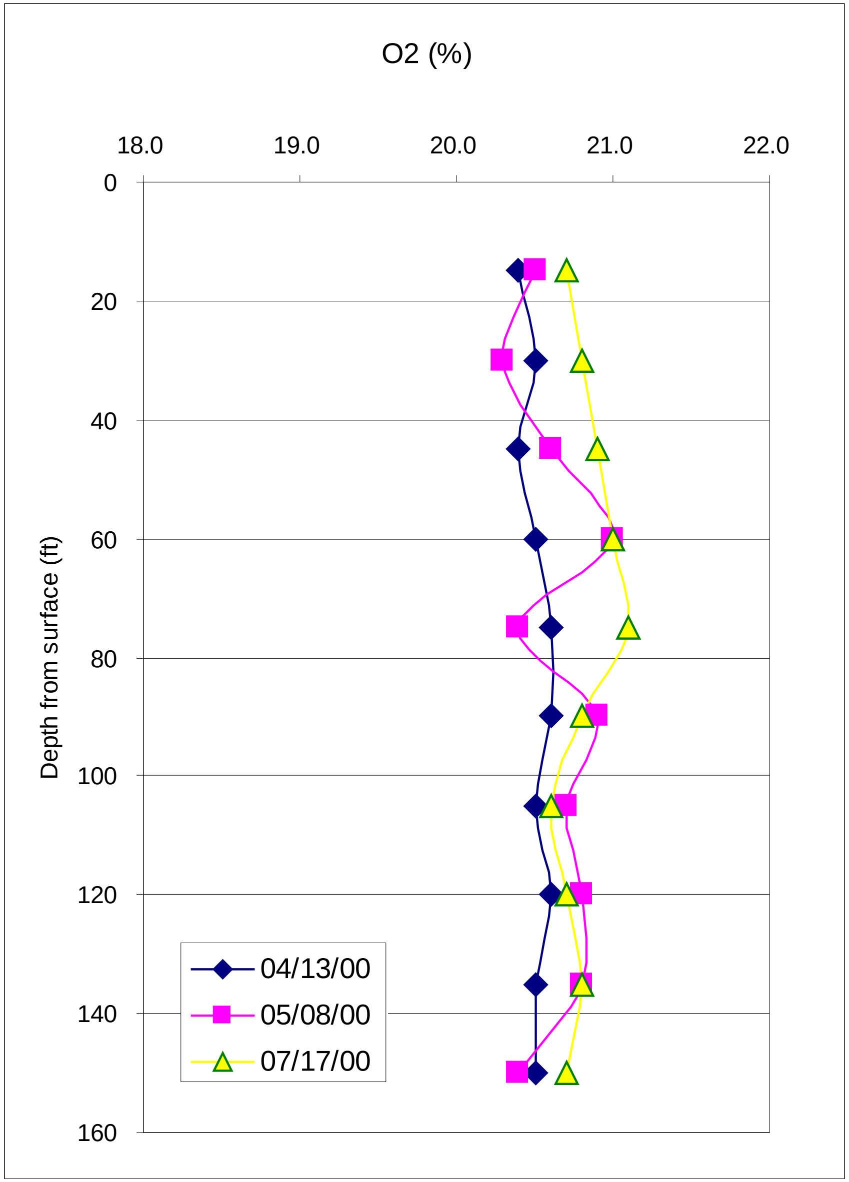
Soluble Amount (mg/kg)
0.00
0.05
0.10
0.15
0.20
Depth (ft) - 5 ft interval starting
0
10
20
30
40
50
60
70
80
90
100
110
Cu
Zn
Co

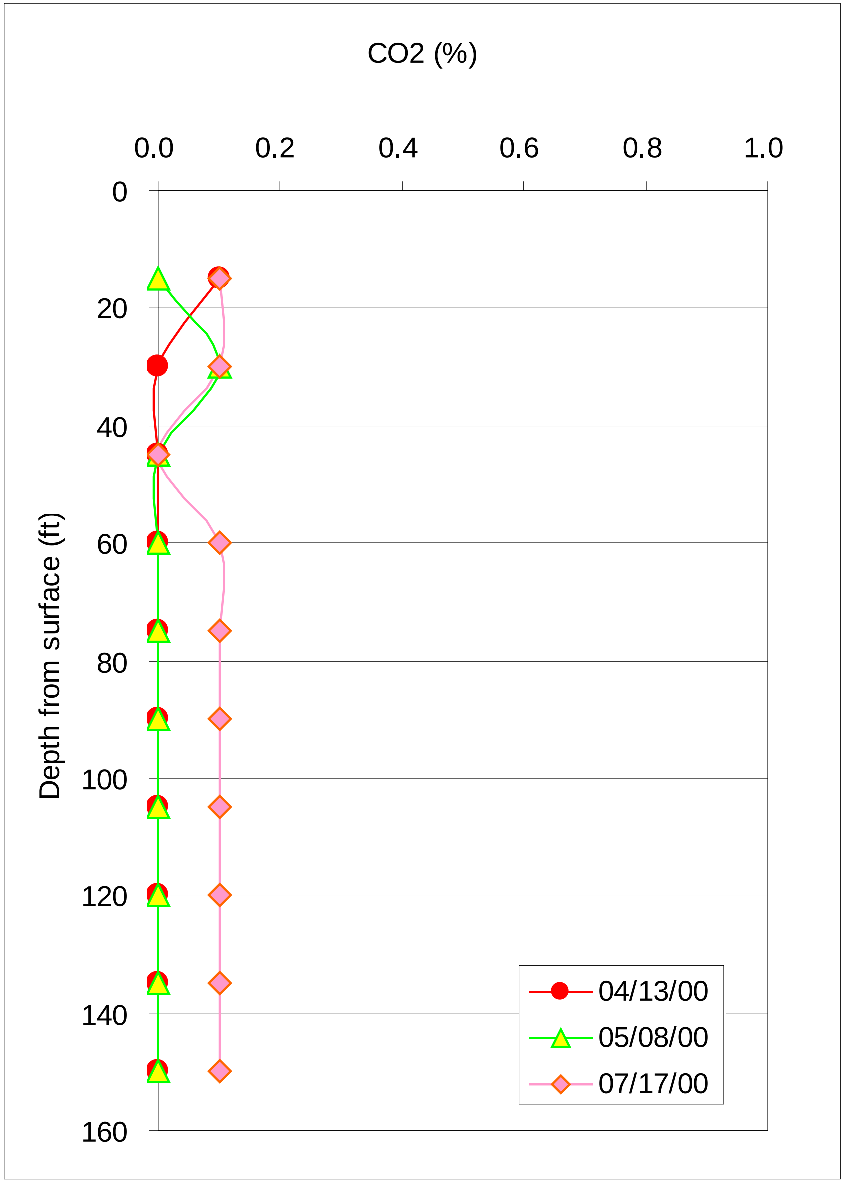
# $O_2$, & $CO_2$ Characteristics With Depth (Lower elevation hole)



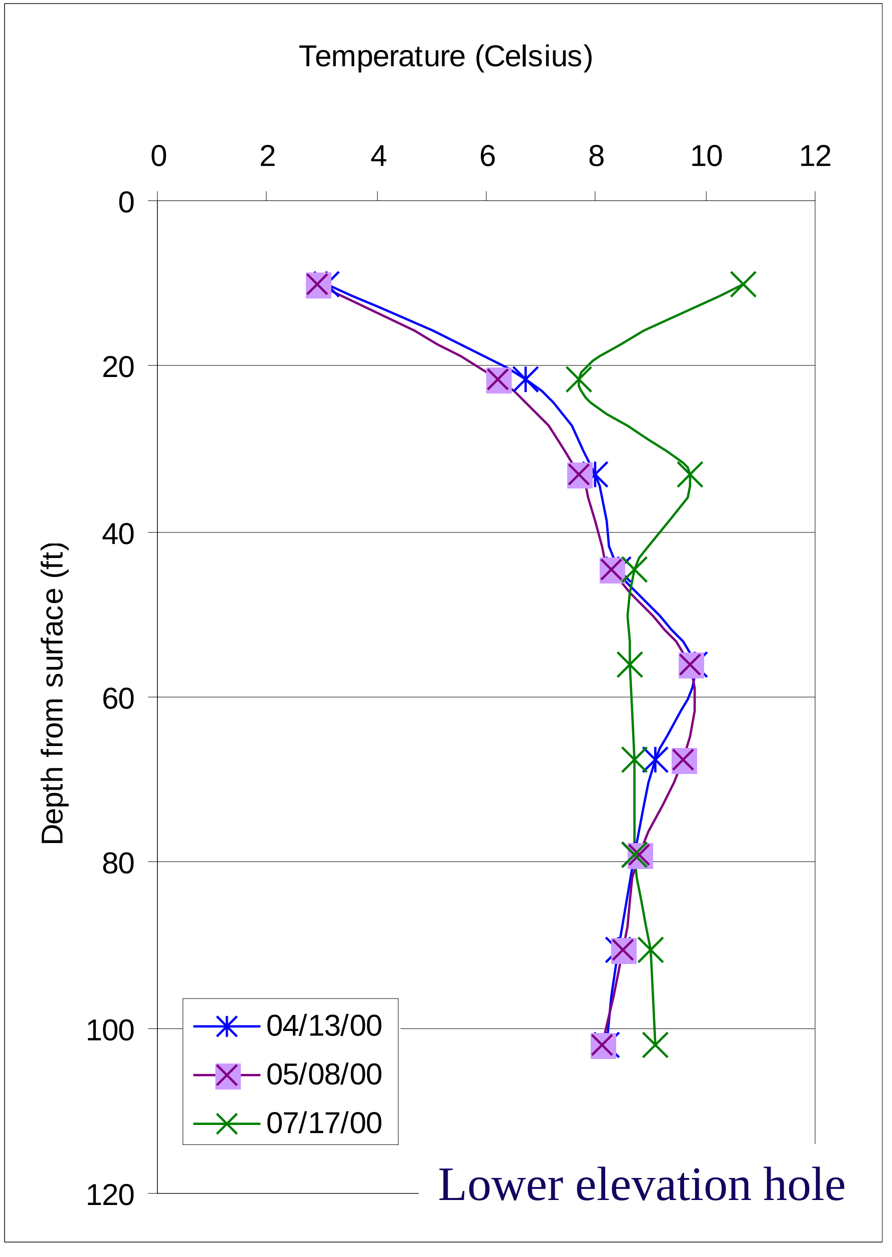



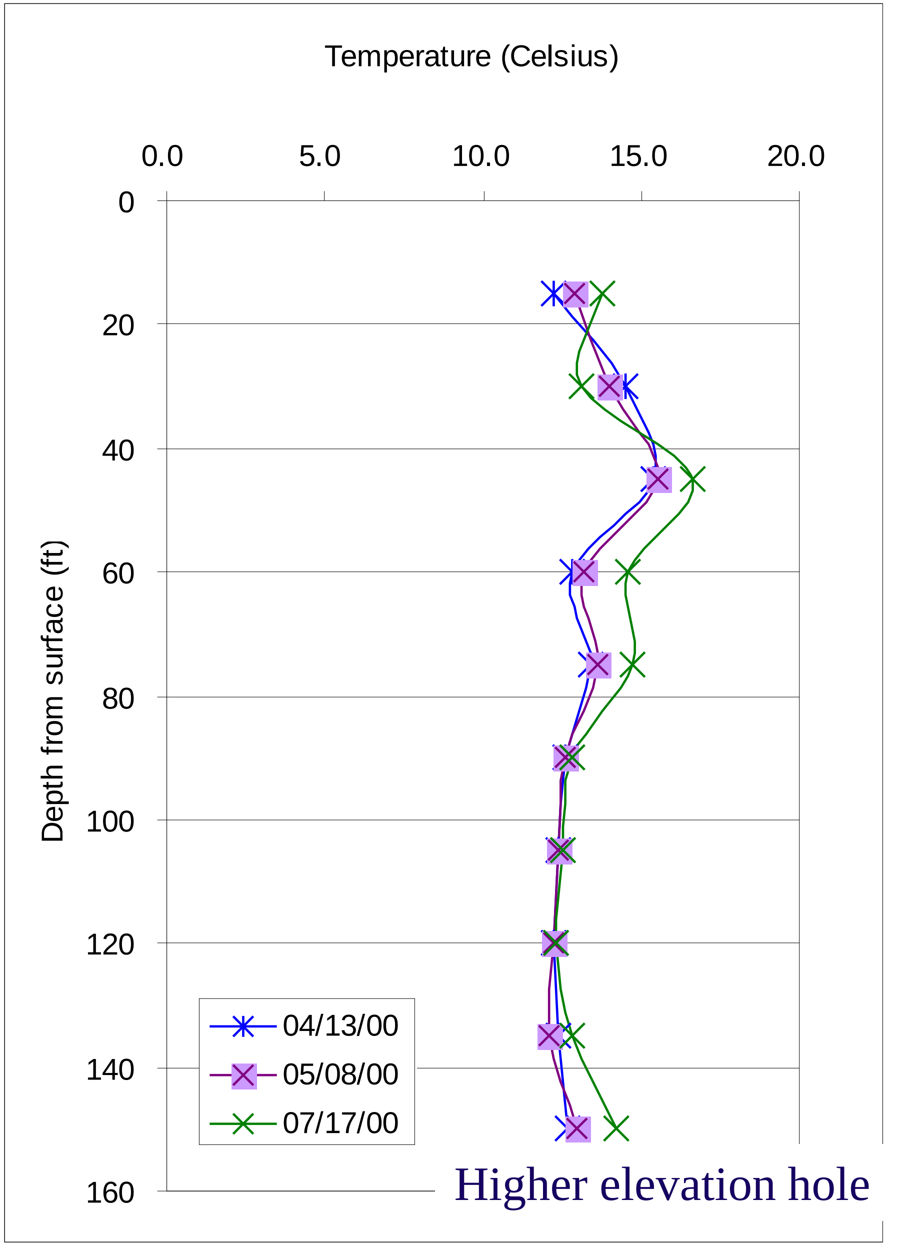
# $O_2$, & $CO_2$ Characteristics With Depth (higher elevation hole)



# Temperature Characteristics With Depth

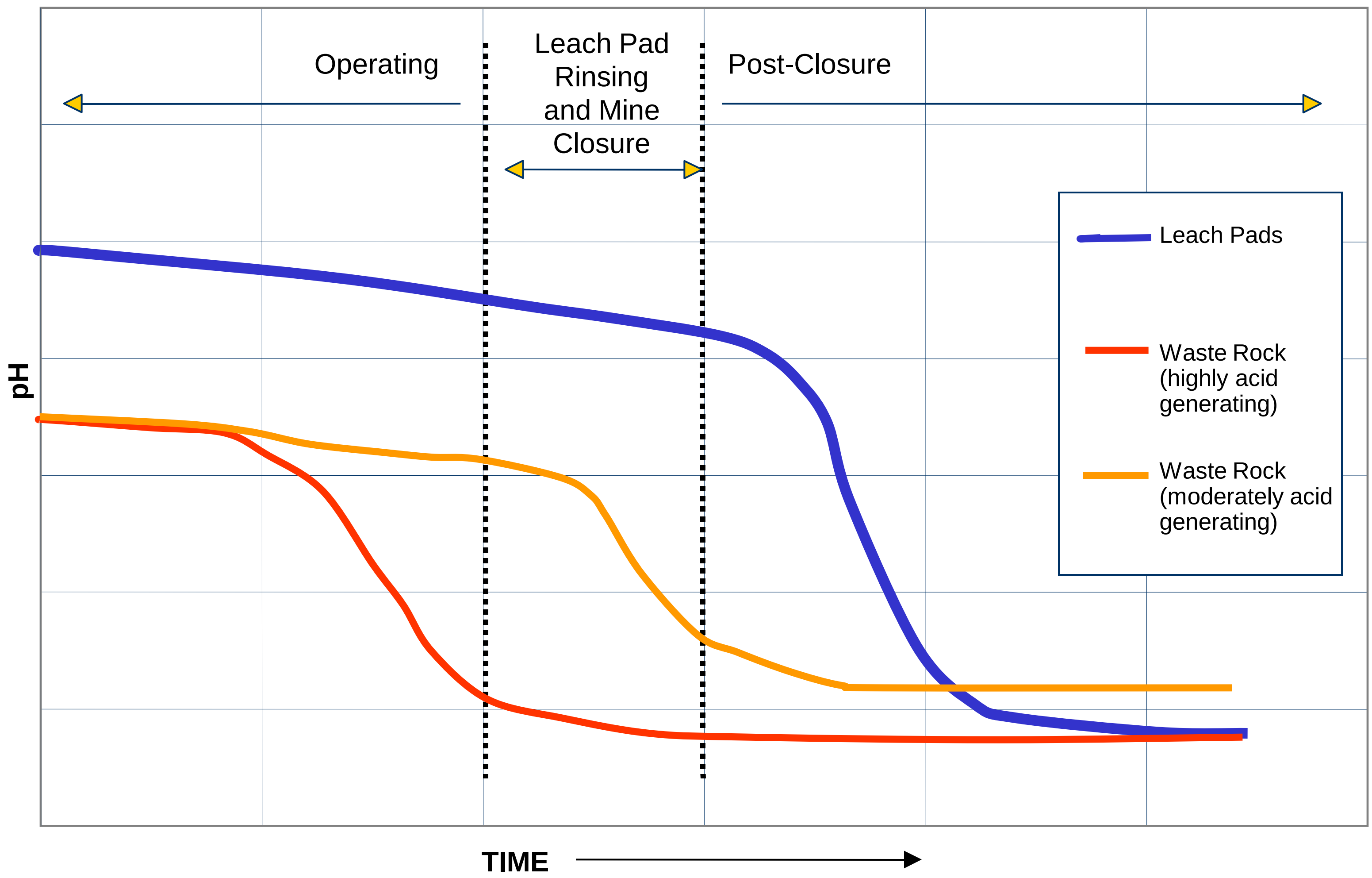


# Results from Instrumented Boreholes suggest:

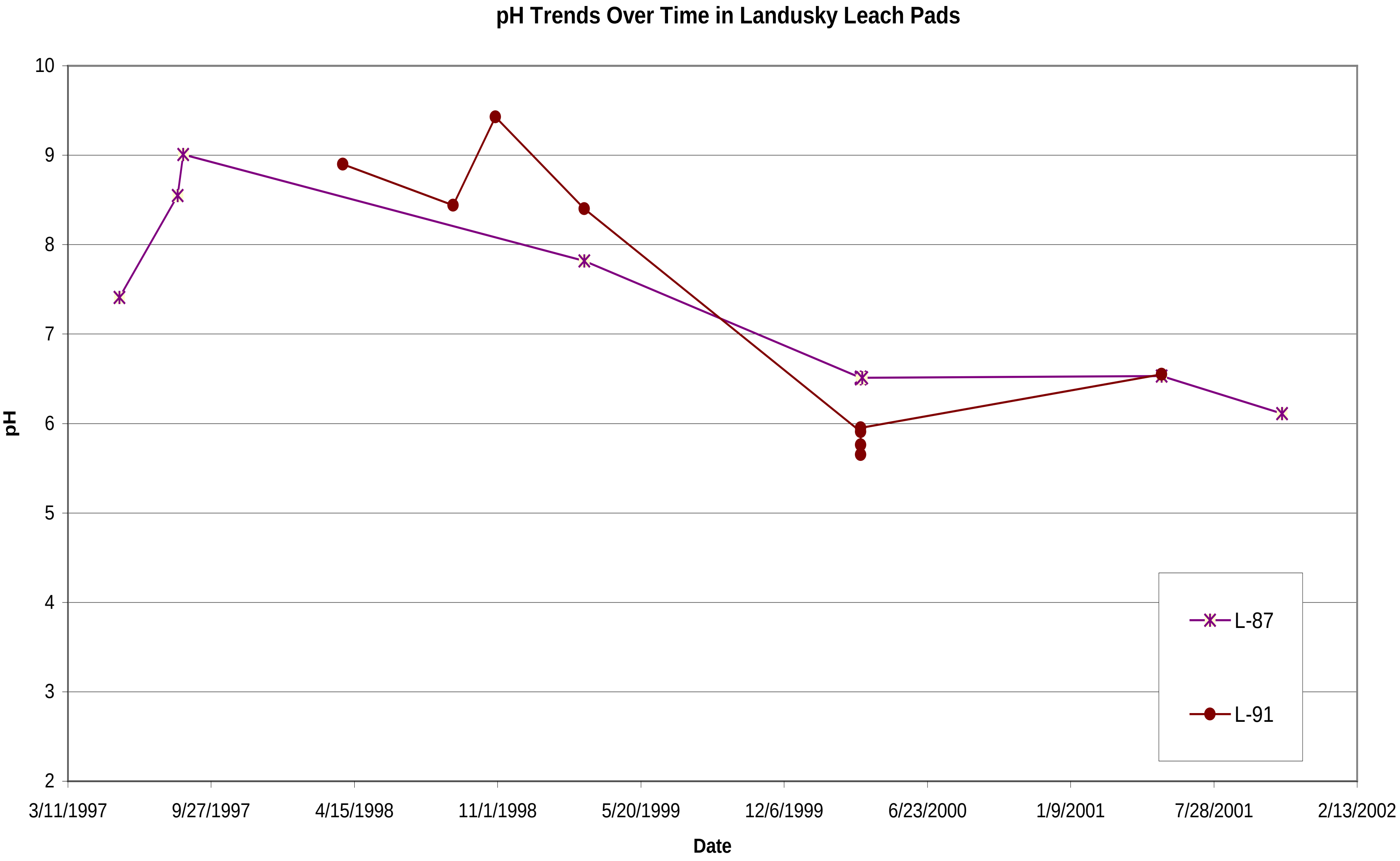
- Leach pads are nearly fully oxygenated - i.e. $O_2$ not limited
- Very small build up of $CO_2$ - indicating either little buffering reactions or continual flush of air through the pad
- Temperatures close to ambient - indicating no substantial build up of heat or continual flush of air through the pad

# LAD ? + LAD HDS LIME TREATMENT



# ?

- Pre-treatment prior to LAD is required before Spring 2002
  - Removal of $NO_3$, Se & CN
- Applied Biosciences out of Salt Lake were selected
- Technology utilizes reducing bacteria that are relatively temperature tolerant
- Pilot plant studies completed in late 2000
- Full scale plant now commissioned - however…
- Water quality has changed since pilot plant studies
- An aluminum precipitate is now causing problems - must be sorted out before Spring 2002

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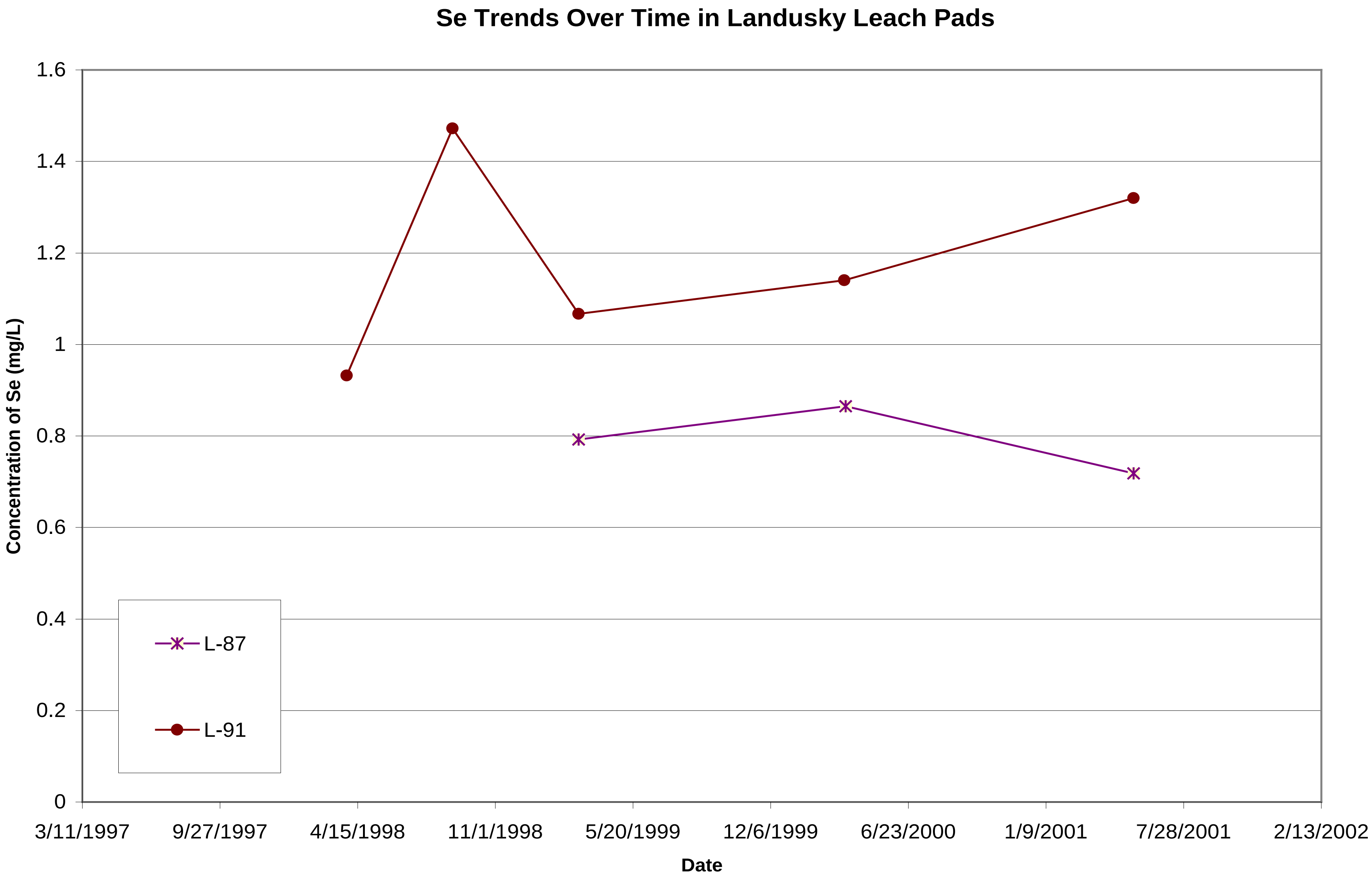
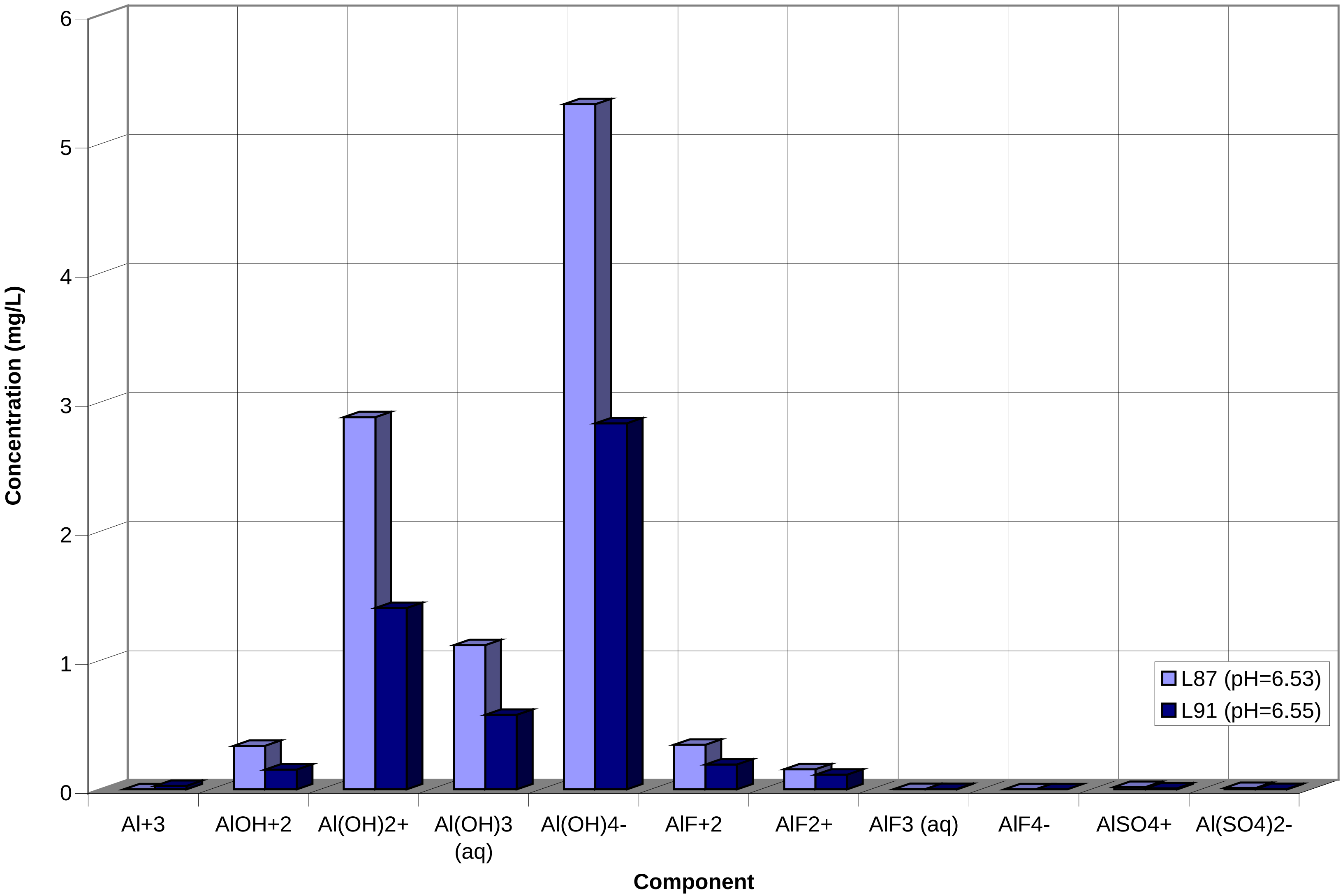
Mining, Geotechnical and Environmental Engineers


Se Trends Over Time in Landusky Leach Pads
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Concentration of Se (mg/L)
L-87
L-91
3/11/1997
9/27/1997
4/15/1998
11/1/1998
5/20/1999
12/6/1999
6/23/2000
1/9/2001
7/28/2001
2/13/2002
Date

# Trying to define the Al problem



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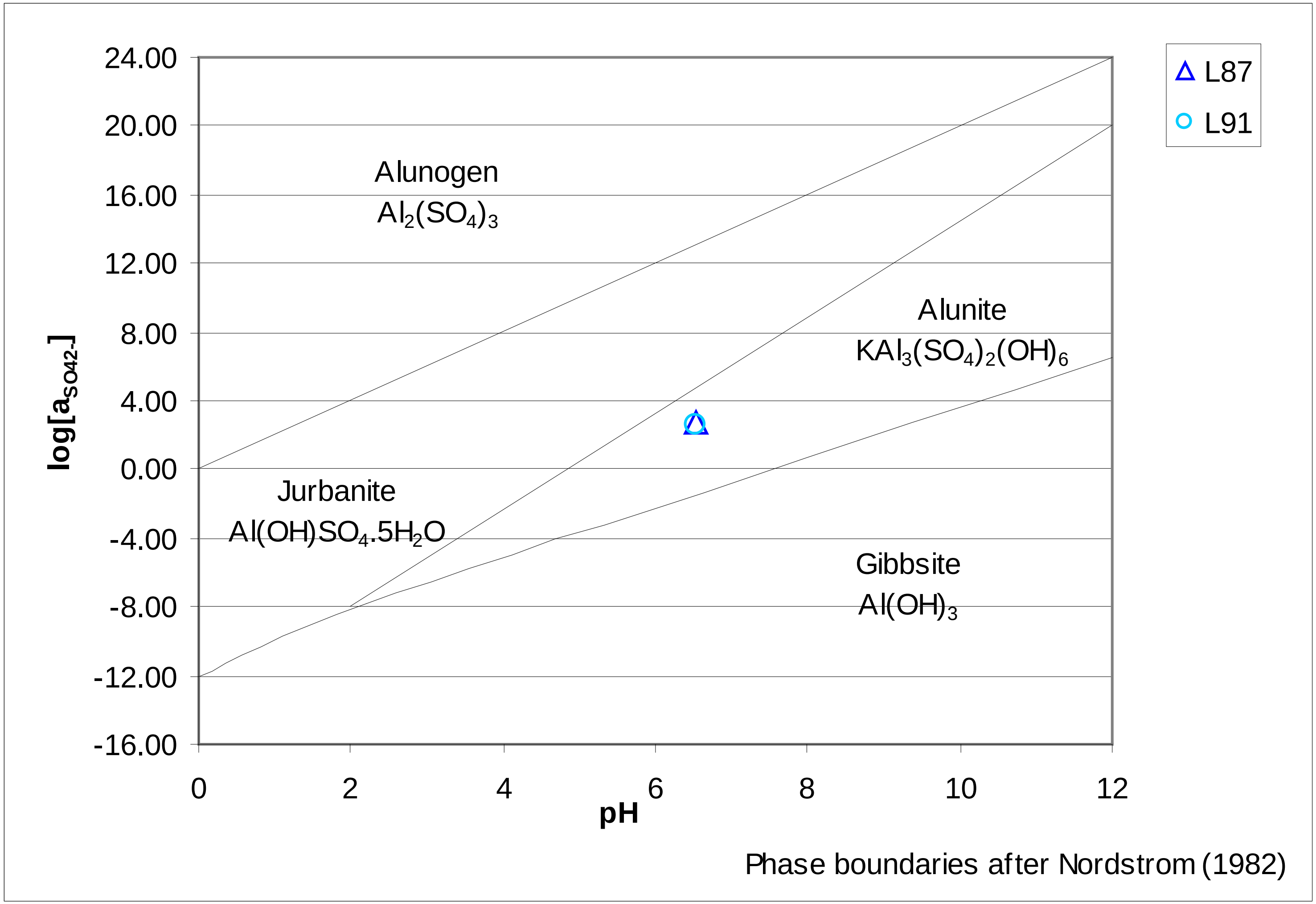
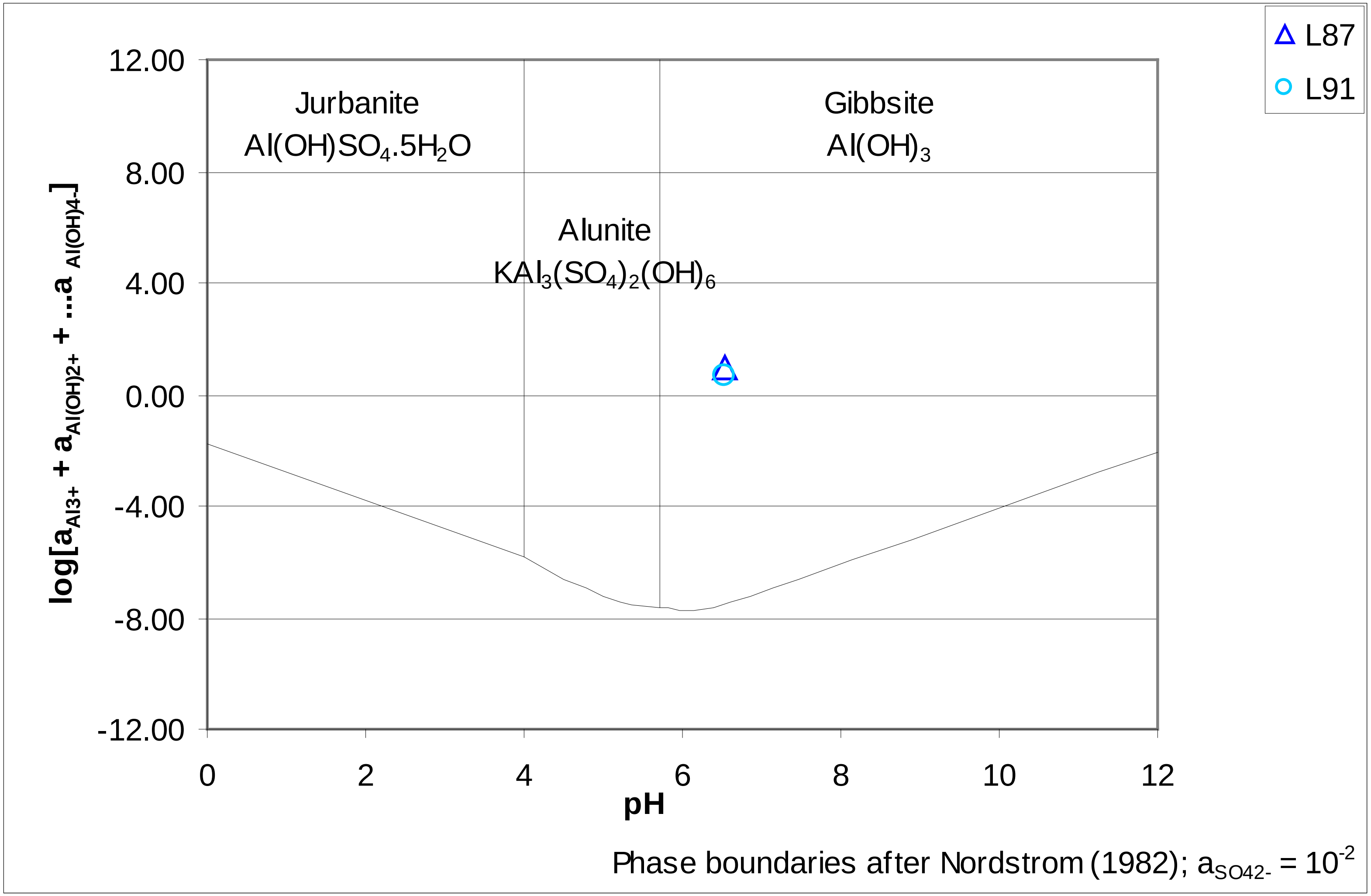


# Trying to define the Al problem



# Conclusions & On-going Work

- It appears to be assumed that once rinsed the spent ore leachates will be dischargeable
- The water quality predictions associated with potentially acid generating spent ore are complex
- Likely to become more complicated by reclamation measures such as regrading, placing covers etc.
- At Landusky, most of the water to be managed comes from one large leach pad that does not behave predictably and is extremely variable and dynamic
- Water management strategies must therefore also be dynamic

# Conclusions & On-going Work

- More frequent and detailed water quality will be taken
  - continuation of in-situ measurements of pH, SC, DO2 and Temp
- Adaptations to the biotreatment plant are being evaluated to remove Al prior to treatment
- Potential *in-situ* (i.e. in the pad) treatments are being assessed that may increase the pH within the pad until such time as the Se and $NO_3$ can be reduced
  - These potential treatments cannot use caustic due to near agronomic limits of Na on the LAD