A Brief Overview of the Procedures used in the Prediction of Drainage Chemistry from Sulfidic Geological Materials

By William (Bill) Price, Natural Resources Canada

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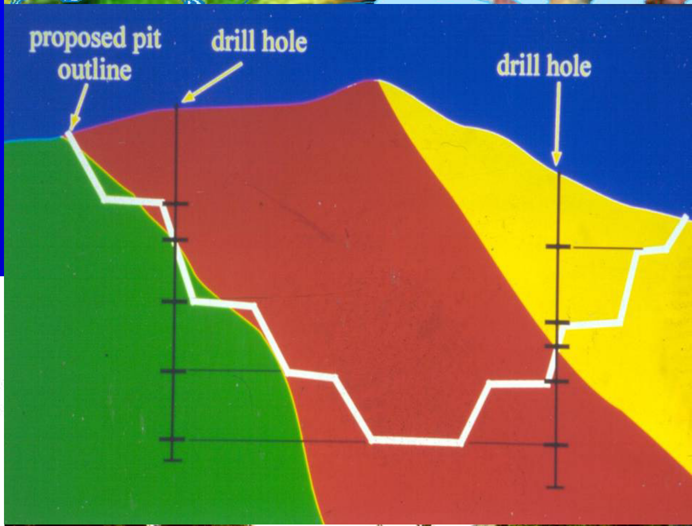
Objectives of Drainage Chemistry Prediction

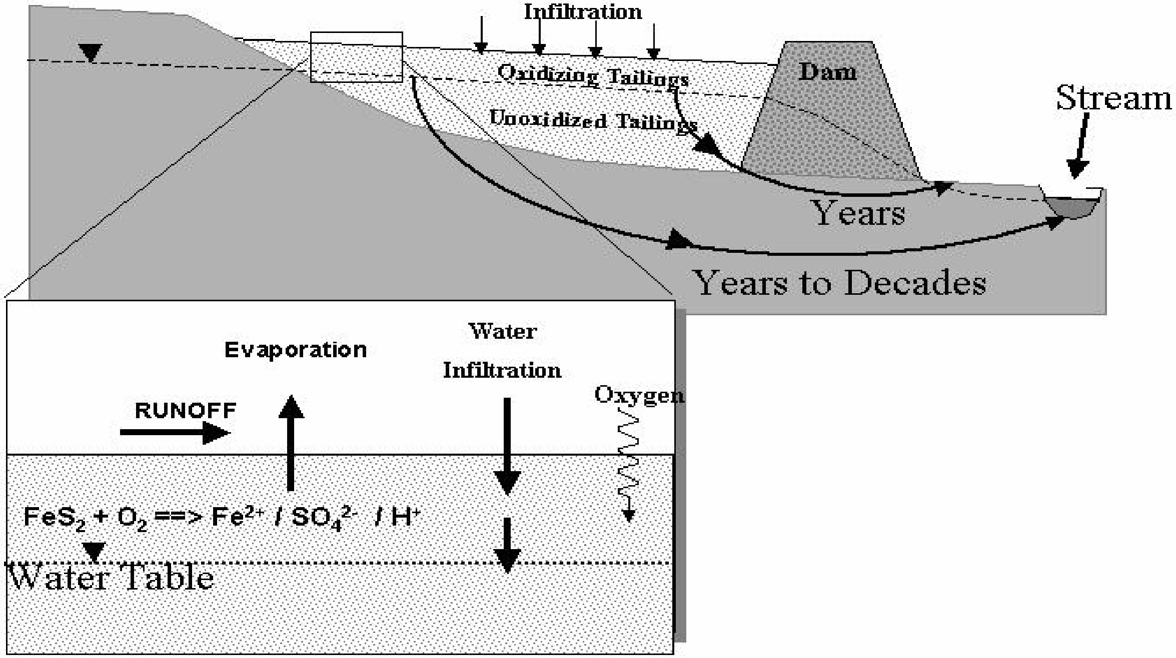
- Determine if and what mitigation is required
- Provide information before actions must be taken
- Consider all pH values and contaminants of concern

Step 1. Determine Key Site Conditions

This should include:

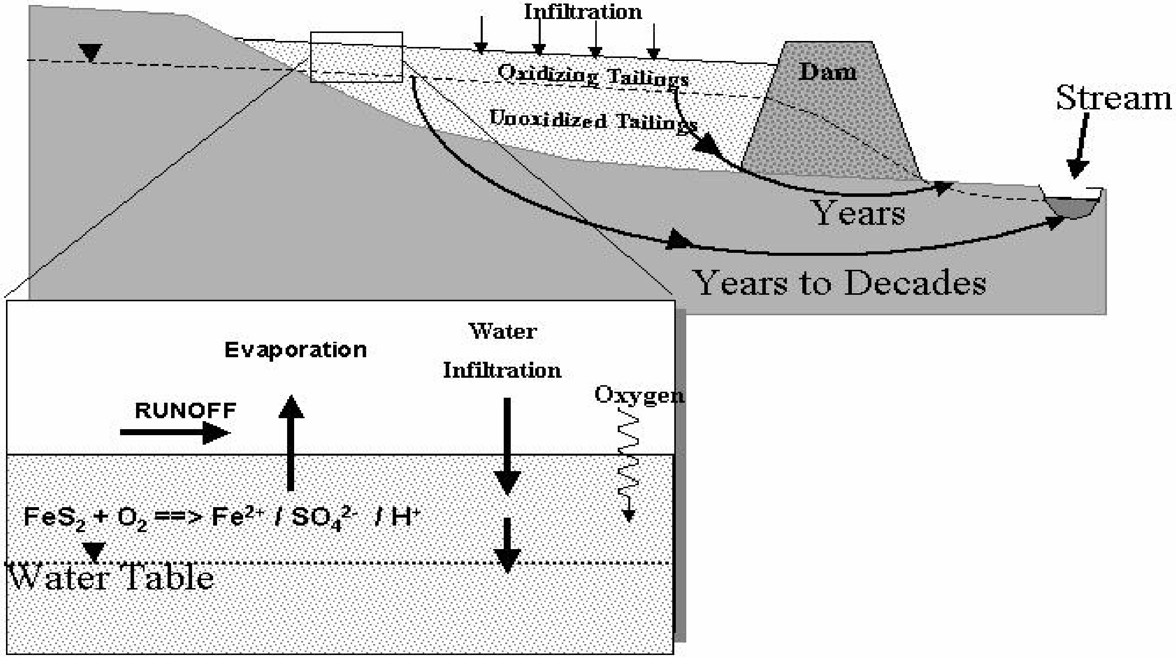
- pre-existing drainage and chemistry
- the climate and geology
- mine plan and physical form, location, extent of site components
- hydrology and hydrogeology of mine site components
- environmental protection objectives

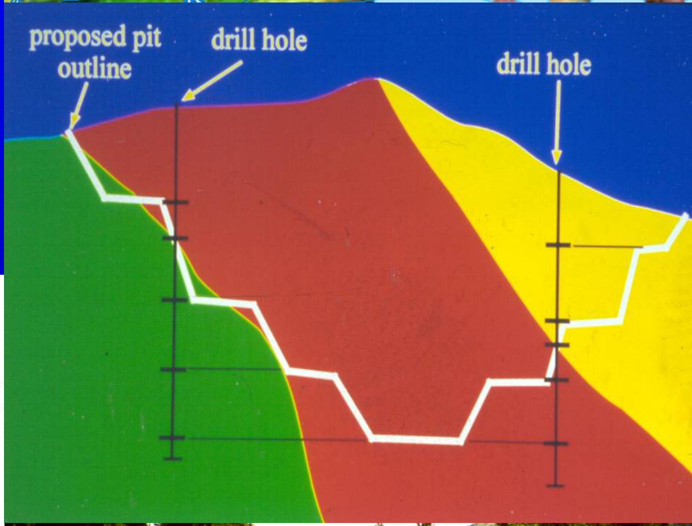




The information is required for:

- selection of samples
- selection of test work
- interpretation of results





Step 2. Predict the Potential Drainage Chemistry

Analysis - Total Elemental Composition

Recommended Method:

- Many methods are acceptable

Use of results:

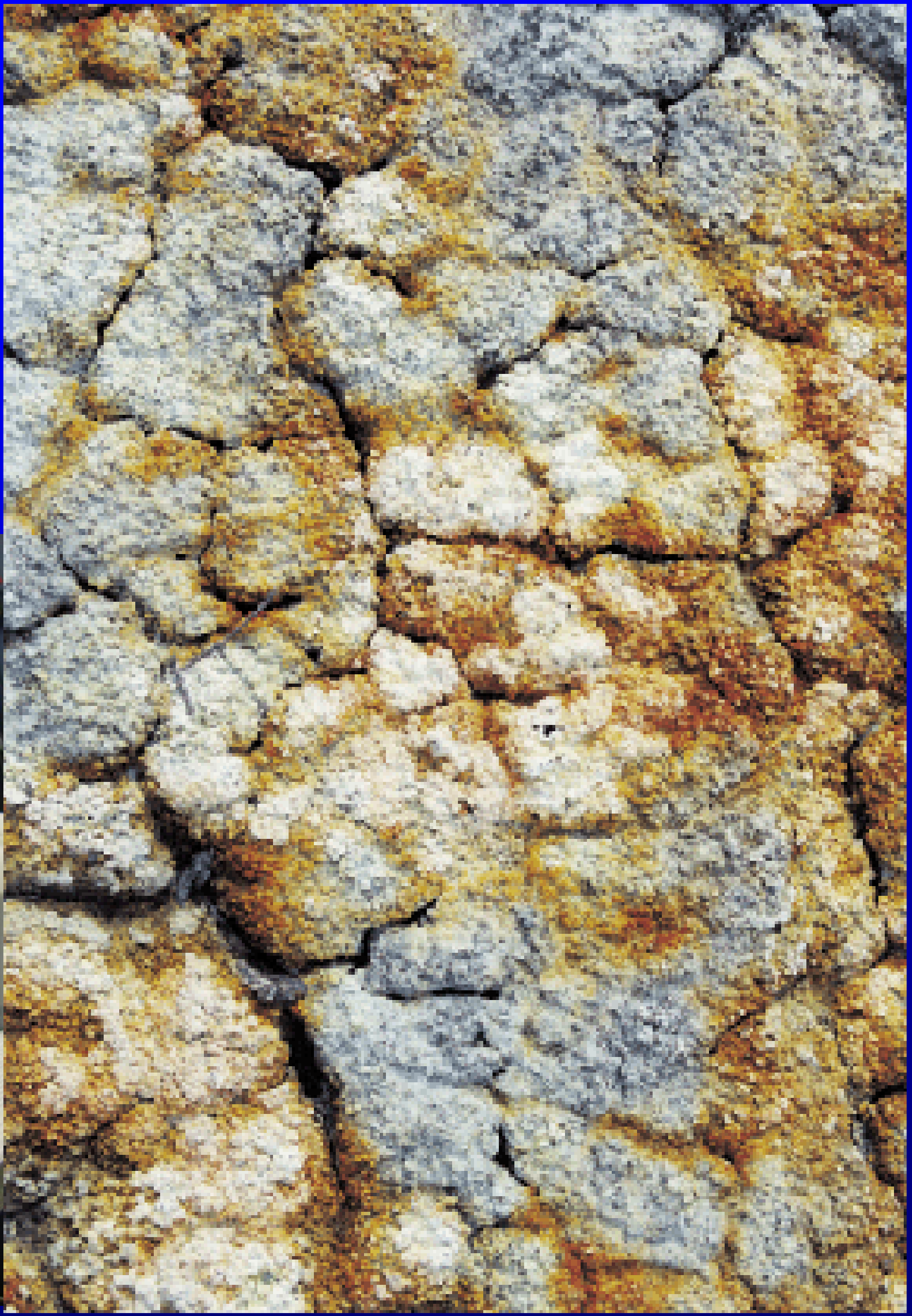
- Determine range in composition and constituents occurring in anomalously high concentrations.
- Interpretation of acid base accounting.

Beware:

- Total concentration is not indicative of drainage chemistry. Introduction of chemical species to drainage depends on their solubility.

Analysis - Soluble (Dissolvable) Composition

Sulfides are usually relatively insoluble (possible exceptions are As and Sb sulfides). Drainage chemistry is usually determined by solubility and mass of secondary minerals (the oxidation products).



Example – pH Test

Objective: predict pH of leachate

Method:

- mix sample and water (ratio of 1:1)
- use electrode to measure pH of the overlying solution

Example – BC Shake Flask Test

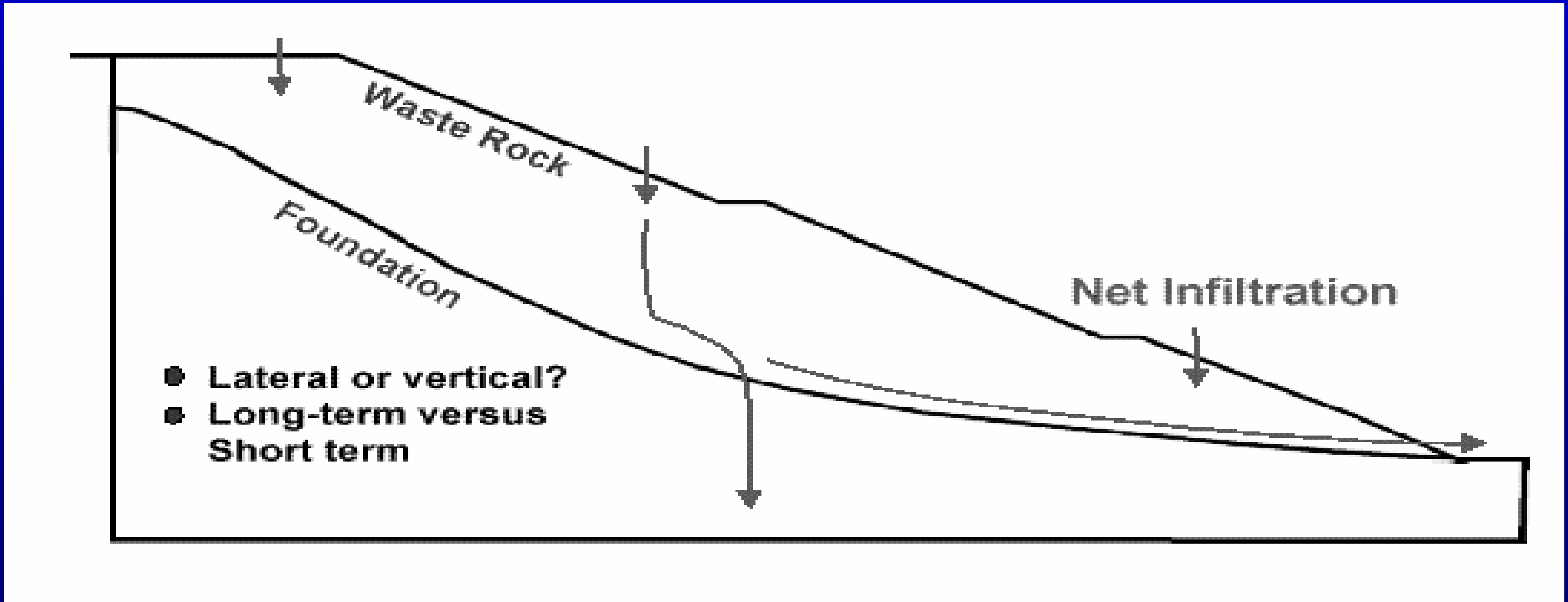
Objective: predict total elemental release (mg/kg of sample) if material in present condition is flooded

Method:

- mix sample with large excess of water (ratio of 1:3)

Solubility Tests: Beware

- Procedure is often determined by regulatory requirements not field conditions and results are of little relevance to actual performance.
- High ratio of leachate to solid may lower concentrations and mask solubility constraints. Actual ratio of leachate to waste is usually far lower.
- Solubility tests include leaching but do not include sulfide oxidation or other weathering reactions that produce soluble secondary minerals.



Sulfides and Other Minerals

↓ Oxidation and Other

↓ Weathering Reactions

Weathering Products

↓ Leaching, Dissolution

Drainage Chemistry

Procedures used to predict impact of continued weathering on drainage chemistry and better estimates of equilibrium mineral solubility constraints on contaminant concentrations are:

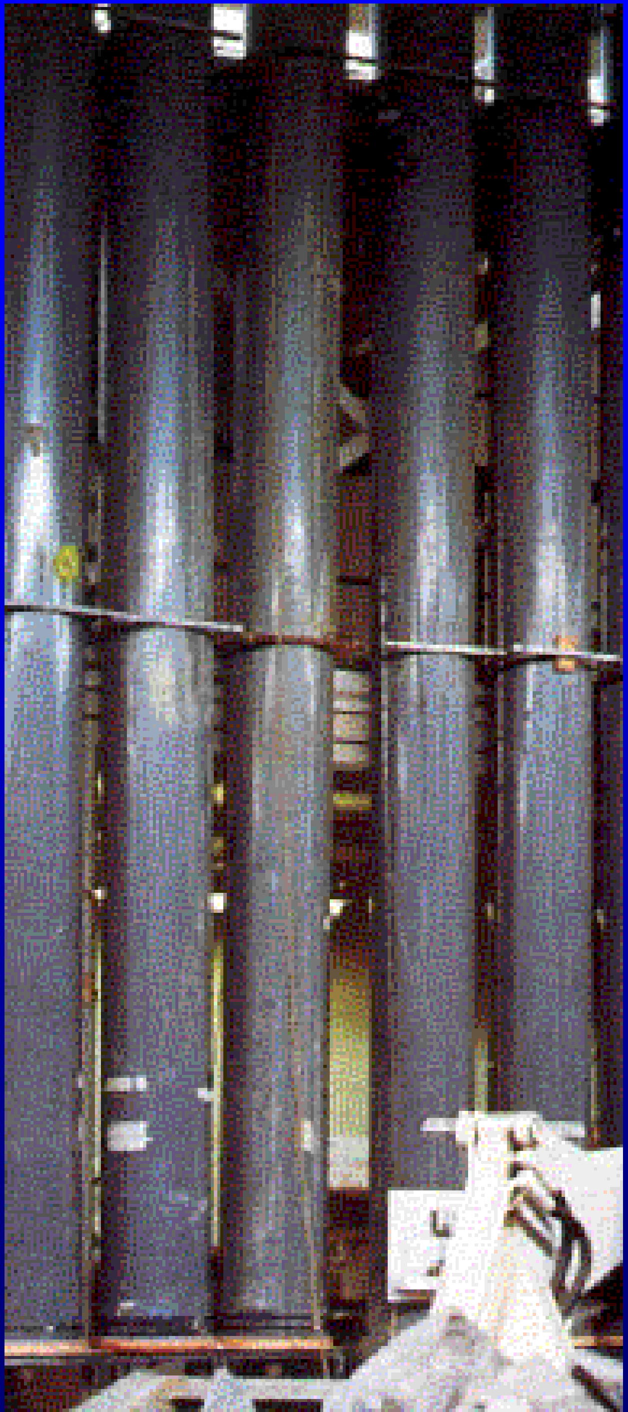
– ‘trickle leach’ laboratory columns

– field test pads

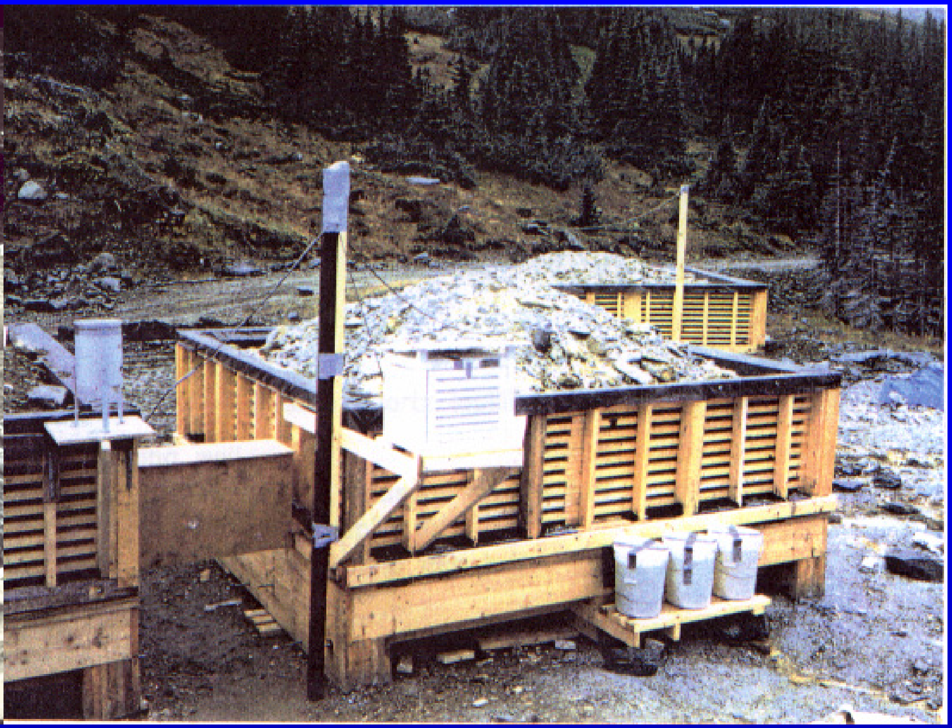
– monitoring actual mine components

Test Procedure - Trickle Leach Columns

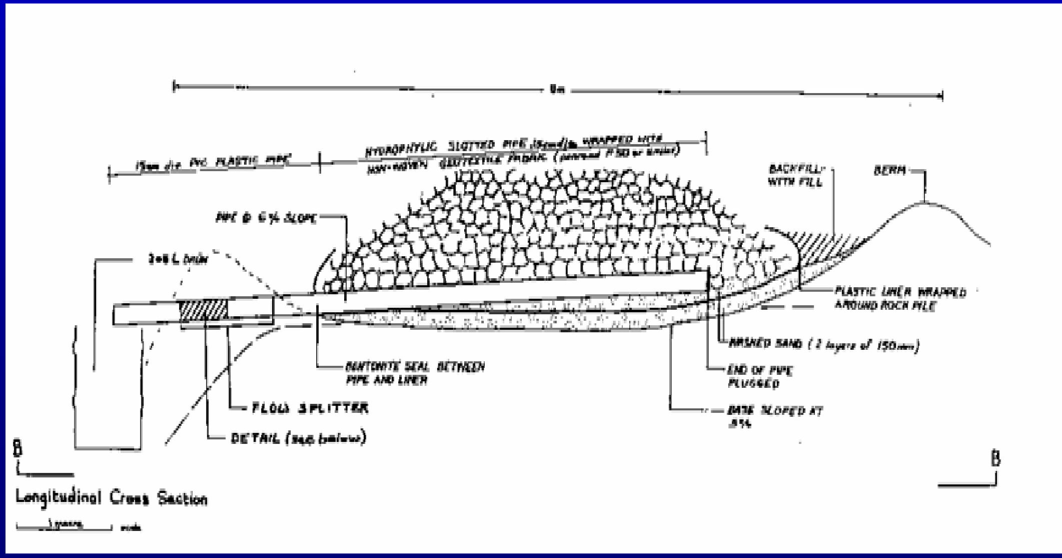
- Procedure should match conditions or properties you want to predict and test conditions required to measure properties of interest.
- Drainage can be re-circulated to increase the solid:leachate ratio and reach mineral equilibrium solubility constraints.
- Need to consider potential differences between field and laboratory conditions and use caution when applying results beyond physical and chemical conditions and duration of the test.



Test Procedure - Field Test Sites



Field test cells or pads measure influence of site conditions on weathering and drainage chemistry.

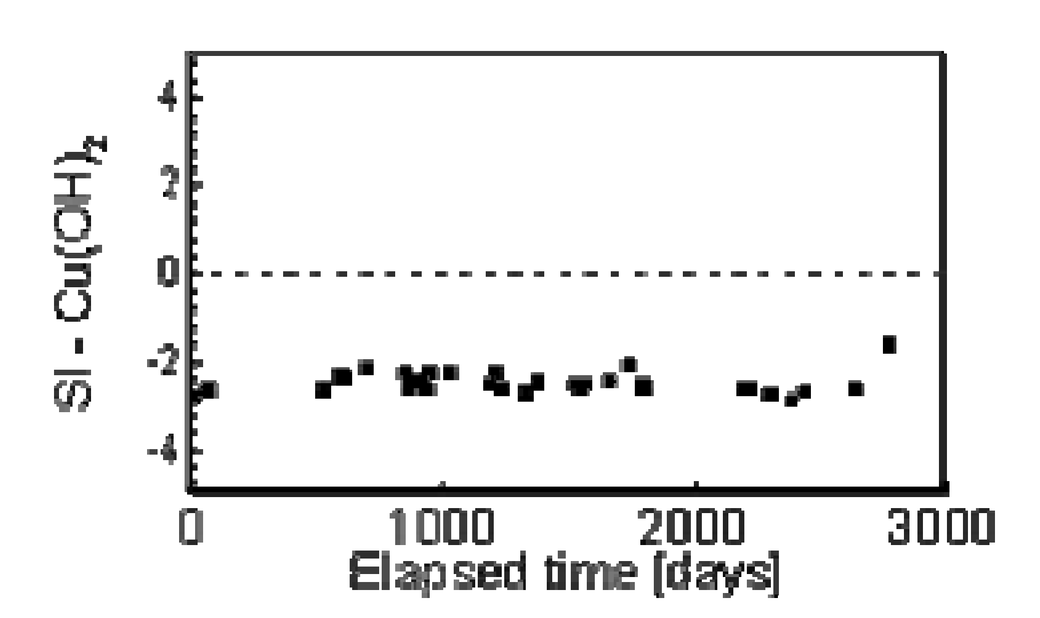


Drainage Analysis - Geochemical Mineral Equilibrium Solubility Models

Phreeque and Minteq are most popular models for estimating maximum dissolved concentrations and saturation indices.

Models require comprehensive characterization of drainage chemistry.

Powerful tool when used in conjunction with field evidence. Beware, changes in mineral composition may significantly alter the solubility of a particular mineral



Will Sulfidic Materials Produce Acidic Drainage in the Future?

Acidity is important because it increases oxidation of sulfide minerals and the solubility of most of the released metals and trace elements

Acid Base Accounting

A series of crude compositional analyses and calculations used to estimate the potential for a sample to generate and neutralize acidic drainage if it is exposed to oxygen and water.

- pH
- analysis of sulfur species and calculate Acid Potential (AP)
- analyses of Neutralization Potential (NP)
- calculation of NPR (NP/AP)

Mineralogy, elemental analysis and humidity cell required to interpret results

Measurement of Sulfur Species and Estimation of the Acid Potential

A variety of analyses of sulfur species are used to calculate acid potential

- total-S (Leco S)
- acid soluble sulfate-S (HCl leach, pH, mineral)
- non- acid soluble sulfate-S (element/mineral anal.)
- organic-S (total-S minus sulfide-S and sulfate-S)
- ~sulfide-S (HNO_3 leach or total-S minus other-S)

sulfide-S = total-S – (sulfate-S + organic-S)

Sulfur and AP Recommendation

- Total-S and acid leachable-S analyses
- Visual observations of geology and sample notes to determine if organic-S potentially present; if it is add sulfide-S analysis
- Use elemental analysis and mineralogy to check potential importance of acid-insoluble sulfate-S
- Use mineralogy to assess potential importance of less acid producing sulfide and as general check
- Need comprehensive data and checks if plan to take short-cuts (e.g., not analyzing for acid leachable-S and just using total-S)

Estimation of the Neutralization Potential

1. Estimation of CO_3 - NP

Calculate CO_3-NP from assay results for C or CO_2, assuming all C or CO_2 is $CaCO_3$ (calcite)

- Can use total-C (Leco) for most rock

Beware:

- Must use acid soluble CO_3-C assay if organic matter present (e.g., mudstones or materials contaminated by peat or plant roots)
- Fe and Mn CO_3 are not neutralizing under oxidizing conditions

2. Estimation of Bulk-NP

- measures ability of sample to neutralize a known volume and strength of a strong acid
- objective is to measures the net neutralization in CO_3 minerals and more reactive silicate minerals
- procedures in common use are Sobek (2 hr) and Modified-Lawrence (24 hr)

NP Recommendations

The information required to 'reasonably accurately' estimate the NP is as follows:

- two static laboratory NP measures, a bulk (acid-titratable) and a carbonate analysis,
- good mineralogical characterization and
- humidity cell testing

Beware: May need to correct bulk or carbonate measures of NP for contributions from:

- Fe and Mn carbonates or
- insufficiently reactive silicate minerals.

Determining the Mineralogy

Geological Components

↓

Mine Components + H_2O

↓

Minerals

↓ oxidation, leaching, etc..

Mine Drainage

↓

Environmental Impact?

Recommended Mineralogical Procedures

- Visual Description
- Petrographic Analysis
- X-ray Diffraction
- SEM/EDS
- Microprobe
- Laser Ablation

At a minimum should conduct first three. Use of other methods if needed to answer specific questions.

Test Procedure - Humidity Cell Test

The objective of the humidity cell procedure is to flush out sulfate, base cations and trace elements produced directly or indirectly by sulfide oxidation enabling:

- Estimation of the rate of sulfide oxidation
- Measurement of a samples ability to neutralize resulting acidity
- Measurement of trace elements loading if there are no solubility constraints

Sulfides and Other Minerals

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↓ Weathering Reactions

Weathering Products

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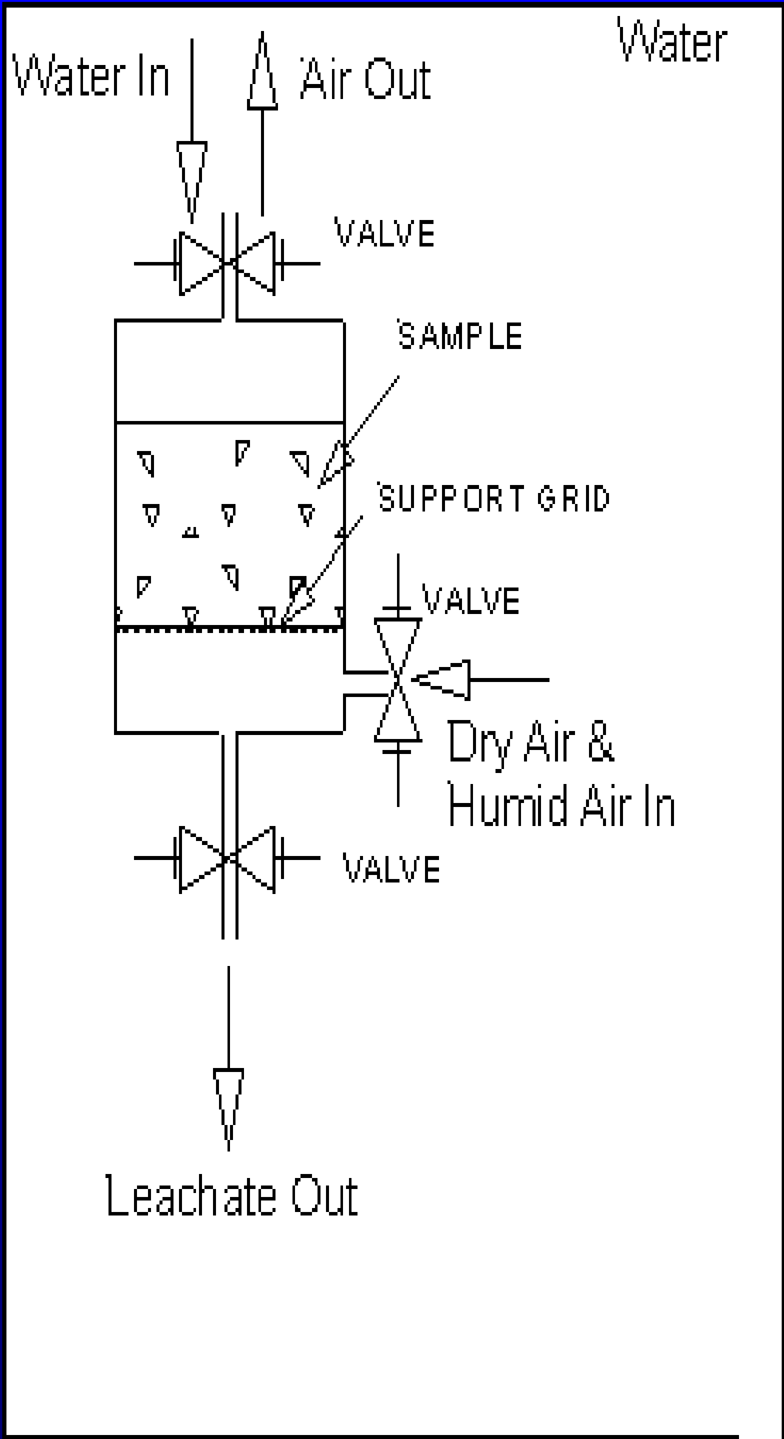
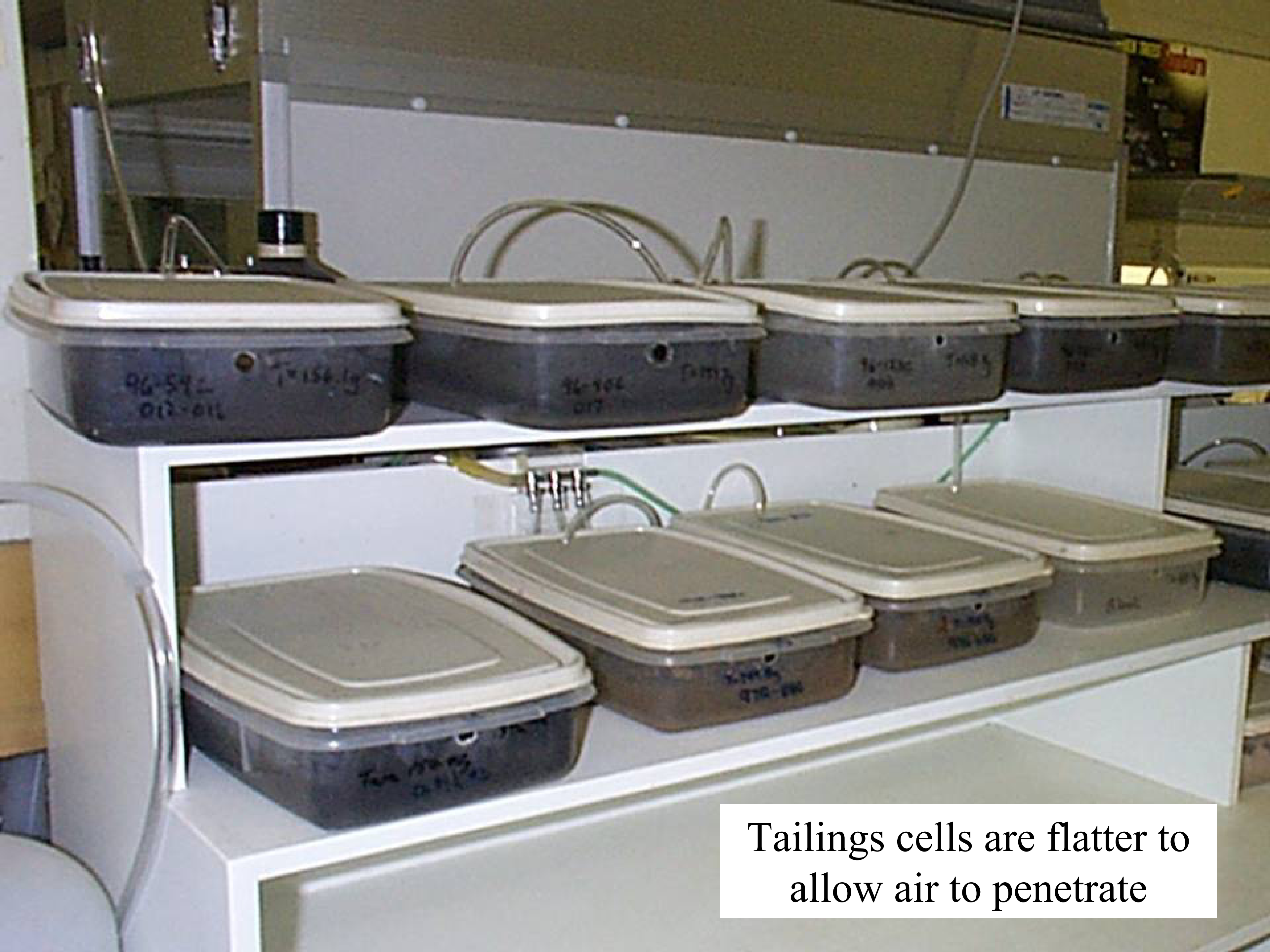
Drainage Chemistry

Procedure

- 3 day dry air
- 3 day humid air
- 1 day leach with excess drainage

Beware: Humidity cell is designed to prevent secondary mineral formation the process that typically controls elemental concentrations in drainage





Tailings cells are flatter to allow air to penetrate

Will Material Produce ARD - Coming to a Conclusion

There are two basic neutralization reactions for calcite.

1. $CaCO_3 + \underline{2H^+} \rightarrow Ca^{2+} + H_2CO_3^0$

2. $CaCO_3 + \underline{H^+} \rightarrow Ca^{2+} + HCO_3^-$

With reaction 1, an NPR < 1 is required for ARD.

With reaction 2, an NPR > 2 is required to prevent ARD.

Under neutral pH conditions, both reaction 1 and 2 are likely to occur, and the NPR required to generate ARD will be between 1 and 2.

Assuming AP and NP are correct:

- Sample is net acid generating if NP/AP < 1
- Sample is net neutral if NP/AP > 2

- Safety factors may be added for limitations in precision and accuracy of sampling, analysis, data interpretation, segregation and other aspects of material handling.

Other Considerations:

- Prediction of drainage chemistry should be conducted even if NPR > 2 because elevated trace element concentrations can also occur in near-neutral pH drainage.

Brenda Mine

Minimum % sulfide-S capable of causing ARD

- The ‘minimum %S capable of causing ARD depends on magnitude of the effective NP.
- Mined rock often has an extremely low NP.
- At the East Kempville Mine, coarse tailings in humidity cells with a sulfide-S as low as 0.09% produced ARD.
- Conclusion: Do not use a %S cut-off when assessing the ARD potential.

Maximum delay prior to ARD occurring

- "If this rock was potentially ARD generating, we would have already seen ARD in the dumps, some of which are over 50 years old."
- Absence of ARD does not prove it will not occur in the future.   Depletion of effective NP may take 10s to 100s of years.

Humidity cell coupled with ABA results provide rough estimates of NP depletion.

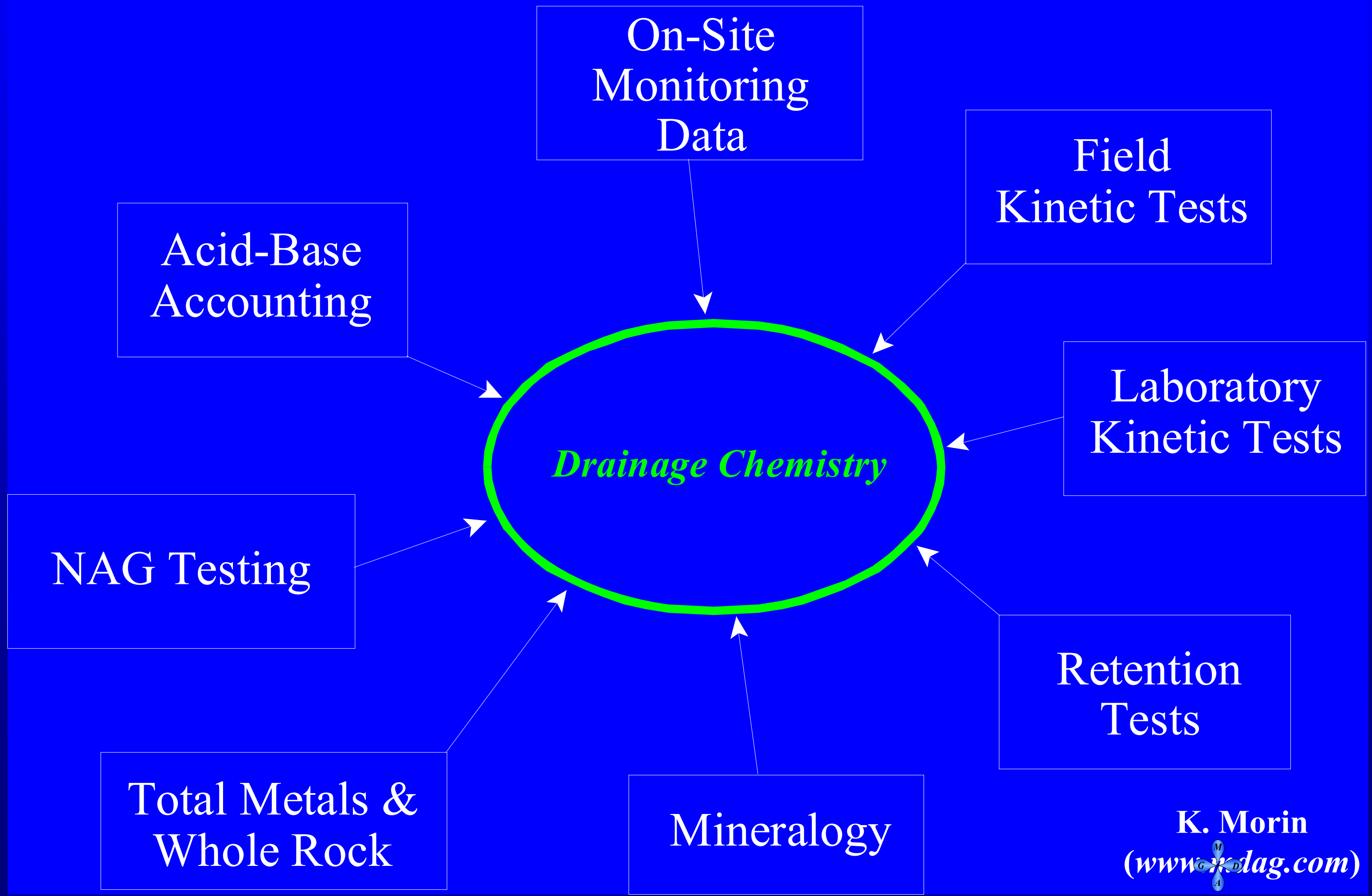
An NP depletion of 5 kg $CaCO_3$/tonne measured in cells suggest it would take 36 years to exhaust an NP of 180 kg/t in the backfill in the Snip Mine.

At colder site temperatures, the depletion of neutralizing minerals required for the onset of ARD may take far longer.

Prediction of Drainage Chemistry

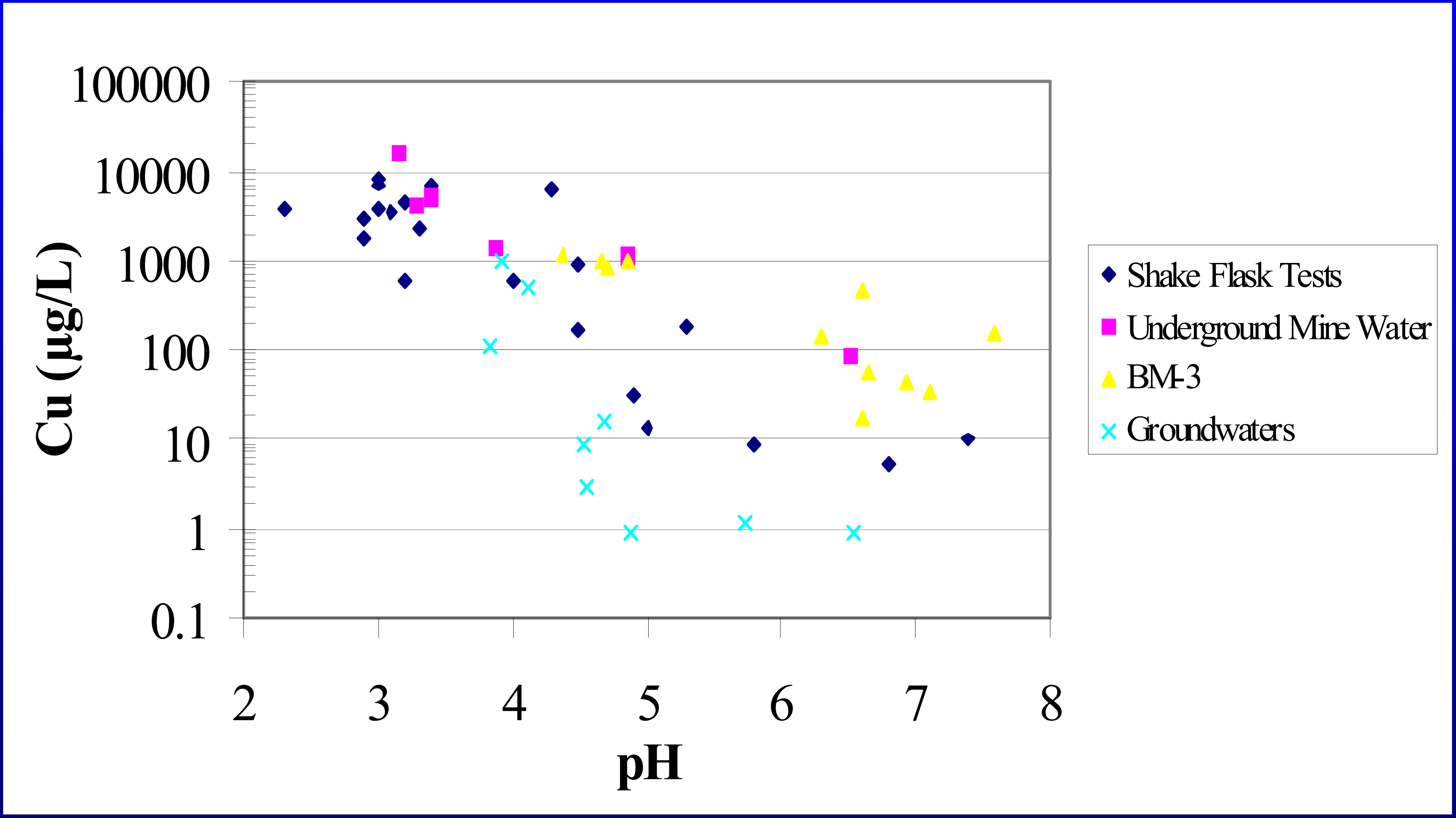
In most cases, several procedures must be used concurrently for reliable prediction.

The “Wheel” Approach for Drainage Chemistry

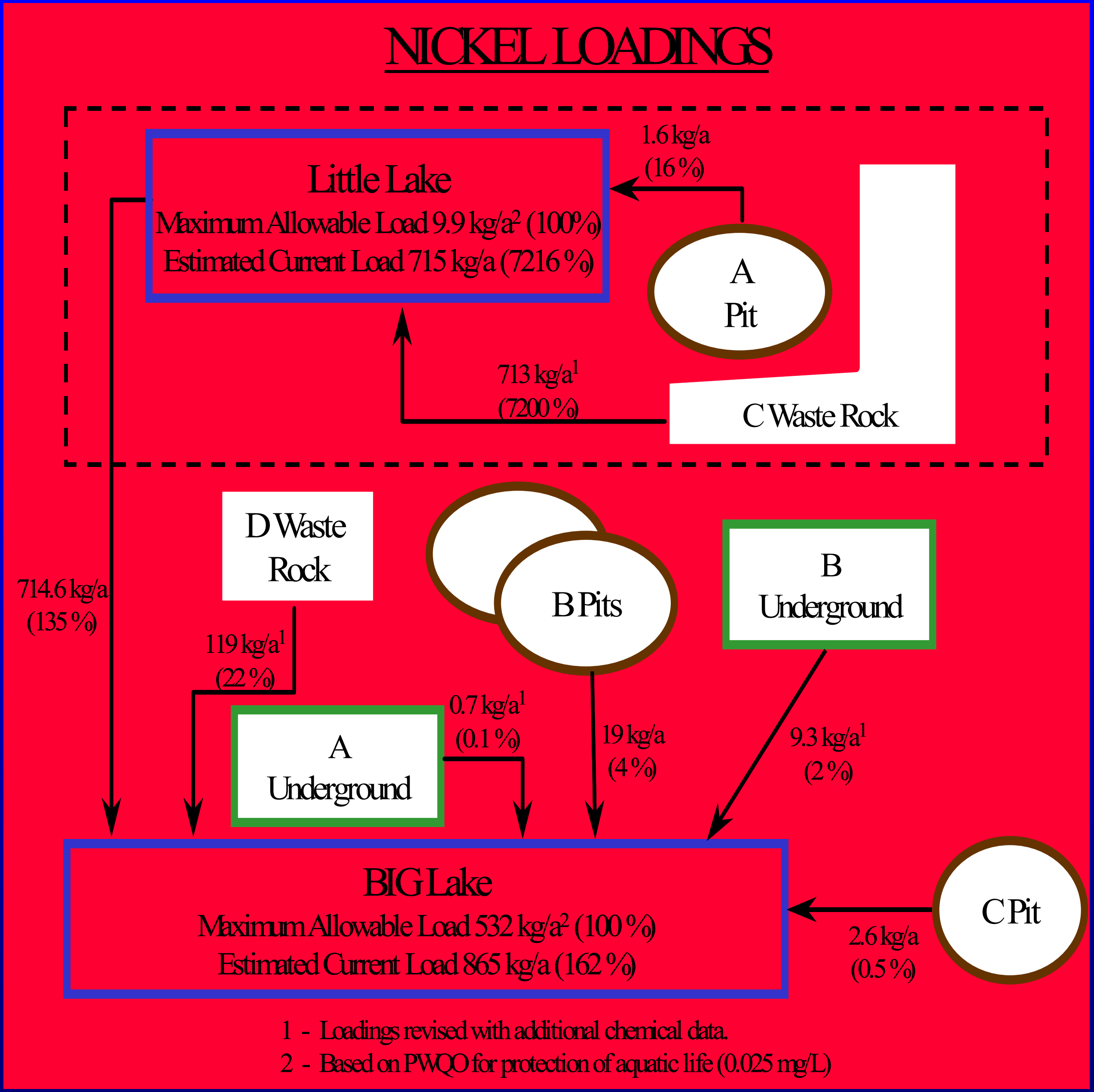


K. Morin
(www.mdag.com)

Use evidence from a variety sources to put together a more reliable prediction of drainage chemistry.



A predictive model, a selective simplification of the processes and site, is typically used in scaling up and assessing the results.



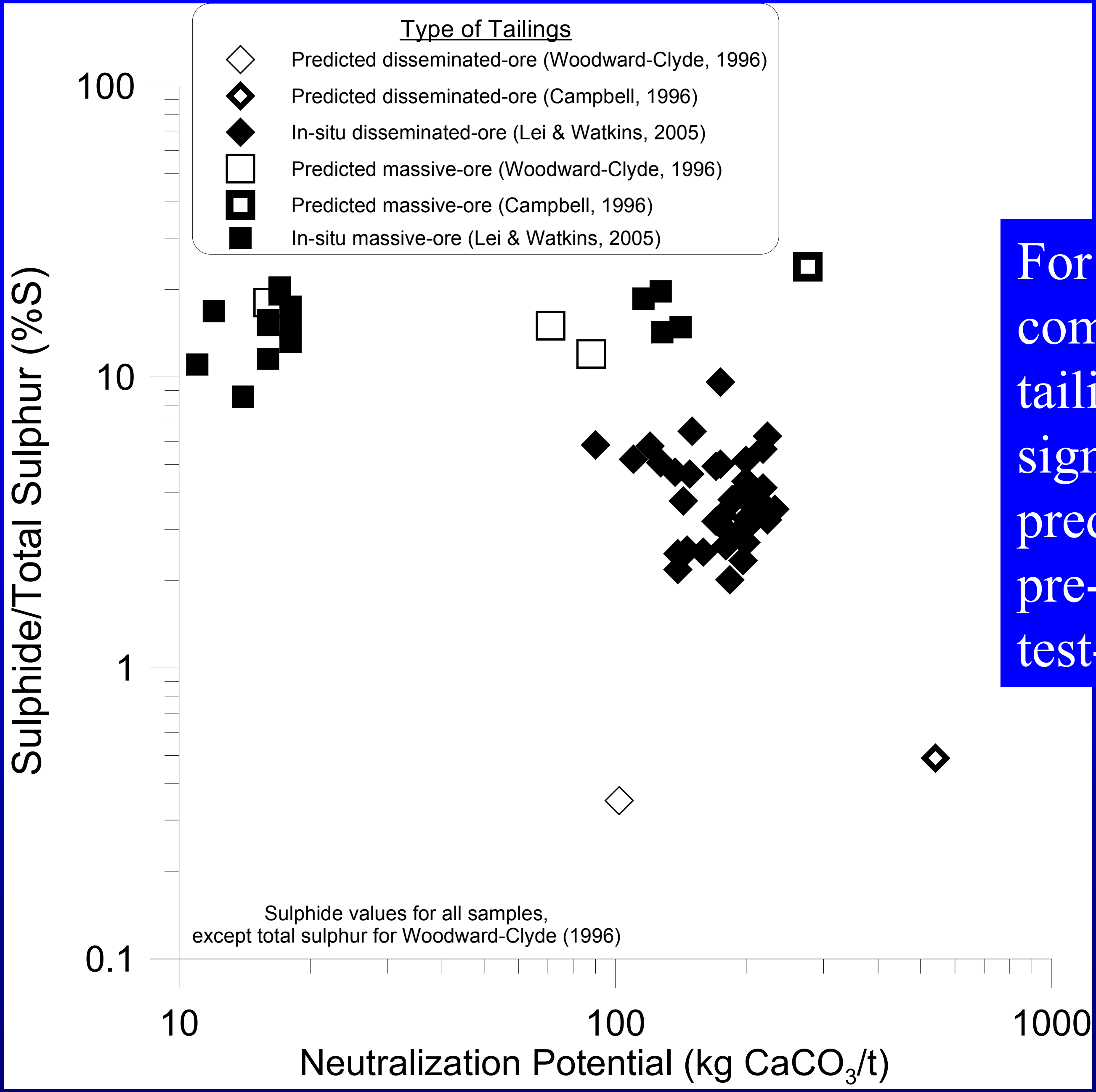
Step 3. Confirm Predicted Drainage Chemistry and Address Information Gaps

Actions required to verify, refine and address gaps in predictions of material composition and future performance

Operational Material Characterization

Operational material characterization is to:

- verify and address gaps in understanding;
- create an inventory of excavated and exposed materials; and
- segregate materials requiring different materials handling and mitigation.



For example, the composition of tailings can vary significantly from prediction based on pre-mine metallurgical test-work.

Operational characterization is especially important for materials not characterized prior to mining, in this case a new source of materials for dam construction.

Verifying Predicted Performance and Filling Information Gaps - Monitoring Weathering, and the Resulting Drainage

The purpose of monitoring is to:

- provide early warning of potential problems
- inform corrective measures and
- allow timely implementation of contingency plans.

Monitoring Weathering

- It is important to set up field test pads ASAP. May also monitor weathering at ‘permanent’ locations on the dump.

Also important to monitor drainage from actual mine components

May be very useful to monitor properties such as heat, an indication of the rate of sulphide oxidation, and oxygen content, which may indicate impediments to weathering.

Not all prediction questions can be answered prior to mining. Most mines need operational and in some cases post-operational studies to complete closure plans and reduce costs and risks.

Conclusions Regarding the Prediction of Drainage Chemistry

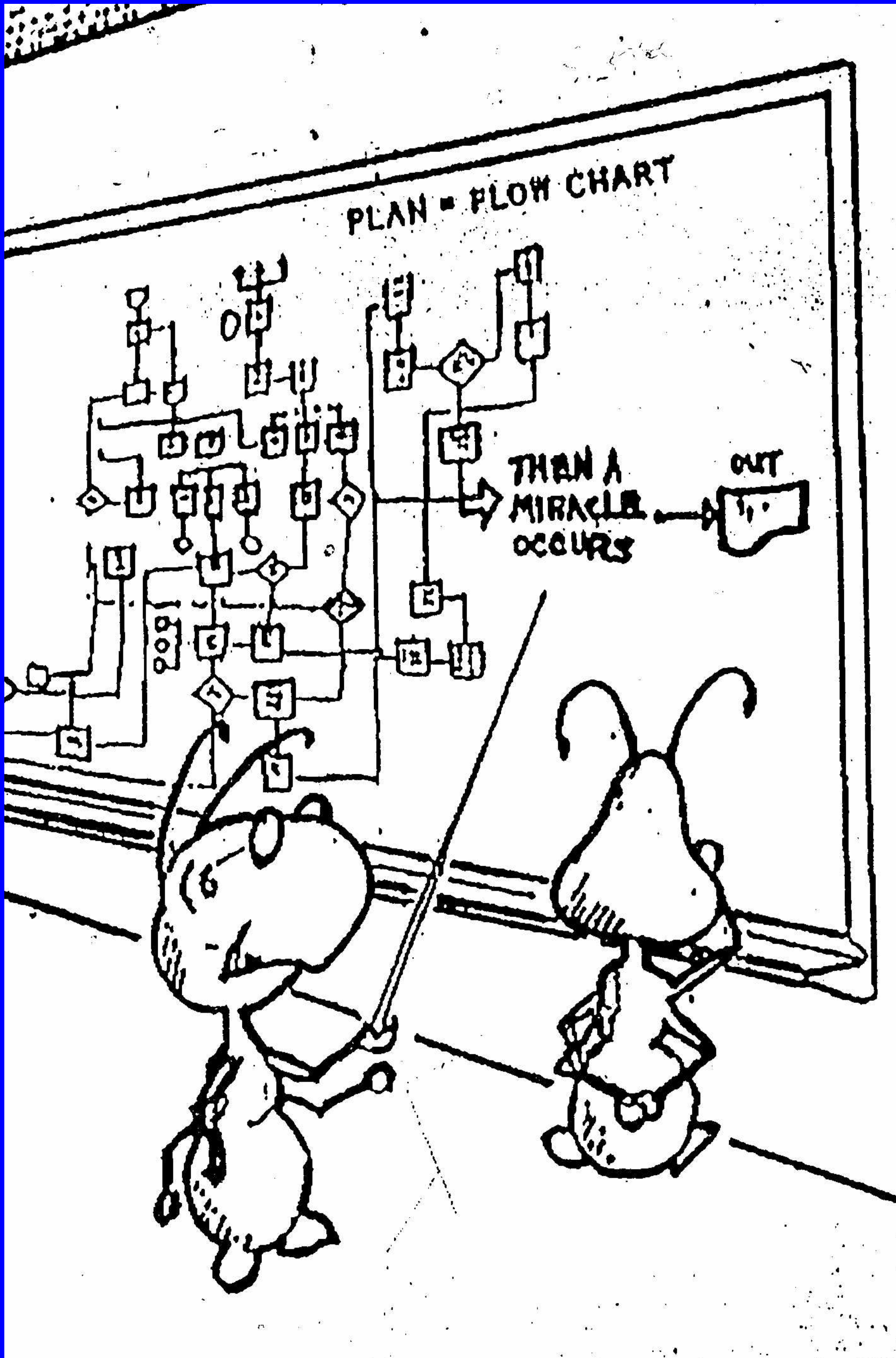
- Prediction of drainage chemistry is a key component of sound environmental and fiscal management.

- Challenges include:
  - many contributing properties and processes
  - many important parameters such as NP are difficult to measure and analysis results that may require correction
  - need to predict over long time frames and widely ranging climatic conditions
  - need comprehensive understanding of the site

- Some tests have very specific procedural and interpretation requirements. For other tests, the procedure and interpretation depends on the questions and site conditions.
- Need to recognize blind spots and understand limitations in the precision and accuracy of prediction tools.
- Properly qualified person or personnel must be accountable for TOR, methodology and interpretation of results.

Take a scientific rather than a technological approach

- Identify and understand the questions
- Make sure samples are physically, geochemically, geologically and spatially representative
- Need to check predictions (hypotheses)
- Need to clearly define materials, methods and terminology



Good predictions of drainage chemistry are possible, but the devil is in the details – use caution when extrapolating, simplifying or generalizing

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