CASE STUDIES AND SUBSEQUENT GUIDELINES FOR THE USE OF THE STATIC NAG PROCEDURE

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Objectives

- What methods/modifications are used?
- What examples are there?
  - Zortman, MT
  - Base Metal Mine, USA
  - Ok Tedi, PNG
  - Various waste dumps in CO, MT
  - Gold Mine, AUS
- What are some suggestions for the guidelines?

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Methods in use

- NAG test varies among users, typically:
  - Adding 250 mL of 15% H_2O_2 at room temp to 2.5 g of sample pulverized to pass 200 mesh.
  - React for 12 h then boiled until visible reaction ceases (or Cu catalyst added) or initial reaction period is extended to 24 h
  - Measure pH of the reacted solution (NAG_{pH})
  - Titrate reacted solution with NaOH to a specified pH end-point (pH 4.5 and/or pH 7) to determine the NAG value of the sample.

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Methods in use

- NAG results generally interpreted as such:
  - If the final NAG_{pH} is > 4.5, sample said to be non-acid forming
  - If the final NAG_{pH} is < 4.5, the sample is said to be potentially acid forming
  - The NAG value then provides a quantitative assessment of potential acid formation in units of kg $CaCO_3$/t equivalent (or kg H_2SO_4/t equivalent)

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Modifications in use

- Modifications include:
  - Sequential addition NAG test (multiple additions of H_2O_2)
  - Kinetic NAG test (track pH, temperature and EC during test)
  - Modifications to account for organic matter effects (analyze for organic acids and sulphuric acid in reacted solution, extended boiling step).
  - Modifications to leach carbonates prior to NAG test (i.e. measure of acidity not net acidity).

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Applications of the NAG

- In conjunction with ABA tests etc to reduce the risk of mis-classification
- As an operational scale management tool (e.g. for segregation of different material types)
- For identifying material for prioritization (e.g. AML ranking)
- As an indicator test that can be run on greater number of samples than if using other methods due to the fact it is quick, simple and inexpensive
- Used very widely in Australasia

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Some potential pitfalls

- Organic matter, Cu, Pb and MnO_2 can catalyze decomposition of H_2O_2. Samples high in these parameters can have unpredictable results (O'Shay et al., 1990)
- Samples with a lot of Zn can be buffered between pH of ~ 4 to 5 by the formation of $Zn(OH)_2$ (Jennings et al., 1999)

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Some potential pitfalls

- NAG test can underestimate potential acidity if samples have (Amira, 2002):
  - Sulphide content > ~1%
  - High carbonate content
  - High organic content
- Not as 'conservative' as ABA testing

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Example - Zortman Gold Mine, MT

- Zortman mine in Montana was an open pit gold heap leach operation.
- Reclamation planning required site-wide characterization and prioritization of waste material.
- Testing aimed at ‘mapping’ the site with respect to ARD and metal leaching potential and defining operational classification tests

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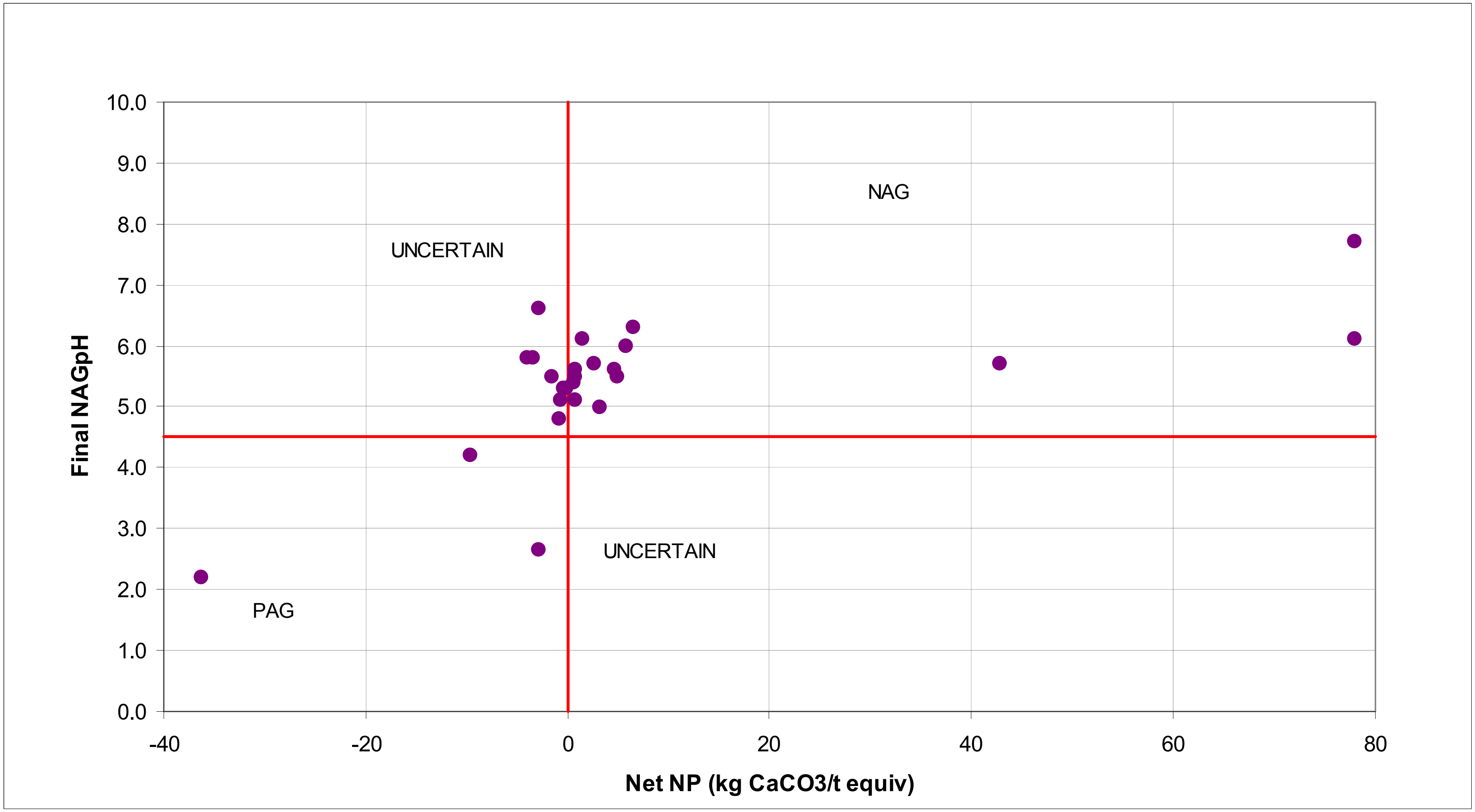
Example - Zortman Gold Mine, MT



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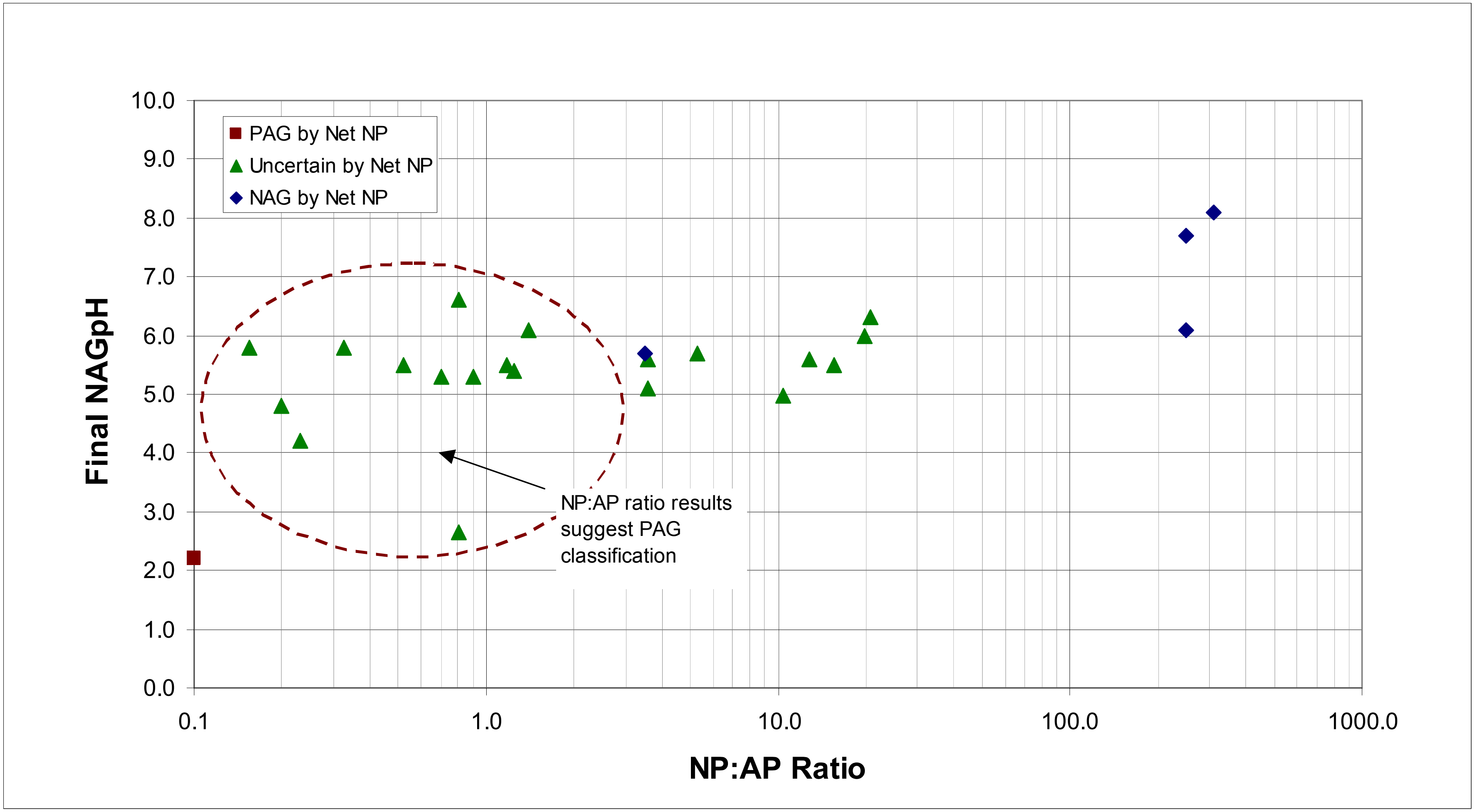
Example - Zortman Gold Mine, MT



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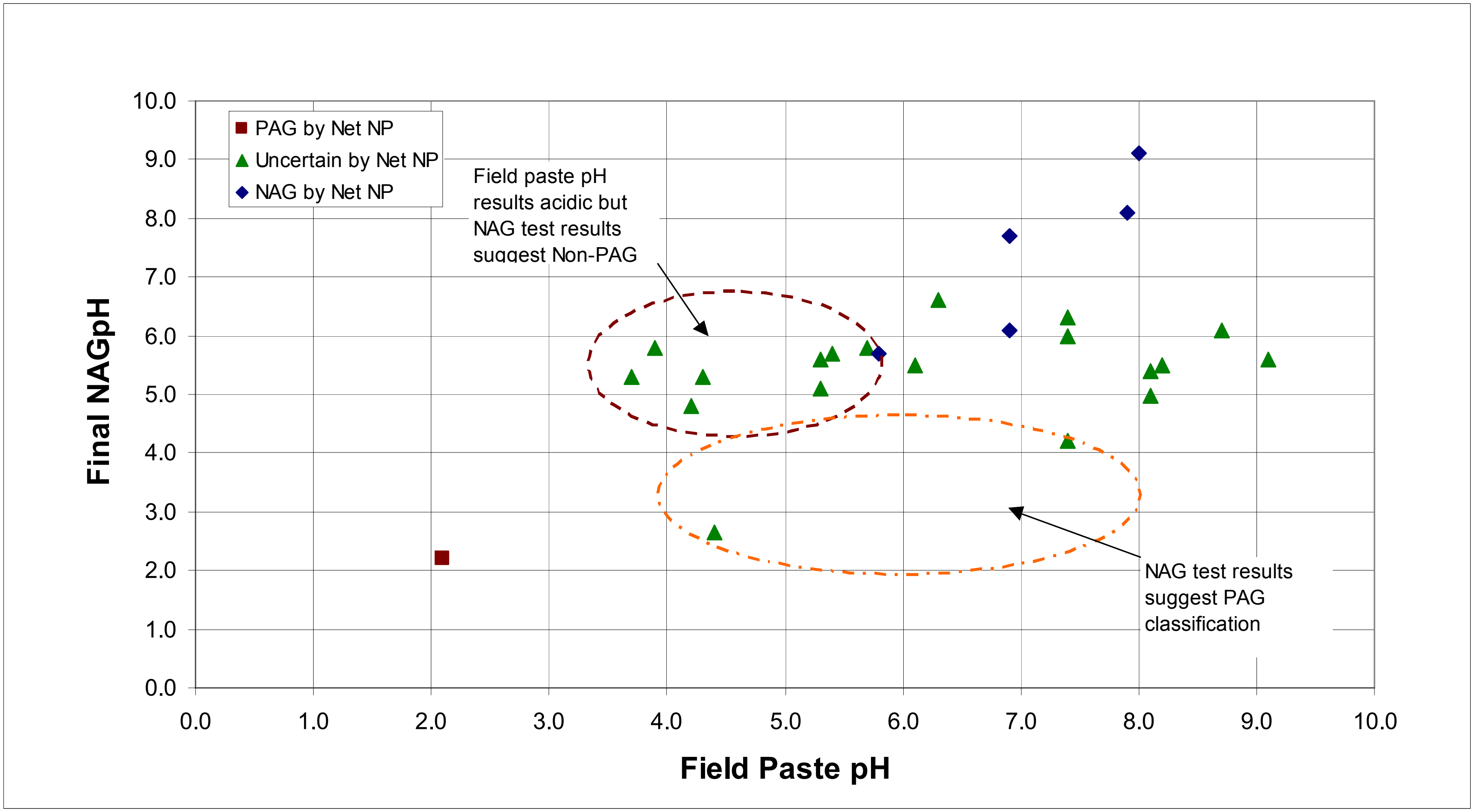
Example - Zortman Gold Mine, MT



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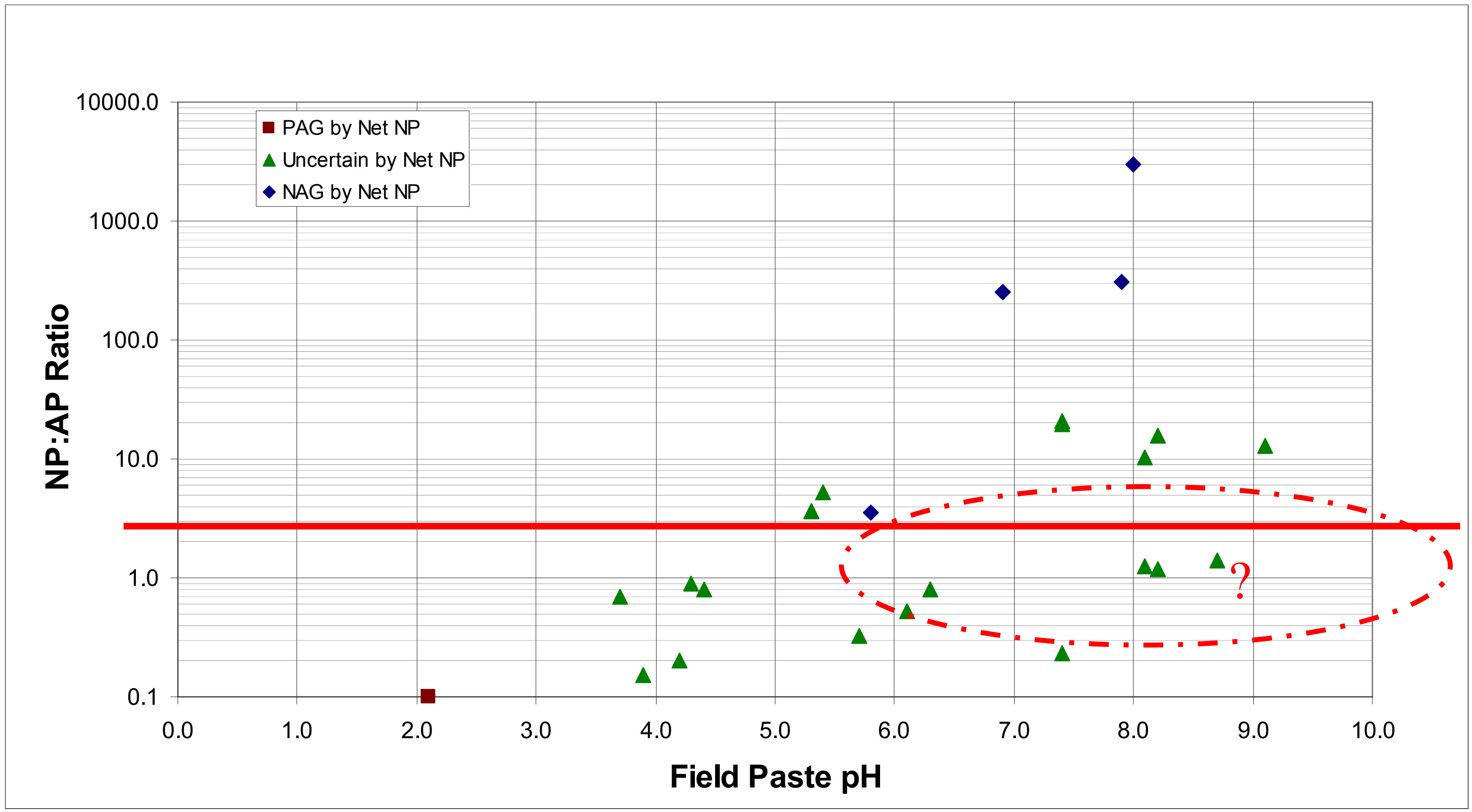
Example - Zortman Gold Mine, MT



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Example - Zortman Gold Mine, MT

- Not great agreement between NAG and ABA results
- NAG test was deemed to carry a risk of mis-classification of PAG material (compared to field paste pH; due to crushing?)
- Because relative amounts of sulphide and buffering minerals were low:
  - Net NP not very discriminating (a lot classified uncertain)
  - NP:AP ratio possibly too conservative

Example - Zortman Gold Mine, MT

- Leach extraction testing suggested samples with pH < 5.5 and/or S > 0.2% could be problematic – neither NAG or ABA that reliable (i.e. more of a leachability issue)
- Field test methods utilized to 'map' waste prior to lime amendment and cover placement included paste pH and total S:
  - field paste pH < 5.5 or total S (%) greater than 0.2 needed a 'higher quality' cover according to a scale developed based on metal leachability testing and paste pH correlations.

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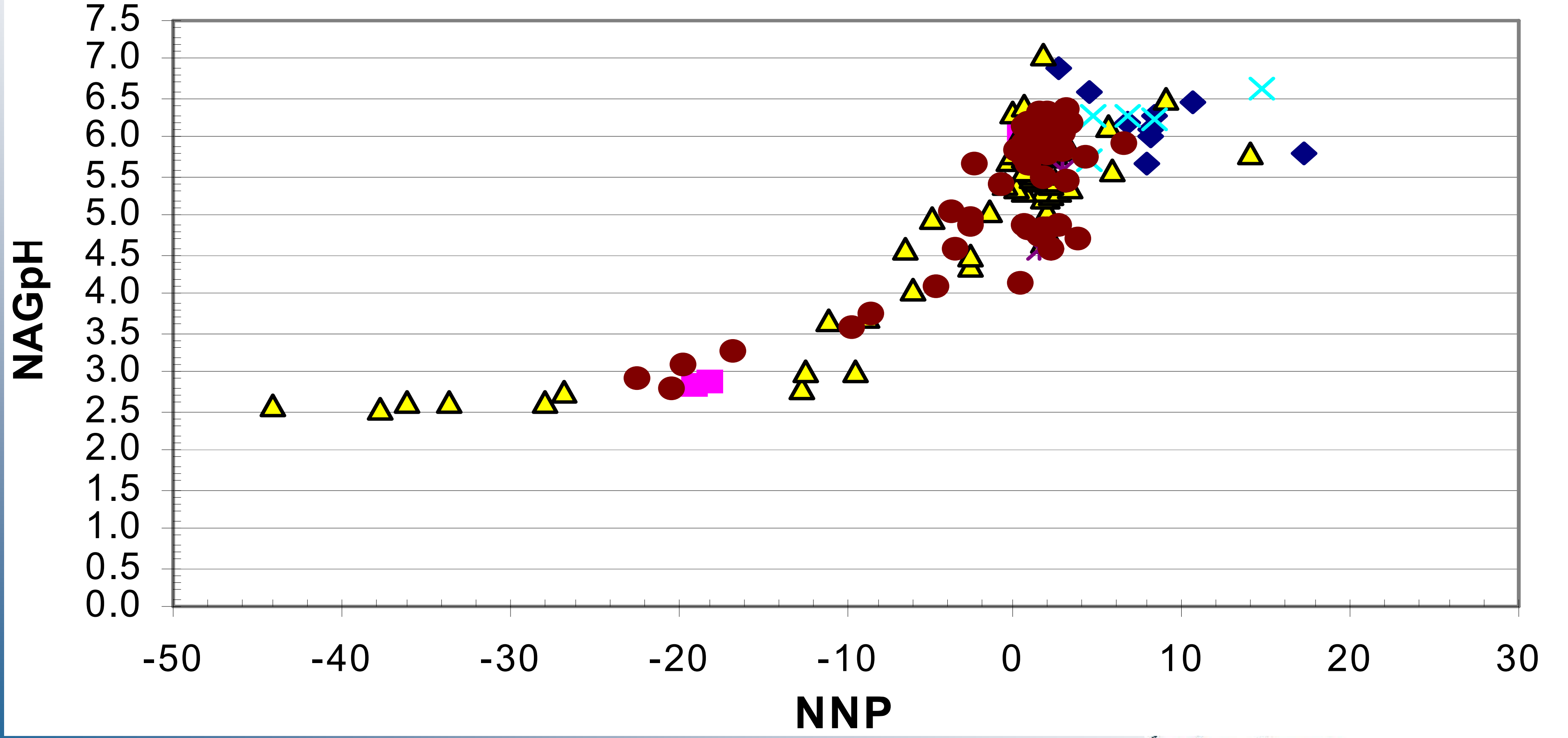
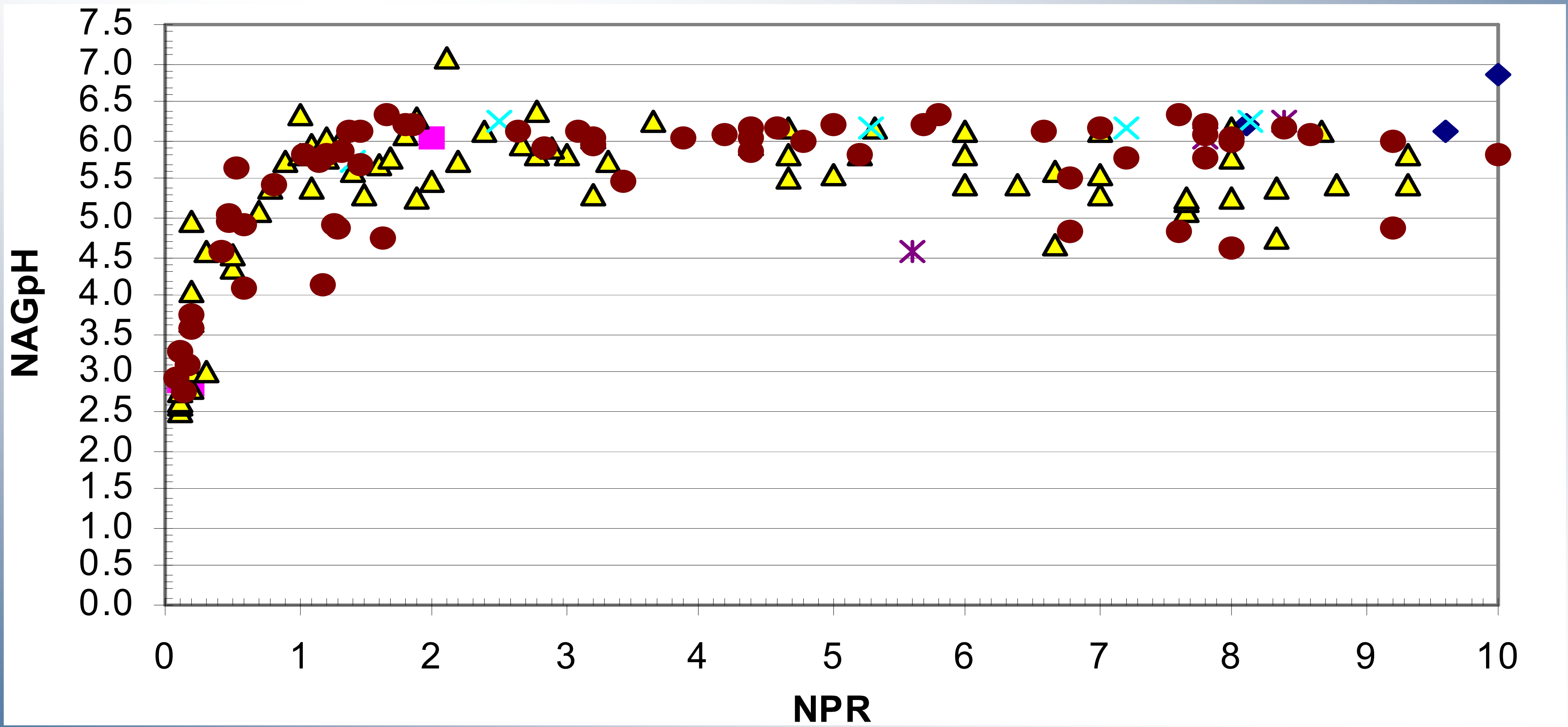
Example – Base metal mine, USA

- Feasibility stage testing as initial characterization and evaluation for operational usage



Example – Base metal mine, USA



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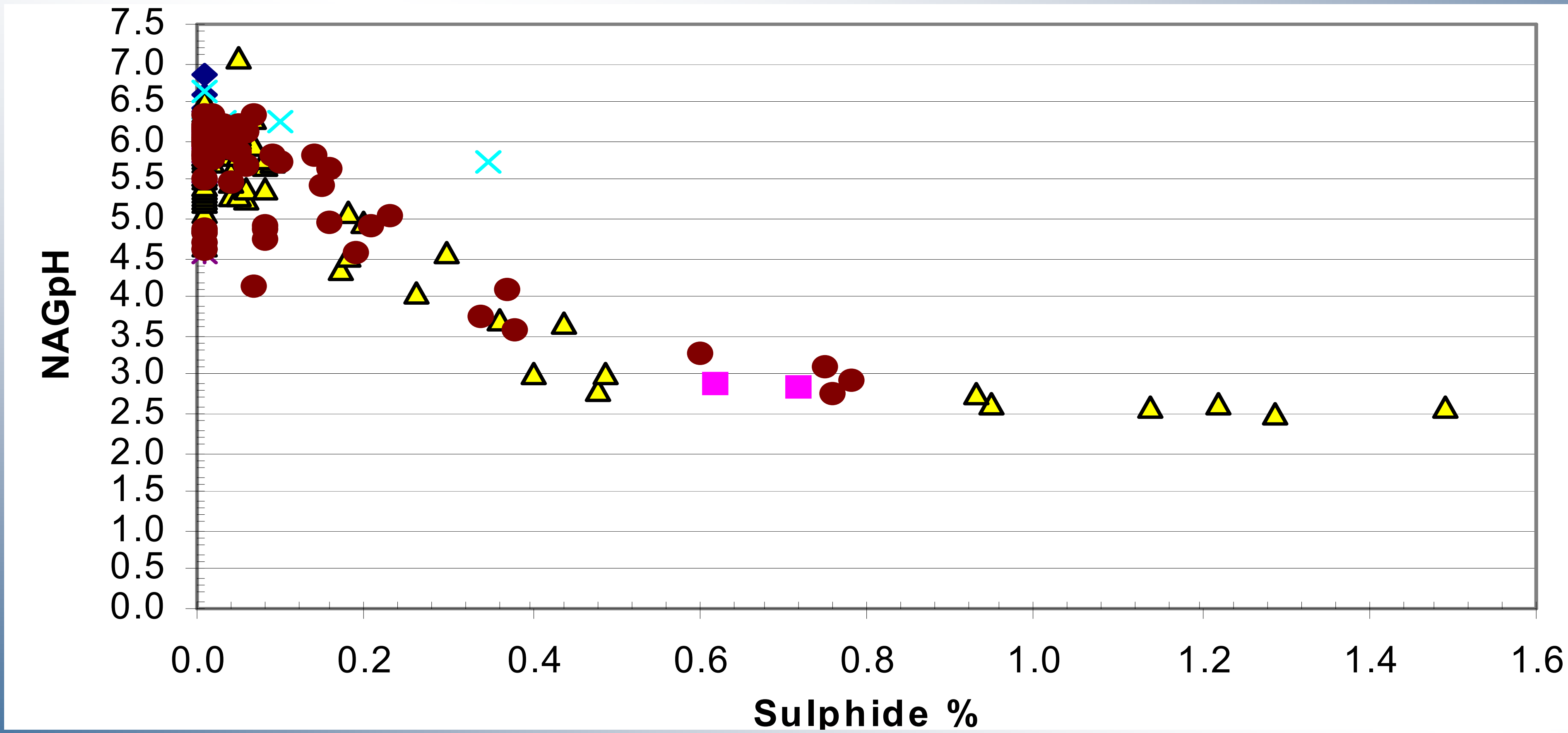
Example – Base metal mine, USA



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Example – Base metal mine, USA

Classification by NAGpH and NNP	Total	
	Number	% of Total
PAG	21	12
Uncertain: NPAG by NAGpH	12	7
NPAG by NNP	1	1
NPAG	137	80
Total	171	100

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Example – Base metal mine, USA

- The two criteria were very consistent: samples with a NAG_{pH} greater than 4.5 generally had a NNP greater than zero
- Where the tests differed, the NNP values were more conservative
- NP:AP classifications (both generic and site-specific) identified numerous samples (16%) as PAG, in which NAG_{pH} values were above 4.5.
- Reported the NP:AP was conservative due to the presence of chalcopyrite in the samples, which would be identified as a sulphide in acid-base accounting and would therefore theoretically provide acid potential and a lower NP:AP ratio.

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Example – Base metal mine, USA

- Also evaluated the use of the NAG_{pH} test method to identifying samples containing soluble copper (soluble copper in a supergene enriched cap).
- Concentrations of NAG copper increased when NAG_{pH} decreased below pH 5. $NAG_{pH} < 5$ might better identify problematic materials than a NAG_{pH} of 4.5 if NAG copper is representative of soluble copper.
- However, there was no clear correlation between the water leachable copper and NAG copper
- Deemed that the addition of copper analysis with NAG testing does not appear to assist in identifying water soluble metals for waste rock management.

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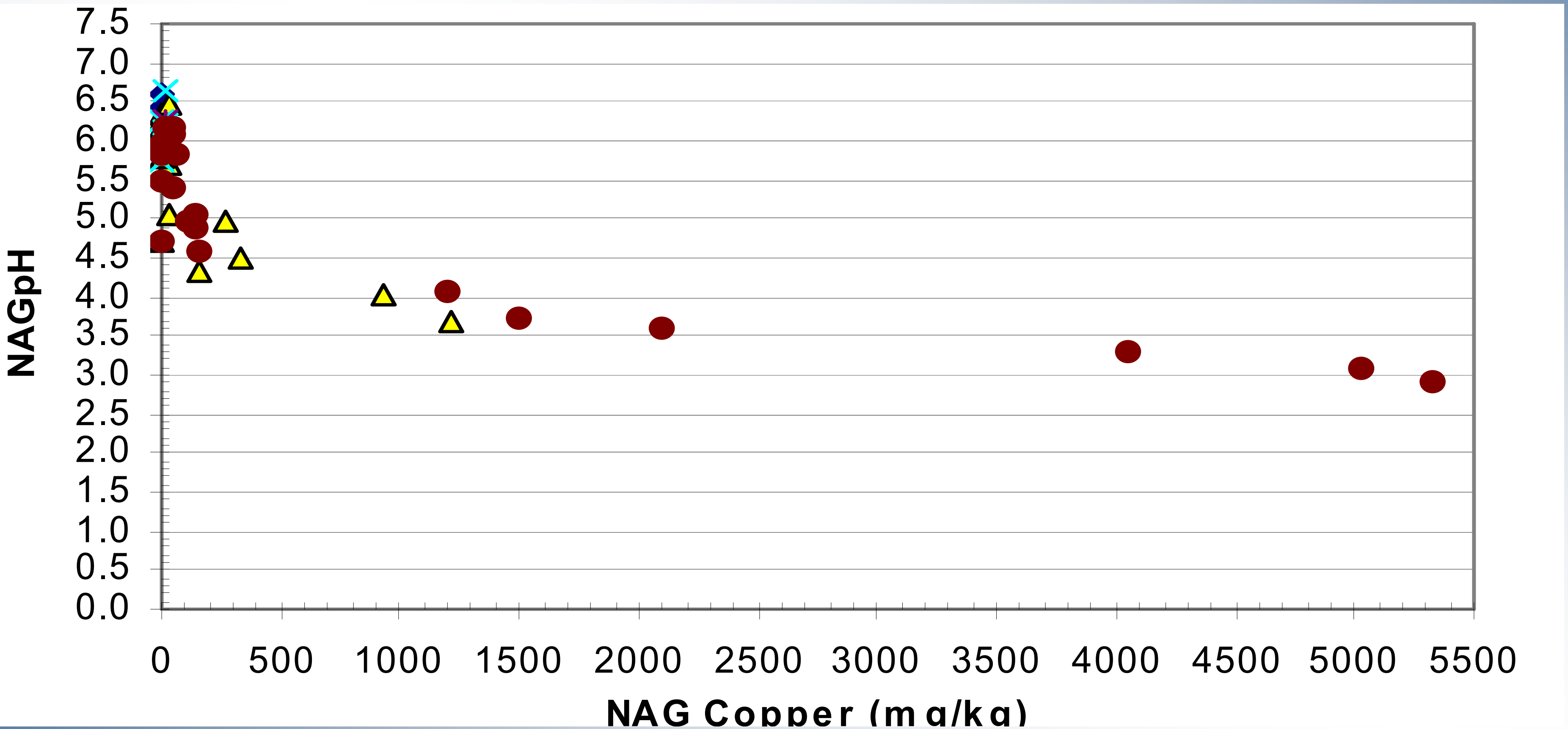
Example – Base metal mine, USA



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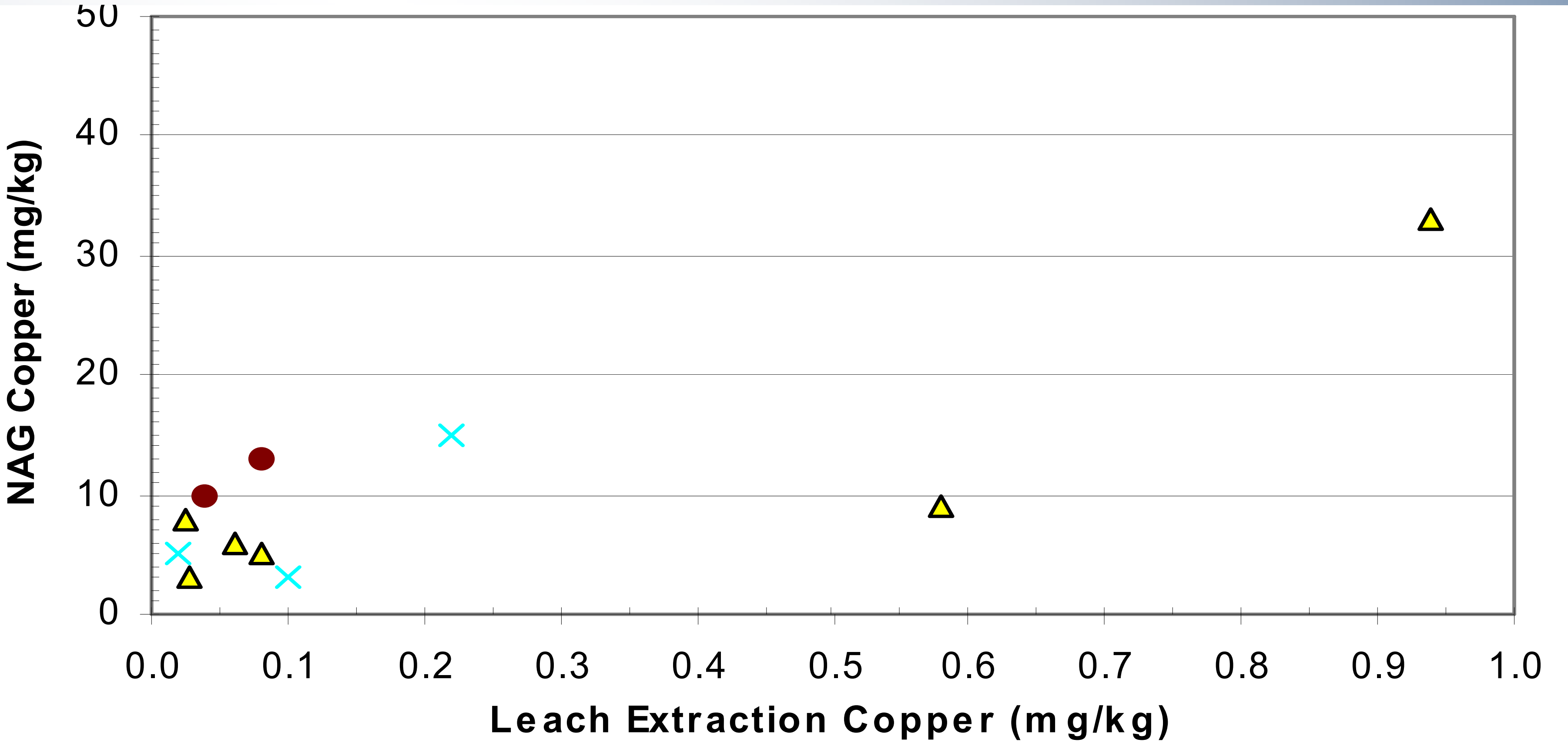
Example – Base metal mine, USA



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Example – Ok Tedi

- Ok Tedi – open pit copper gold porphyry with riverine tailings deposition and waste rock slumpage into river system.
- ARD management included mining and dumping additional limestone into the dump to provide an overall net alkalinity to the system – termed co-dumping (essentially a very coarse blend)
- Waste rock sampling in co-dump indicated an average S% of 1%; 75% of samples had NP:AP ratios >3 (range of ratios from 1.5 to 266)
- All samples had NAG_{pH} values >7.0 (i.e. none PAG)

[Rumble et al. 2003 ICARD proceedings]

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Example – Ok Tedi

- NAG test not conservative enough given the blend was so ‘coarse’ in nature
- Selected the modified Sobek ABA for field checks in the waste-limestone dump defining a target NAPP value of –150 kg H_2SO_4/t equiv (excess NP) based on maintaining an NP:AP ratio >3
- Needed to be able to assess 2 variables and not the net acidity so that they could add excess NP if the MPA was to high

[Rumble et al. 2003 ICARD proceedings]

Example – Ok Tedi

- NAPP target in the dump provided 150 kg/t excess NP (as H_2SO_4), but what does this mean further downstream as segregation along the river occurs and the waste, tailings and natural sediment mix and deposit?
- Tailings are high sulphide (~5%) – silicates, calcite, magnetite, pyrite, chalcopyrite and chalcocite
- Risk identified downstream in river bars at Bige
- Dredging and stockpiling undertaken near Bige – sediments at Bige a mixture of material with ~ 3% pyrite

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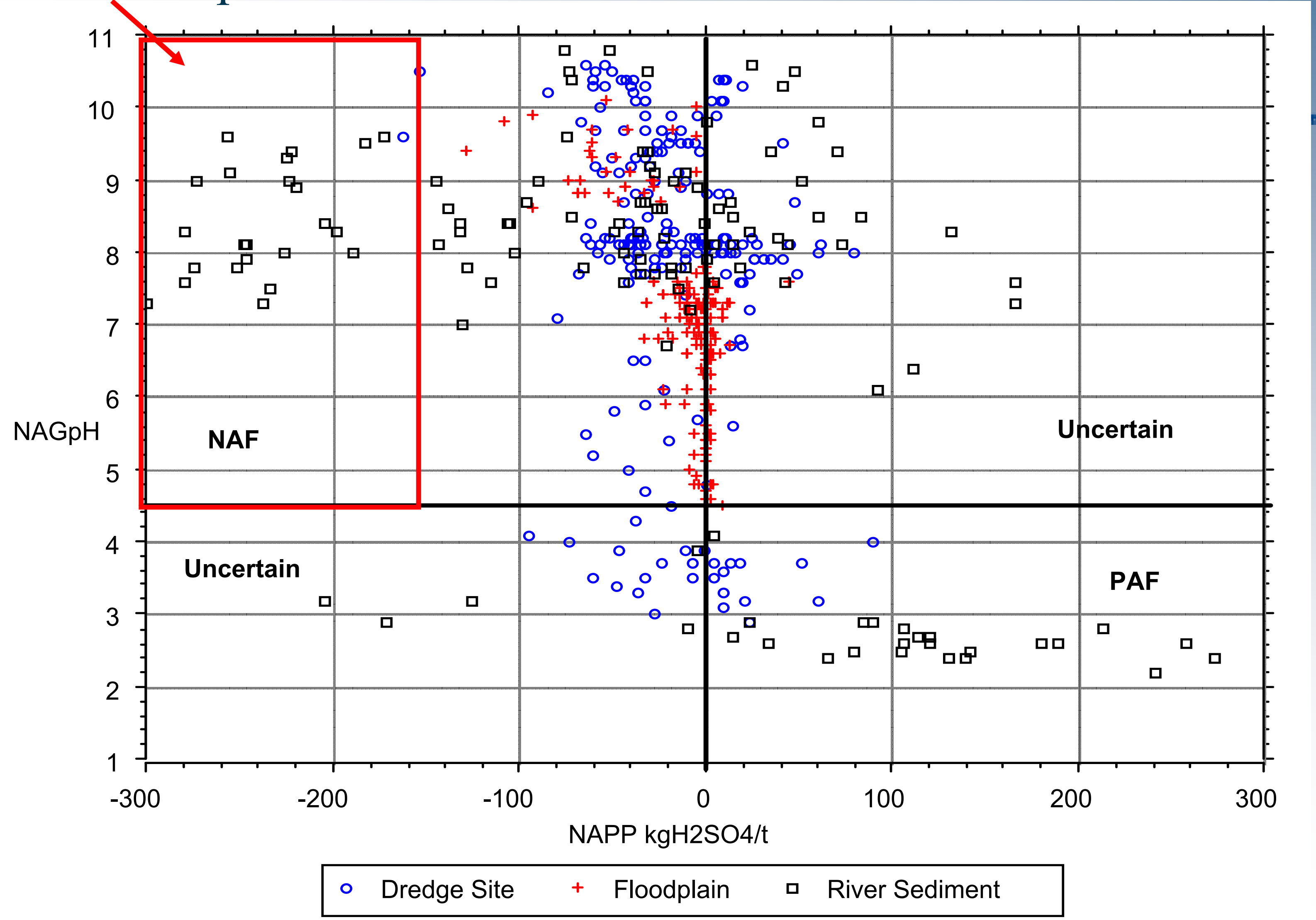
Target at the dump



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Example – Ok Tedi

- Single addition NAG test showed the dredged material was NAF – but river bars showed elevated SO_4 and metals and slightly depressed pH
- Sequential NAG test consistently showed a drop in the NAG_{pH} of the material below 4.5 after additional H_2O_2 additions

[Pile et al. 2003]

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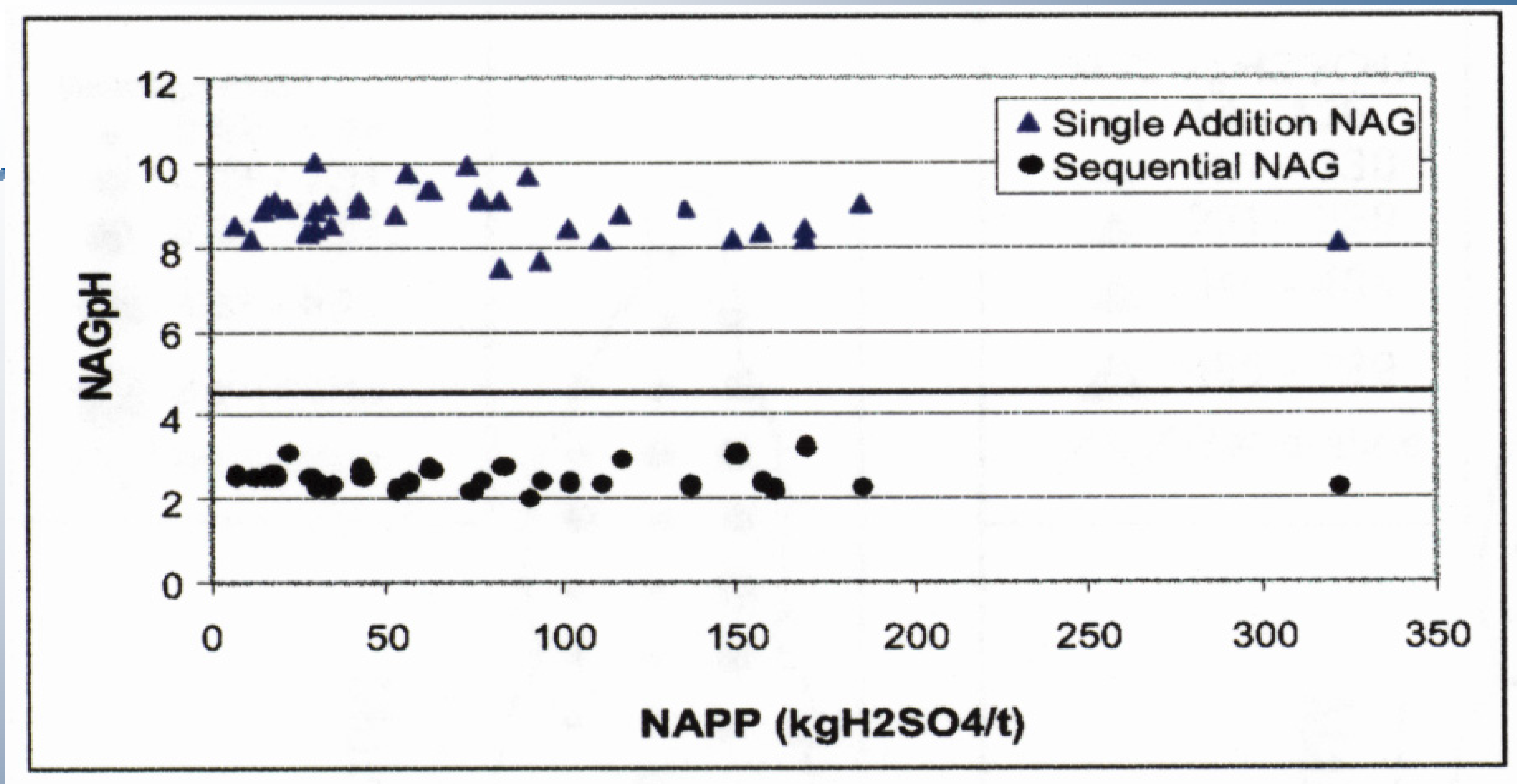

- Single addition NAG_{pH} did not identify PAG samples, sequential NAG test did – perhaps due to presence of Cu or higher S content
- Did not identify neutral drainage issue

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Example – Ok Tedi

- Re-classified the dredged material as potentially acid-forming with a 'lag' period (not quantified).
- Interstitial waters were generally described as (relative to river water)
  - Slightly acidic to neutral
  - High alkalinity
  - High soluble salts (mainly SO_4 and Ca)
  - High metals (Cu, Mn and Cd)

[Pile et al. 2003]

Example – numerous waste dumps in Colorado and Montana

- Fey et al (2000) used the single addition NAG test (termed NAP test by them) as a tool for ranking the sites for remediation or removal
- All sites were poly-metallic typically containing pyrite, arsenopyrite, galena and sphalerite; with some enargite, chalcocite and covellite

[Fey et al. 2000 ICARD proceedings]

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Example – numerous waste dumps in Colorado and Montana

- Derived a relationship between NAG value (in kg $CaCO_3$/t) and the sum of dissolved As+Cd+Cu+Pb+Zn; and between NAG value and dissolved Fe.
- Prioritized sites for remediation based on the group classification
- Note – couldn't rely solely on the NAG results; possible to rely solely on the leach extraction results (with less differentiation at very high leachate concentrations)

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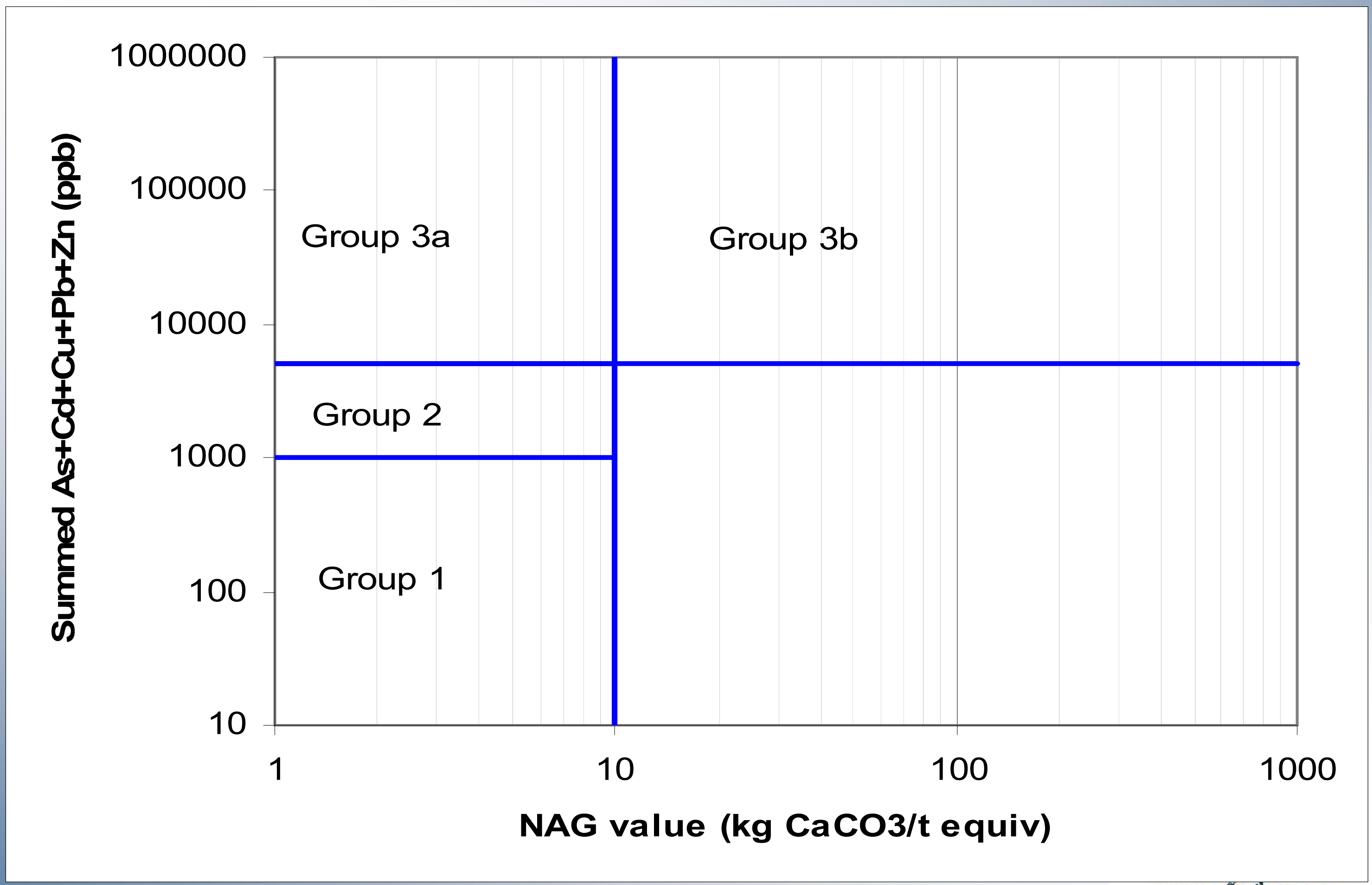
Example – numerous waste dumps in Colorado and Montana



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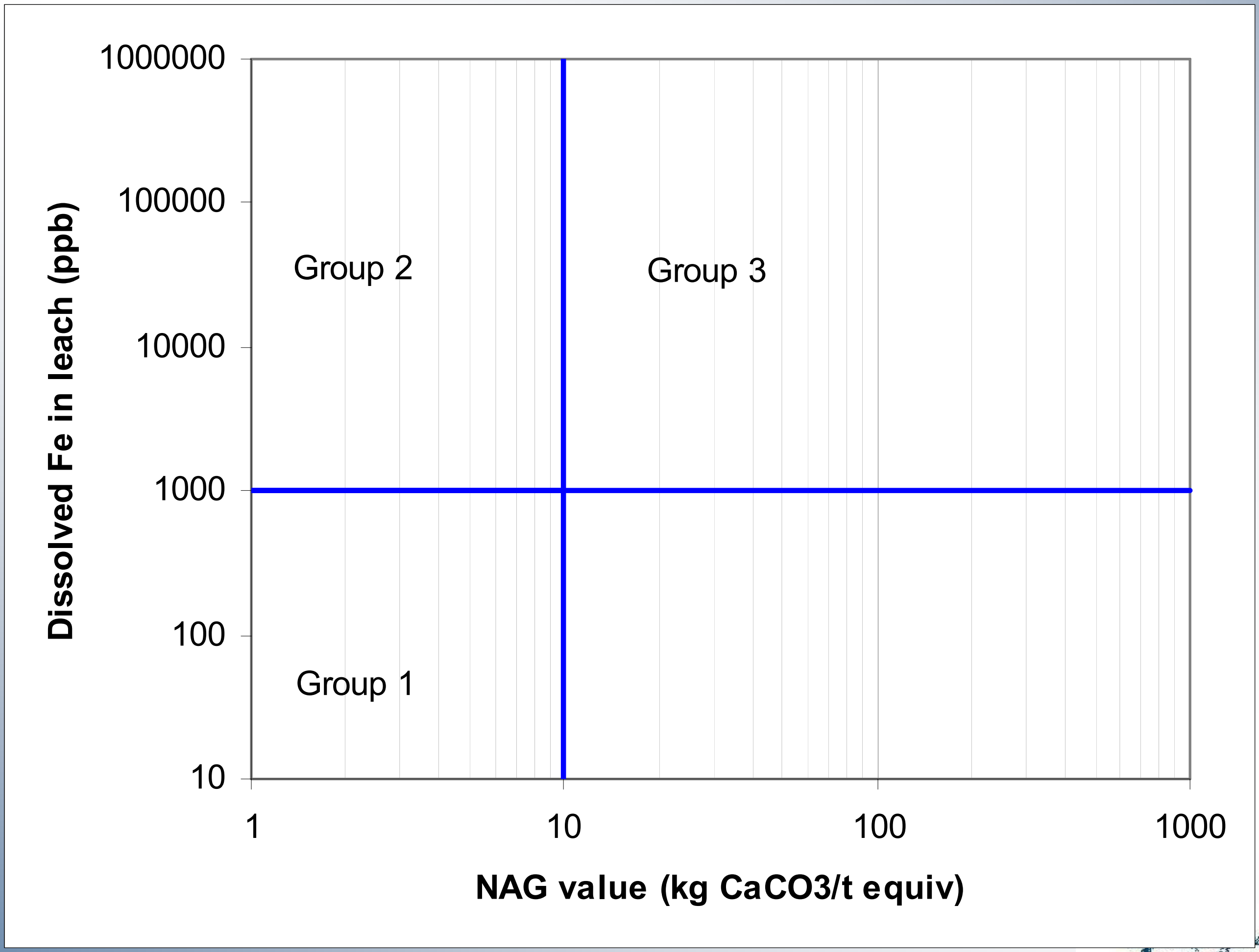
Example – numerous waste dumps in Colorado and Montana



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Example – Operating Gold mine, AUS

- Gold mine in Australia, currently using total S for segregating PAG from non-PAG; evaluating the use of NAG_{pH} as a replacement field method to total S due to dump capacity limitations.

Method	% non-PAG	% PAG
Total S (%)	62	38
NAG_{pH}	85	15
Net NP	84	16

- Initial characterization suggested S%<0.35 would maintain NP/AP>3

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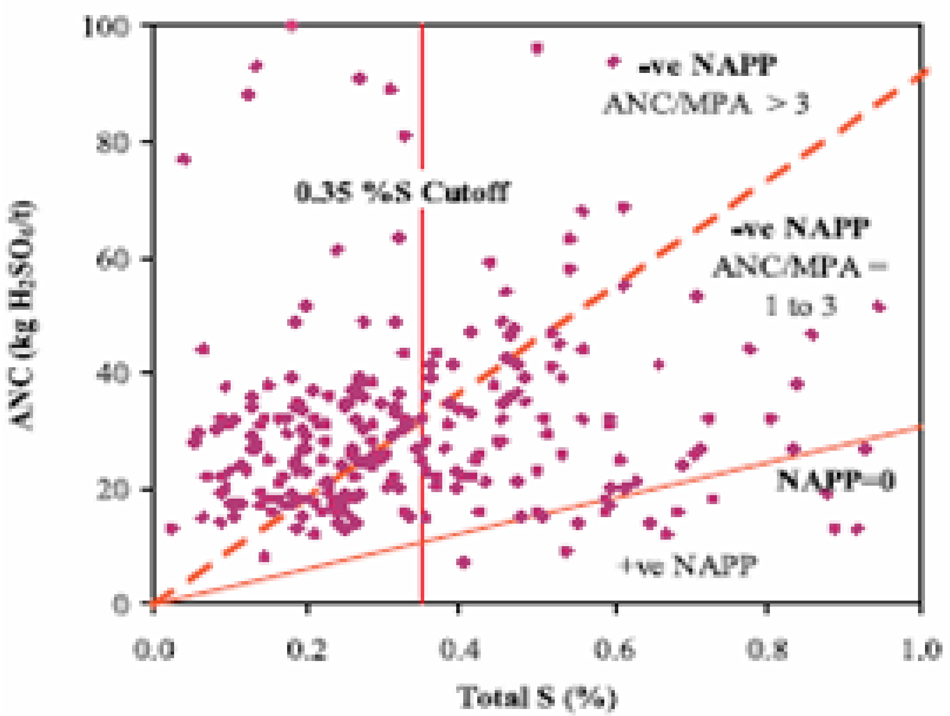
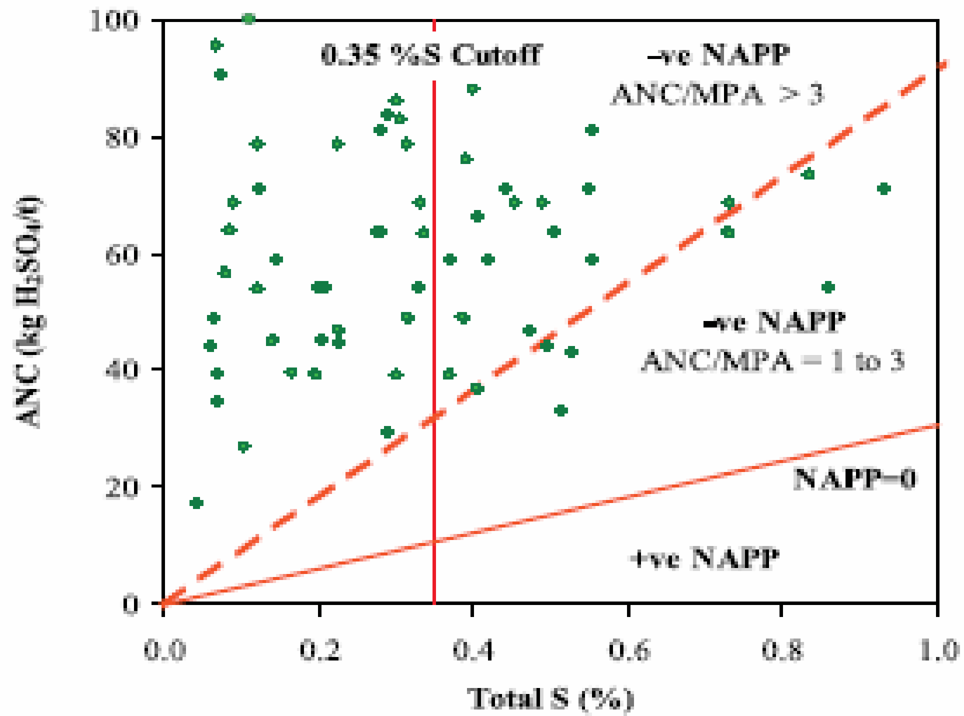
Example – Operating Gold mine , AUS



PAG dump



Non-PAG dump

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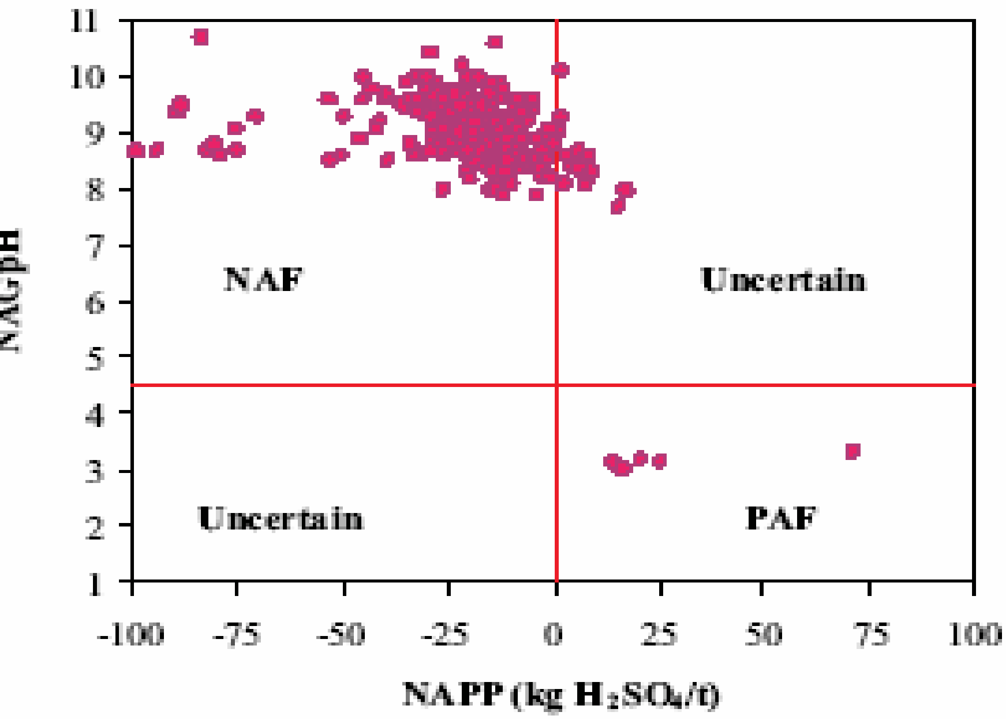
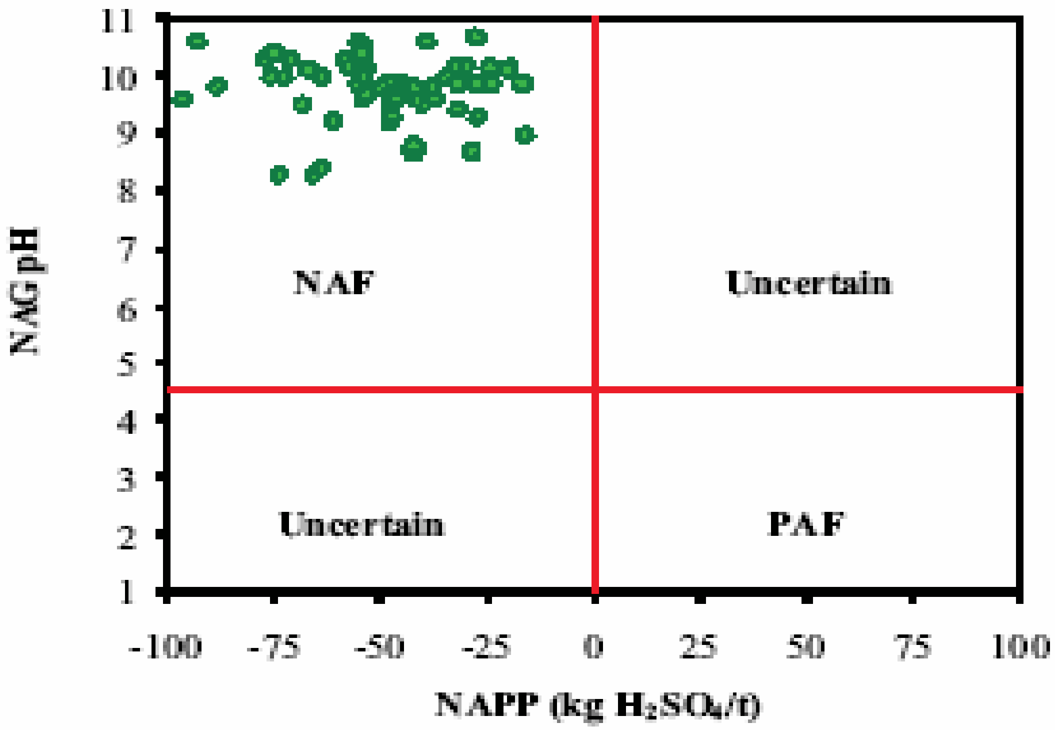
Example – Operating Gold mine , AUS



PAG dump



Non-PAG dump

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Example – Operating Gold mine , AUS

Some typical column test results.

Geological description	Acid-base characterisation						Leachate quality		
	%S	ANC (kg H_2SO_4/t)	NAPP	NAG pH	ARD class	Waste type	pH	SO_4 (mg/L)	Cu (mg/L)
Monzonite porphyry (G-Fault)	4.7	4	140	2.4	PAF	PAF	2.5 - 3	3000 - 4000	20 - 100
Monzonite porphyry, strong propylitic alteration, moderate sulfides	0.61	43	-24	> 7	NAF	PAF	7 - 8	100 - 200	< 0.01
Monzonite porphyry, major propylitic alteration, trace pyrite	0.25	7	0	5.1	NAF	NAF	7 - 8	50 - 100	< 0.01

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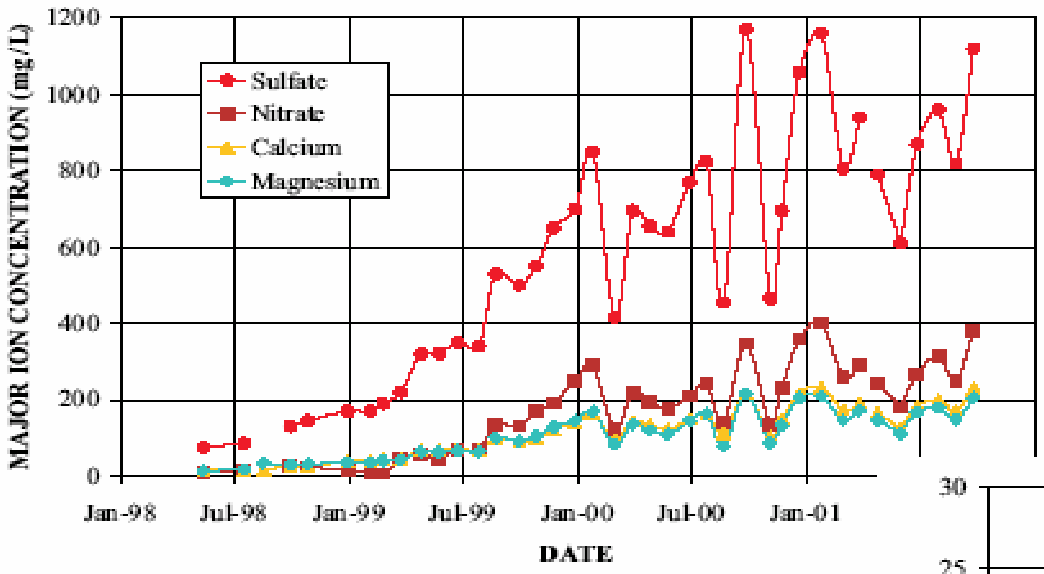
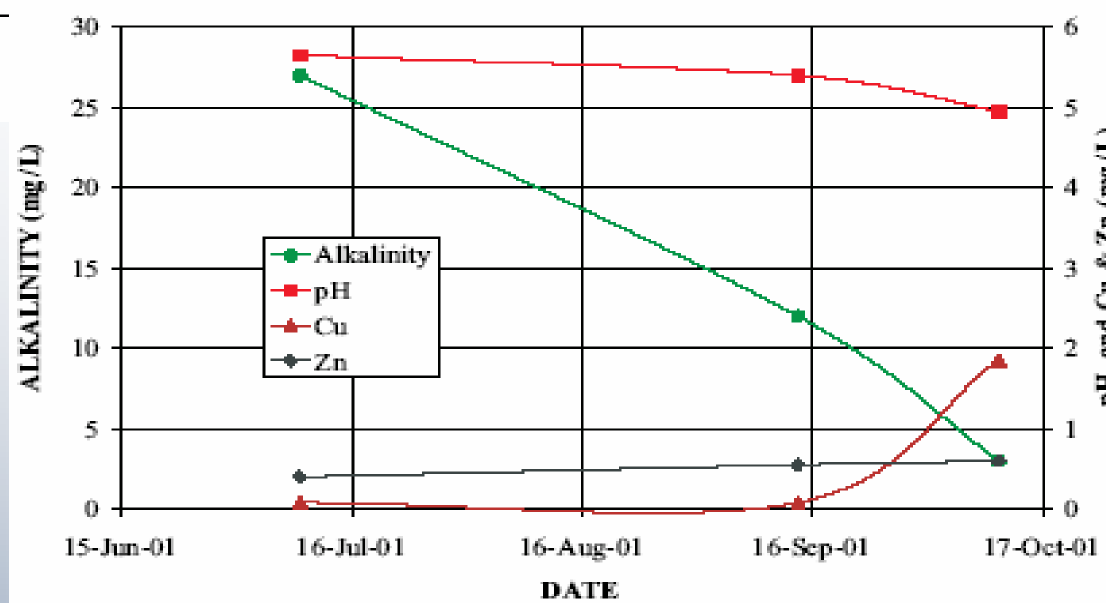
Example – Operating Gold mine , AUS





Example – Operating Gold mine , AUS

- Forward acid titration tests showed that most of the neutralization capacity was slow reacting at lower pH ranges
- Leachate collection ponds show neutral pH but increasing concentrations of SO_4 etc.
- Recommended to stick with the more conservative total S classification, set-up field tests to further evaluate potential metal leaching issues and look at waste management options for ‘over-run’ of PAG volumes (e.g. building an encapsulated ‘cell’ within the non-PAG dump).

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Summary of Examples

Site	Material description	Comments re NAG testing
Zortman, MT	Low S, low NP weathered material	NAG test generally not indicative of field paste pH or metal leachability, not used for reclamation ‘mapping’.
Base metal mine, USA	Low S, low NP fresh material	NAG_{pH} generally agreed with NNP, where different the NNP was more conservative, useful for potential acidity prediction but generally not useful for metal leachability predictions

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Summary of Examples – cont'd

Ok Tedi, PNG	Moderate to high S, substantial limestone, fresh and transported material	Management at dump required separate measure of AP and NP, single addition NAG in river transported material inappropriate, sequential NAG required.
Various waste dumps in CO and MT	Variable S and NP contents, very weathered material	Derived relationships of NAG value with concentrations of soluble metals, allowed for 'groupings' to rank sites for reclamation, noted that NAG alone would not discriminate except for the extreme sites, required leach extraction tests as well.

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Summary of Examples – cont'd

Australian Gold Mine	Moderate S, low to moderate NP, relatively fresh material	Reviewed NAG test to substitute for %S criteria for segregation, blasthole samples and in-dump samples suggested %S very conservative, NAG would substantially reduce volume in PAG dump. Collected leachate and leach extraction results suggest SO_4 and metals increasing from seepage - recommended to stay with %S criteria

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Suggestions for guidelines

- It should be included in the guidelines, but with qualifiers:
  - Must be calibrated with other tests on a site specific basis
  - If used as tool to monitor and classify wastes during mining operations, need QA/QC testing of other calibration tests initially used
  - Can be a helpful tool for prioritizing material for reclamation
  - Should discuss implications of samples with high Cu, Pb, MnO_2 and Zn.
  - Single addition NAG tests should be checked with sequential NAG tests, in particular for samples with high NP or NetNP values ~ 0
  - Others? Estimating 'lag phase'?
- Generally not appropriate for identifying metal leaching

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Thank You

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