Tweed Shire Council
Kinnears Quarry

Report on Acid Rock Drainage (ARD) Investigations and Remedial Solutions

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Executive Summary

Kinnears Quarry is one of three (3) adjacent hard rock quarries (the other two being Singh's and Sandercock's) established in the western flank of a steep, heavily wooded ridge, formed in deeply incised terrain of hard, resistant rocks of the Neranleigh Fernvale Beds. The quarries are located at Harry's Road, off the North-Arm Numinbah Road, approximately 6km west of Murwillumbah.

Kinnears quarry has been worked as a typical hillside quarry commencing from Harry's Road (~ RL 24m AHD) and gradually working back (east) into the slope and upwards with a series of four (4) faces and benches. Within benches (and faces) 2 and 3, a narrow 5-8m wide bed or lens of naturally occurring pyrite-rich, graphitic shale is exposed and is generating low pH surface and groundwater. During and after rainfall events, the impacted (acidic) water drains and seeps down-slope through face 1 which exhibits distinctive iron oxide surface discolouration. The existing sediment ponds at the base of the quarry workings are small, shallow and can't provide sufficient retention time to treat acid rock drainage (ARD) prior to discharge.

The untreated water leaving the site is impacting on the water quality of the adjacent creek which flows through a wooded valley then across farmland joining the Rous River about 500m north of Kinnears Quarry. Testing of creek water quality indicates that un-connected Sandercock Quarry workings adjacent to Kinnears Quarry (and upstream) are also producing acid drainage. Water quality testing by Tweed Shire Council has indicated that uncontaminated creek water has a typical pH of 6.2 which falls to pH 4.1 after passage beside Sandercock's quarry and which falls again to pH 3.4 downstream of the influence of Kinnears Quarry. During and following rainfall events, the pH of the creek water can increase to 6.5 or higher because of dilution.

Bedding wise (stratigraphically), the offending potentially acid-forming (PAF) rock exposures in both the Sandercock and Kinnear quarry sites are independent of each other, but the PAF shale material encountered is not uncommon in quarries working the metasediments of the Neranleigh Fernvale beds - most often the carbonaceous shales occur as beds or lenses in conjunction with quartzites and argillites, the predominant rock types being quarried at the Harry's Rd quarry sites.

The PAF rock exposures are the most obvious source of ARD at Kinnears and the Sandercock quarry (where they appear less prevalent) but broken or crushed PAF rock material from historical activities may also be present within quarry works and stockpiles and contributing to low pH run-off. It should also be appreciated that disseminated pyrites can and often does occur throughout the general rock masses of the Neranleigh Fernvale beds, particularly within the quartzites and cherts. This is evident to at least some extent at the Harry's Rd sites. During weathering, the acid generating nature of the rock can contribute to lower ambient pH levels.

The sediment pond water at Kinnears Quarry has an average pH of around 3. Multi-element testing indicates levels of soluble metals including Al, Cu, Fe, Mn, Cd Zn, Cl and possibly Cr (depending on type) that exceed trigger thresholds for metal toxicants in the 2000 ANZECC/ARMCANZ Water Quality Guidelines (for a highly disturbed aquatic eco-system where it is intended to protect 80% of aquatic life). Untreated sediment pond water is therefore not suitable for off-site discharge because of these concentrations of dissolved metals and elevated acidity levels.

There is a hierarchy of ARD remedial control and treatment measures that can be applied to Kinnears Quarry. In general order of complexity they are:

1) minimising PAF rock exposures,
2) dilution of impacted water with uncontaminated water,
3) diversion of uncontaminated water,
4) selective handling of PAF rock and
5) encapsulation/covering of PAF material.

Control measures 1, 2 and 3 have historically been applied at Kinnears Quarry. These have reduced the quantity of water impacted by ARD and discharged from site, but not its quality.

Measures 4 and 5 involve further quarrying activity at the site. This presents a significant difficulty for Kinnears Quarry because its development approval has lapsed and DECC are pressuring for the quarry landform to be rehabilitated. The complexity and cost of gaining a new quarry approval is high and is unlikely to be justifiable unless the quarry sites were ultimately integrated under a longer-term quarry operation.

This could provide a permanent solution to minimize ARD from the combined sites but existing conflict with a particular neighbour whose amenity is impacted by the proximity of the quarries is a major impediment to renewed or expanded quarrying. Any attempt to revegetate the existing ARD affected landform is most unlikely to be successful and because the existing works are essentially self-draining, revegetation on its own does not resolve the problem of impacted surface runoff and groundwater quality.

Therefore, over the short to medium term the following remedial actions are recommended:

- Re-profiling diversion drains to further reduce the flow of uncontaminated surface water into the existing sediment ponds;
- Application of a low cost alkaline material such as the cement waste washout from concrete plants to the sediment ponds, bunds and the base of PAF rock face exposures and acid seepage points;
- Testing program to establish the efficacy of various alkaline chemical treatments on reducing metal toxicants. Without removal or encapsulation of the exposed PAF rock, ongoing chemical treatment of ARD seepage will be necessary. Modest chemical dosing plants should therefore be investigated and budgeted for;
- Subject to testing of rock, extend the sediment ponds laterally and at depth to create sufficient storage capacity to treat impacted water. A minimum two-stage pond configuration would need to allow for chemical dosing of impacted water, and recovery or storage of metal sludges which precipitate when pH is increased. These sludges require regular removal and subsequent storage/disposal;
- Investigate whether dental treatment of PAF rock exposures and shotcreting to provide and air/water seal might be effective in reducing ARD from the source rock;
- Undertake a feasibility study into future quarrying options for the site and surrounds with a view to removing PAF rock exposures through selective quarrying and encapsulation in clay/shale covers in quarry voids.

1. Introduction

1.1 Purpose

This report has been prepared by Ecoroc Pty Ltd[1] for Tweed Shire Council (TSC) to provide advice on the investigations and remedial treatment of acid rock drainage (ARD)[2] from Council's Kinnears Quarry (the project site) situated at Harry's Road, North Arm Road, approximately 10km northwest of Murwillumbah. The project site is described as Lot 1 on DP 1004207.

ARD is not uncommon in open cut metalliferous and coal mining operations when naturally occurring iron sulfide minerals (such as pyrite) are exposed to air (or water) through excavation, processing or waste disposal processes. Less commonly ARD can be associated with acid forming rocks exposed from civil construction and hard rock quarrying activities.

At Kinnears Quarry, localized naturally occurring pyritic (pyrite-rich) rock exposed by hard rock quarry workings is oxidizing to produce low pH surface and groundwater. This acid drainage is impacting on the water quality of the creek that flows beside the site. The creek water is also impacted by ARD from upstream quarry workings.

This report presents the results of geological and geochemical investigations at Kinnears Quarry undertaken in May and June 2009 to locate and characterise the source and nature of the ARD. The report also provides a summary of the results of Tweed Shire Council's water quality monitoring program and along with a consideration of current and future quarrying practices, provides advice on management options for mitigation and/or remedial treatment of ARD from the project site.

1.2 DECC Letter

By letter to TSC dated 19 March 2009, NSW Dept of Environment and Climate Change (DECC) advised it has issued a draft prevention notice requiring the Council to engage an appropriately qualified consultant to investigate and report by 30th June 2009:

- the likely causes of acid generation within Kinnears Quarry,
- the total acid generating potential of the Kinnears Quarry and surrounding lands; and
- the immediate and long-term options available for treatment and management of the source of acid generation in the quarry.

This report also responds to the DECC requests for action.

[1] Refer Appendix 5 for Ecoroc Capability Statement
[2] Referred to as Acid Mine Drainage (AMD) in the minerals industry

2. Description of Quarry Site and Surrounds

2.1 Quarry Land and Tenure Details

Site details are set out in Table 1 below. Photos 1 and 2 in the **Table of Photos** to this report show the location of the Kinnears and adjoining quarries as well as other quarry development and ARD features at the project site.

Table 1: KINNEARS QUARRY SITE DETAILS

ITEM	DESCRIPTION
Name	Kinnears Quarry
Owner	Tweed Shire Council
Operator	Tweed Shire Council
Quarry Location	Harry's Rd , North Arm, approx. 6 km west of Murwillumbah
Access	Gravel road at end of Harry's Rd, off North Arm-Numinbah Road
RP Description	Lot 1 on DP 1004207
Tenure	Freehold
Local Authority	Tweed Shire Council
Licenses and Permits	Kinnears – previous quarrying approvals have lapsed

2.2 Description of Kinnears Quarry

Kinnears Quarry is one of three (3) adjacent hard rock quarries (the other two being Singh's and Sandercock's) that have been established in the western flank of a steep, heavily wooded ridge, that has formed in deeply incised terrain of hard, resistant rocks of the Neranleigh Fernvale Beds, approximately 6km west of Murwillumbah near the North-Arm Numinbah Road.

A geological description of the site with a focus on the sources of ARD from Kinnears Quarry has been prepared for Ecoroc by geoscientist Gary Basford from Geobas Consulting Pty Ltd. The Geobas report is included as **Appendix 1: Geological Assessment and Quarry Development Report**. The findings of the Geobas report, along with its reference numbering of faces and benches, have been applied in this report.

The dominant rock type being quarried on the project site is quartzite. The quartzite deposit has been worked to its current development profile as a typical hillside quarry commencing from Harry's Road (~ RL 24m AHD) and gradually working back (east) into the slope and upwards with a series of four (4) faces and benches. Bench 4 is at RL 58m AHD with the top of

face 4 at RL 68m AHD. Two small sediment ponds are established at the base of the workings. Detailed descriptions and photos of these quarry features are included in the **Table of Photos** of this report and the Geobas report in Appendix 1.

Kinnears Quarry has been intermittently worked by the Tweed Shire Council as a source of road gravels and drainage aggregates over many decades. No processing plant is stationed on site and there is limited room for processing and stockpiling of materials.

In some years the quarry has produced up to 20,000 tonnes of roadbase materials during quarrying and crushing campaigns. In other years it has been largely inactive, as it is at present.

A section of the quarry workings (bench 2) is used to gain access to Singh's quarry (worked by TSC) which is established on the ridgeline immediately above the Kinnears quarry. Singh's quarry is being worked by top down extraction using the receding rimline method to minimise visual and environmental amenity impacts. Large resources of quartzite and associated meta-sediments remain in the wider extractive precinct of the Kinnears and Singh's quarries.

In a localized section of the older benched quarry workings of Kinnears Quarry a discrete yet highly jointed lense or 'pod' of pyritic carbonaceous shale is exposed across at least two faces and benches (refer photos 5-8 in Table of Photos).

Exposure of this material is not uncommon in quarries in South East Queensland and Northern NSW that work quartzite deposits of the Neranleigh Fernvale beds. After exposure and in the presence of air and water the pyrite oxidizes to generate acid rock drainage. Similar acid rock geology though less evident, occurs at the Sandercock quarry, adjacent to and upstream of the Kinnears Quarry.

2.3 Drainage from the Project Site

Stormwater runoff from undisturbed land within the steep and wooded Kinnears quarry site flows in a westerly direction into an un-named creek. The creek flows in a northerly direction besides Harry's Rd crossing under the North Arm Rd and flowing ultimately into the Rous River.

Within disturbed areas, water impacted by acid rock drainage from surface workings (and groundwater seepage) is presently directed via surface channels and contours to two shallow sediment ponds established at the base of quarry workings beside Harry's Rd (refer photos 9 and 10 in Table of Photos).

Overflow from this system reports, via a pipe under Harry's Rd, to the un-named creek. The creek is formed in the 'V' between two steep adjacent ridgelines. The ridgeline to the east hosts Singh's quarry whilst the ridgeline to the west hosts rural land including a rural residence. The drainage line that forms the un-named creek originates several hundred metres upstream of the Kinnears Quarry in cleared pasture land. It then flows through the western edge of Sandercock Quarry and thence past Kinnears Quarry. The un-named creek has its confluence with the Rous River approximately 500m downstream (north) of the project site (refer photos 12 to 15 in Table of Photos).

The current sediment ponds at the base of the quarry workings are small and shallow and of insufficient capacity to contain and treat the acid rock drainage. During rainfall events acid drainage from the site therefore overflows via the under-road pipe into the un-named creek.

TSC have undertaken water quality monitoring of the project site and the un-named creek. Summarised data for the period 2007 to 2009 for both upstream and downstream locations is set out in **Appendix 2,** Table 2. The implications of these results for ARD management are discussed in section 4 of this report.

2.4 Surrounding Land Uses

In valley and lowland areas, rural pursuits such as cattle grazing occur both upstream and downstream of the project site.

Kinnears Quarry is well buffered to the north, south and east by adjoining quarry or buffer lands but like its neighbouring quarries has a rural residential neighbour to the west who is impacted by noise and dust from quarrying operations. Figure 1 in **Appendix 1** is an aerial photo showing details of Kinnears quarry and its surrounding property boundaries.

For the project site, Harry's Road forms the western property boundary. Sandercock Quarry and an unformed road reserve adjoin the project site to the south. Singh's Quarry (Lot 2 on DP 772166) adjoins the project site to the east. TSC own another parcel of undeveloped land immediately to the southeast.

The northern part of the project site consists of wooded steep land with a westerly aspect through which an access road has been cut to gain access to the elevated Singh's Quarry workings immediately to the east. The northern boundary of the quarry adjoins a rural residential property.

Two rural residential properties to the west are situated on an adjacent ridge system. The closest and least topographically shielded from quarry workings is sited in an elevated position approximately 150m east of Harry's Rd and almost within line of sight of the Sandercock Quarry. The occupants of this house have been a significant source of noise and dust complaints triggered by the extraction, hauling and processing of quarry materials from the nearby quarries.

Kinnears is not worked because no current approval is held. The adjoining Sandercock Quarry is worked on an intermittent basis by the Sandercock family. Singh's Quarry is worked by TSC in accordance with approval conditions and to mitigate against ongoing complaints.

3. Geological & Geochemical Investigations

3.1 Geological and Quarry Development Investigations

Similar exposures of pyrite-rich carbonaceous shales to those exposed in faces 2 and 3 of Kinnears Quarry are known to produce acid rock drainage from other quarries in the Neranleigh Fernvale beds.

These exposures are discrete rather than pervasive and this seems to be the case at the project site where there is obvious evidence of acid drainage from an exposed bed of carbonaceous shale (sulphidic smell, low pH runoff, iron staining and iron floc in impacted waters.)

To further assess these exposures and conduct additional geological reconnaissance, Ecoroc engaged Gary Basford from Geobas Consulting to:

- Describe the regional geology, topography and site geology;
- Comment on the rock types exposed in the quarry workings with a focus on the occurrence of the carbonaceous shale and its potential to generate acid drainage; &
- Include a consideration of future quarry development options that might assist with the long-term mitigation of ARD from the project site.

These findings are set out in the report by Geobas Consulting in **Appendix 1: Geological Assessment and Quarry Development Report**.

Figure 1 in Appendix 1 shows the site layout for Kinnears Quarry and surrounding quarries. Figure 2 in Appendix 1 is a cross section through a section of the quarry showing the inferred location of the carbonaceous shale bed and a conceptual future pit development outline.

The principal observations and comments from the Geobas report are summarized below.

Site Geology

- The quartzites are structurally complex because of bedding, folding, faulting and cleavage features but can generally be described as consisting of well-developed thin bedding with a northerly strike direction and westerly dipping bedding planes at moderate to high angles. Occasional low angle bedding/cleavage dips in sympathy with localized folding.
- Because of the dominance of quartzite (a hard resistant rock), rock weathering is shallow with limited soil development.
- As evidenced at both Kinnears and Sandercocks quarries, the bedding planes of the quartzite are at times disrupted with local faulting and shearing and local, minor tighter folding. The rock mass is fractured with close to medium joint defect spacing with the main fracture orientation following the bedding within the rock. Other superimposed joint sets cause the blocky nature of the quartzites.
- Fracturing leads to intense iron staining (shades of yellow, brown, orange and red) with the mottled more fractured quartzites often superior (for use as aggregate) to the un-

stained blue-dark grey quartzites and cherts where active clay traces may still exist along joint planes and microfractures.

Carbonaceous Shale Exposures and Acid Rock Drainage

- These materials occur in the Neranleigh-Fernvale beds often as lenses, pods or discrete beds consisting of black, soft graphitic clay often heavily mineralized with finely disseminated sulphides (predominantly iron pyrites). They originate from highly organic muds deposited (in Upper Devonian to Carboniferous times) under anaerobic conditions in layers or infilling depressions within coarser sandier marine sediments, thus explaining their discontinuous nature.
- At Kinnears Quarry a significant 'bed' of pyrite-rich carbonaceous shale, nominally 5 to 8m wide and exposed in faces 2 and 3 (and their associated benches) occurs as a south-westerly and outwardly dipping stratum of medium dip angle and is a major contributor to the ARD from the quarry – both through contamination of surface water and the potentially more serious longer-term groundwater seepage. Groundwater seepage from face 1 requires treatment/controls as it receives the acidic groundwater from the rearward faces.
- Samples of potentially acid-forming (PAF) rock were visually identified and taken from face 2 (Samples 2A and 2B) and face 3 (samples 3A and 3B) for further geochemical testing by others (For sample locations, refer Figure 1 of the Geobas report in Appendix 1).
- From site observations, no other PAF carbonaceous shales appeared to be outcropping at Kinnears quarry workings but other beds or lenses of this material could occur within the wider rock mass. The lateral extent of the problematic bed or lense is not known because of folding, shearing and a flanking fault. A similar but structurally unrelated bed or lens of potentially acid forming pyrite-rich carbonaceous shale occurs at Sandercock quarry which also presents similar water quality risks.
- It should be noted that disseminated pyrites can and often does occur throughout the general rock masses of the Neranleigh Fernvale beds, particularly within the quartzites and cherts. During weathering, this acid generating nature of the rock can contribute to a lower ambient pH of groundwater.

Future Quarry Development Options

These can assist in providing longer-term ARD mitigation solutions for the project site and surrounding quarry sites.

- Large resources of quartzite and argillite materials potentially occur over a wider north-south area in the Kinnears quarry land. These resources could be quarried via multiple benches including additional development below the present workings which would allow larger and more effective sediment ponds to be created.
- If Sandercock quarry which is close to depletion were purchased then the land separating the two quarries could also be quarried adding to reserves. Dropcuts in the floor of Sandercock quarry could also provide further ARD mitigation options for

treatment of ARD and storage/ encapsulation of any high PAF rock that was encountered during quarrying.

- Provided environmental amenity issues with neighbours can be managed, the Sandercock quarry presents an ideal location for crushing, screening and stockpiling of quarry products from the combined development.
- An integrated development of the quarry resources could also include the Singh quarry and part of the undeveloped Council owned land situated to the southeast of the project site. This development would use a receding rimline quarrying method to minimise visual and environmental amenity impacts and could assimilate ARD remedial measures and controls into the quarry development.

3.2 Geochemical Characteristics & Acidity Potential of PAF Rock Exposures

At the Kinnears Quarry the potentially acid forming (PAF) carbonaceous shale materials account of only a small percentage of total rock exposures. Despite their relatively small exposure (probably less than 5% of excavated surfaces), in the presence of air and water the sulfides decompose to release sulfuric acid and soluble metals. Aside from its corrosive impact on equipment and steel/concrete infrastructure, acid drainage if not appropriately managed and remedially treated can degrade water quality and if released without appropriate treatment can damage aquatic ecosystems.

Following geological reconnaissance during site inspection, potentially acid forming (PAF) source rocks outcropping in faces 2 and 3 of the Kinnears quarry have been identified, sampled and subsequently tested in the laboratory to determine their net acid forming potential. The location of the sampling sites is shown in Figure 1 of the Geobas report in Appendix 1. The PAF rock samples taken from different benches are from within the same bed or lens of carbonaceous shale.

Testing of the acid-base chemistry of the PAF rock samples and their net acid generating potential was undertaken by Tweed Laboratory Centre using the ACMER guidelines for management of sulfidic mine wastes and acid drainage[3].

This technical guideline and its supporting documents provide an ARD rock characterisation and risk assessment framework for acid mine (or rock) drainage which is applicable to the site. The ACMER publications and reports are widely used by the minerals industry to guide ARD management.

The results of the tests to determine the acid generating potential of suspected PAF rock samples are set out in **Appendix 2: Table 1-NAG Test Results for Rock Samples from Kinnears Quarry**.

The rocks are assessed against the risk of producing acid drainage and unacceptable water quality from rock or rock waste materials, according to one of five categories as shown in Table 2 below.

[3] ACMER (1999) Management of Sulfidic Mine Wastes and Acid Drainage, Australian Center for Mining Environmental Research (ACMER), University of Queensland

Table 2: ARD RISK ASSESSMENT FOR ROCK AND REJECT MATERIALS

Category	Acronym	Probability that exposure will result in unacceptable water quality
Acid-Consuming Material, non-sulfidic	ACM	Very low risk
Non-Acid Forming, Low Sulfur	NAF-LS	Low to moderate risk
Non-Acid Forming, High Sulfur	NAF-HS	Moderate risk
Potentially Acid Forming – Low Capacity	PAF-LC	Moderate risk
Potentially Acid Forming – High Capacity	PAF-HC	High risk

The test results in Appendix 2.1 confirm that the carbonaceous clay-shale from Face 3/ Bench 3 (Sample 3B) is PAF-HC and poses a high water quality risk. The adjoining quartzite (Sample 3A) was NAF-LS and poses a low to moderate risk to water quality.

Both the quartzite and the carbonaceous shale samples from Face 2/ Bench 2 are classified as PAF-LC indicating an acid generating capacity, albeit lower than the PAF-HC material. These PAF-LC materials therefore present a moderate risk to water quality.

Almost all the PAF rock exposures occurring in the terminal benches of quarries in rocks of the Neranleigh - Fernvale beds are legacies of historical quarrying practices where the acid drainage threat was not widely understood or appreciated. Because the materials encountered are weak, friable and frequently unsuitable for making good quality quarry products, quarries that encountered such rocks often stopped development there, leaving the PAF material exposed to air and water. When such exposures persist in faces or benches they can be difficult to treat. This is the situation at Kinnears quarry, though because the PAF rock exposures are small, there is scope to mitigate ARD through treatment and future quarry development.

3.3 Quarried and Waste Materials

Quarries with known PAF rocks have historically disposed of any incidental material removed as part of the quarry development by blending it with non PAF rock, which constitutes the vast majority of the rock mass being quarried. In larger quarries, void space has also been used to encapsulate and contain unearthed PAF materials, using both wet and dry methods.

Where the ARD threat is not understood, PAF rock can be dispersed around the quarry in fill, in product stockpiles and sometimes as roadbase materials on haul roads or in bund walls. This adds to the ARD problem by allowing PAF rock more opportunity for oxidation and acid generation.

When dispersed in quarry infrastructure, these materials can be difficult to detect. Whilst there are no known stockpiles of waste PAF material at either the Kinnears or Sandercock quarry sites, some ARD from PAF material being dispersed around the quarry is likely to exist.

4 Water Quality Monitoring

4.1 TSC Monitoring Program

Tweed Shire Council has been conducting quarterly water quality sampling (and some event monitoring) from several sites along the un-named creek as well as the sediment ponds within Kinnears Quarry. These monitoring locations are shown below in **Figure 1: Water Quality Monitoring Locations**.

The averaged data from the monitoring sites for the period 2007 to 2009 is set out in **Appendix 2: Table 2 - Water Quality Test results**. Five (5) parameters have been consistently monitored: pH, electrical conductivity (EC), suspended solids, chloride, sulphur as sulphate and total iron.

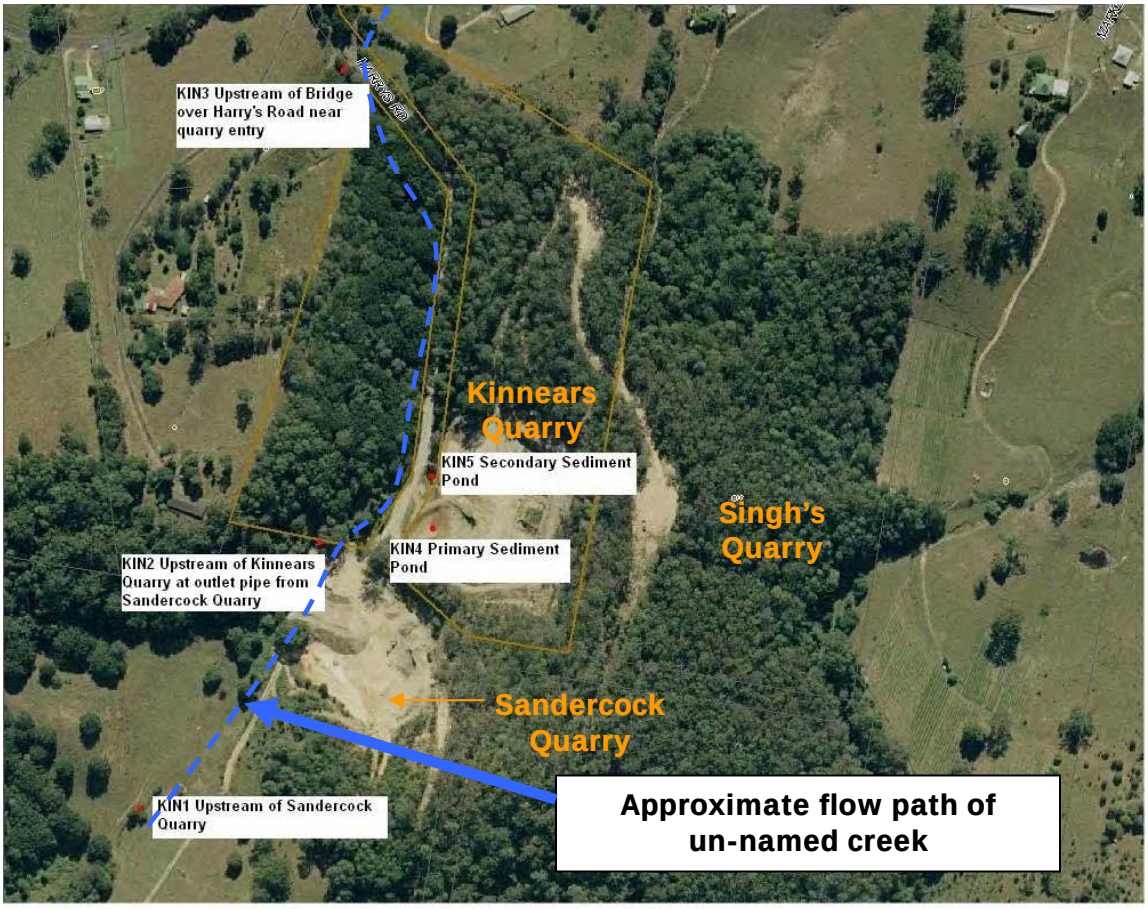

Figure 1: Water Quality Monitoring Locations

The average pH and electrical conductivity results for these 5 monitoring locations (KIN 1 to KIN 5) are shown in Figures 2 and 3 below.

For the un-named creek, the monitoring results show a progressive lowering of pH as the water flows past the two quarries. Upstream of Sandercock's Quarry on pasture land the water has a pH of 6.2. This reduces to 4.1 after the creek water leaves the Sandercock Quarry (SQ) site and

drops again to pH 3.4 downstream of the Kinnears Quarry (KQ). The pH of the ARD water in the Kinnears Quarry sediment ponds averages about 3 (refer photos 10 and 11 in Table of Photos).

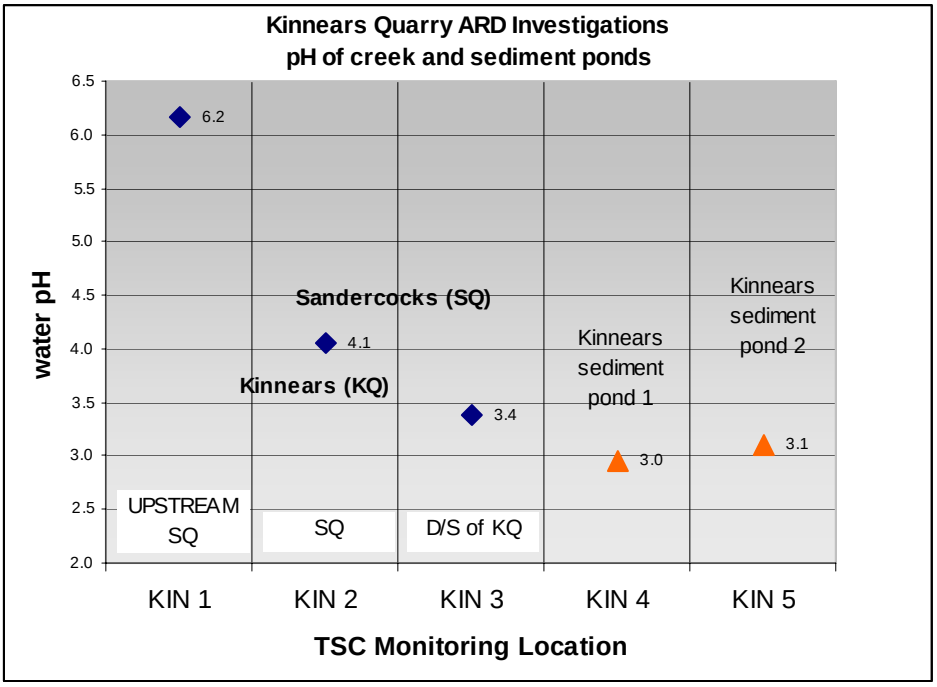

Figure 2: Average pH of creek and sediment ponds

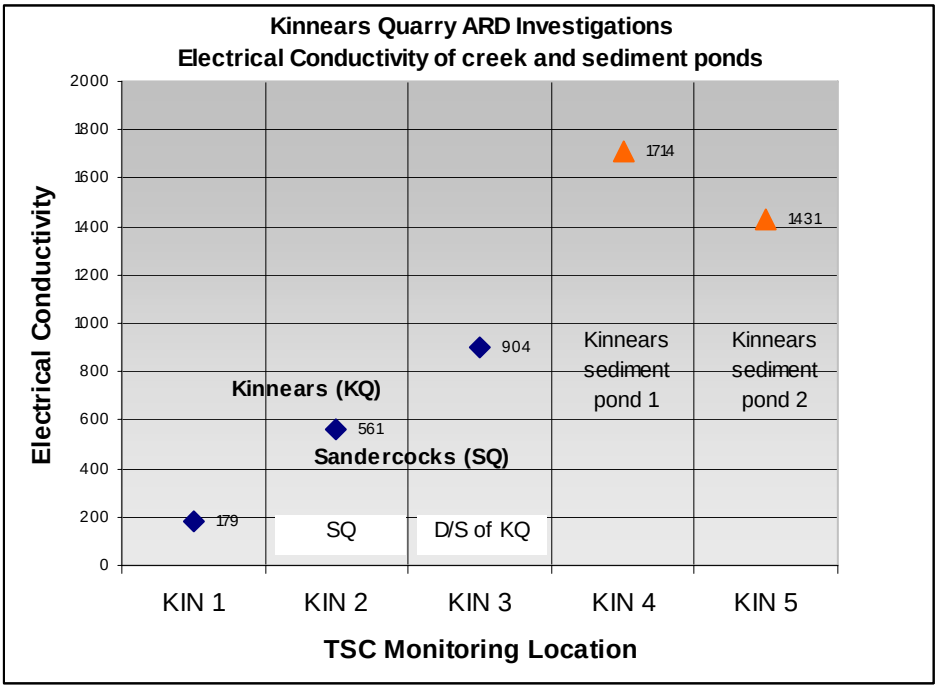

Figure 3: Average EC of creek and sediment ponds

The water quality data in Figures 2 and 3 supports the view that both quarries are producing acid drainage and contributing to the impairment of water quality in the un-named creek.

The PAF rock exposures at Kinnears Quarry are more obvious than at Sandercock's and in both cases there is little scope within current works to contain contaminated water.

4.2 Water Quality of Sediment Ponds – Multi-Element Analysis & Receiving Environment

The un-named creek that receives the overflow water from the quarry sediment ponds is classified as an 'uncontrolled stream' under the NSW Water Quality and River Flow Objectives for the Tweed River Catchment, May 2006[4].

It can be described as a moderately to highly disturbed system arising from agricultural (weirs, livestock) and quarrying activities. This includes a likely legacy of receiving low pH flows from the quarry workings. Environmental values for the creek would include supporting a modified aquatic eco-system, ability to support associated wildlife, secondary contact & visual recreation, irrigating crops and watering stock.

Water sampled on the 18th May 2009 from both the primary and secondary sediment ponds at Kinnears Quarry was tested by Tweed Shire Laboratories for concentrations of soluble elements as part of a multi-element analysis. The results are tabulated Appendix 2: Table 3 Multi-Element Analysis of Sediment Pond Water.

The data indicate that both ponds have similar water chemistry and are strongly acidic and quite saline. The pond water which consists primarily of groundwater seepage (and contaminated surface water run-off from rainfall events) from the PAF shale exposed in benches (and faces) 2 and 3 (above to the east) contains elevated concentrations of sulfates and dissolved metals (Al, Cu, Fe, Mn and Cd). These levels are greater than the trigger levels recommended in Australian surface water (ANZECC) and groundwater (NEPM) guidelines related to livestock drinking water.

In terms of the 2000 ANZECC/ARMCANZ Water Quality Guidelines, the eco-system type for the receiving environment for the ARD is 'uplands rivers and streams'. In addition to the above-mentioned elements, the pond water also triggers values in the ANZECC 2000 guidelines for metal toxicants in highly disturbed systems (i.e. intended to protect 80% of aquatic life in the highly disturbed aquatic eco-system) for the metals Zn and possibly Cr (depending on type).

Untreated sediment pond water is therefore not suitable for off-site discharge because of these concentrations of dissolved metals and elevated acidity levels.

[4] Refer References

5. ARD Remedial Solutions

5.1 Introduction

Best practice environmental management of ARD involves the early characterization and classification of the acid generating potential of materials, the development of strategies to minimize the oxidation of sulfides and where acid drainage is unavoidable, the implementation of suitable short-term and long-term control and treatment options. ARD should be operationally managed to minimize any environmental risk after mine closure.

Once rocks with acid generating potential are exposed, successful approaches to limit acid rock drainage basically comprise:

- Limit the exposure of the acid rock to air;
- Limit the exposure of the acid rock to flowing water.

5.2 ARD Management Options

The choice of single or multiple control techniques is site specific and the success of measures can vary considerably. Important factors that can influence the choice of a remedial solution for the Kinnears Quarry are summarized in the following table:

Table 3: ARD MANAGEMENT OPTIONS FOR KINNEARS QUARRY

INFLUENCING FACTOR ON ARD CONTROL CHOICE	KINNEARS QUARRY COMMENTS
Nature and extent of current and potential acid drainage problems (sulfide content, type, distribution, reactivity)	PAF rock exposure is a bed of graphitic shale with disseminated pyrite, 5-8m wide, dipping SW in faces and benches 2 and 3; probably a lens; sheared and fractured; similar geology in U/S quarry as well; potential for loose PAF around site
The sensitivity of the receiving environment (environmental values and risk)	The un-named creek has a slightly to moderately disturbed ecosystem from human activities including a likely legacy of receiving low pH flows from the quarry workings. Environmental values for the un-named creek may include supporting a modified aquatic eco-system, ability to support associated wildlife, secondary contact & visual recreation, irrigating crops and watering stock.
Existing natural amelioration factors (such as high river flows, alkaline water, natural wetlands)	The creek is incised into a deep gully and so high intensity rainfall events which are common on a seasonal basis tend to flush the pond and downstream drainage system, diluting the low pH water. After rain, creek pH can rise to over 6.5. At the Harry's Road crossing the creek flows into a pasture/wetlands area. Some iron floc. is trapped by water weed.
The regulatory regime (water quality discharge standards, compliance requirements)	ANZECC/ARCANZ 2000 Water Quality Guidelines; Suggest as reference: A Guide to the Application of the ANZECC/ARMCANZ Water Quality Guidelines, ACMER, September 2003.
Climate (local hydrology, site water balance)	Coastal region of Northern NSW - relatively high rainfall; no site water balance has been conducted
Site logistics (terrain, water storage and retention capability, availability of space)	Existing sediment ponds at base of workings and below PAF rock are in the correct location but are too small to retain anything other than seepage flows – after rain they overflow via pipe; ponds contain the same water type- insufficient room or infrastructure for alkaline amendment (lime treatment) of contaminated water; no storage capability for any metal sludges derived from future lime treatment
Local natural or waste resources suitable as control and treatment measures	Local rock types are not likely sources of alkaline material; hydrated lime or other limestone products available from Unimin (Warwick) but relatively expensive; cement washout from agitators can be useful for ARD control, but regulatory approval to use the waste at the quarry may be required.
Post Extractive End Use	No specific plans - longer-term quarrying plans are uncertain. Likely rehabilitation would include revegetation of benches and disturbed areas with local provenance species but there are minimal stocks of topsoil; Kinnears quarry has no development approval as it has lapsed. Large resources of quartzite and argillite materials remain within the extractive precinct occupied by the Kinnears and Singh's quarries – if these quarries were joined (and perhaps the Sandercock quarry) the present PAF rock could be removed as part of future quarrying. Future quarrying on a prolonged basis is only possible if amenity issues with rural residential neighbour can be resolved.
Community and stakeholder expectations	DECC would like to see TSC rehabilitate the Kinnears quarry site. In terms of the present hillside quarry and its ARD problems, from a water quality management perspective some further excavation activities to create sufficient pond space for treatment of contaminated water is recommended. Bench 2 of the quarry site also provides access to Singh's quarry above. The stability of upper benches would also need evaluating – it may in fact be more effective if the Singh and Kinnear quarries were allowed to join to remove the steep upper faces. Neighbour impacted by dust and noise problems wants quarrying to cease. Sandercock family wants to work their existing deposit until exhausted, which realistically is within a few years (depending on sales). The Sandercock quarry will leave a very high, relatively unstable eastern highwall.

The review of management options in Table 3 suggests there are two basic courses of action for TSC:

i) over the immediate to shorter term, treating contaminated water and attempting to limit the existing PAF exposures at the quarry and

ii) over the longer term expanding quarry workings and selectively quarrying and storing high PAF material within an integrated quarry development.

In the shorter term, the quarry could construct larger pond storage areas for receipt and treatment of acidic water at the base of existing workings and remove and/or cover or neutralise as far as is practical the existing PAF rock exposures in faces 2 and 3 (and where possible their respective benches). Remedial chemical treatment of low pH seepage and contaminated surface water with lime or other alkaline materials would be required. The efficacy of these measures in improving the water quality of the creek's downstream waters is less certain because of other likely sources of ARD contamination from the Sandercock quarry site and perhaps from loose PAF rock and fill within the quarries. Some diversion of uncontaminated surface waters to minimize the volume of ARD flow from the site and remedial 'housekeeping' to remove obvious PAF rock materials would also be undertaken. These remedial measures and a recommended hierarchy of controls are discussed in section 5.3 of this report.

With the right infrastructure and dosing regimes, ongoing chemical dosing of contaminated waters with pulverized limestone ($CaCO_3$), hydrated lime ($Ca(OH)_2$)), soda lime ($Na_2 CO_3$) or quicklime (CaO) can be effective but costly and it is important that the chemical method used is appropriately tested and costed, prior to adoption. Metal sludges are also generated from chemical treatment to elevate pH and the sludges require ongoing removal from ponds and subsequent disposal.

Appendix 3: Overview of Acid Mine Drainage Treatment with Chemicals provides a useful technical summary of the practical measures used to chemically treat AMD from coal mine sources in West Virginia USA, where AMD from coal and other mines is a significant environmental problem. The paper provides some useful discussion on treatment methods and comparative costs (the costings themselves being outdated).

Over the longer-term the option to integrate the Kinnears quarry development into the Singh's (and possibly the Sandercock) quarry sites and in the course of quarrying remove and encapsulate on site any high PAF material incidentally encountered, should not be discounted. This provides for the formation of a post extractive landform and ARD mitigation solutions such as selective quarrying and strategic re-burial, that can act to dramatically reduce the long-term cost of ARD chemical treatment.

The difficulty for the Kinnears site is that there are no current quarrying approvals and furthermore that the proximity and record of environmental amenity-related complaint from the rural residence on the adjoining ridgeline would make an approval for integrated quarry approval difficult. The decision to proceed with an application for integrated quarry development would also require sub-surface geological assessment of rock types and given the likely costs would also need to be justified in terms of sales quantities from the quarry. Realistically this scenario would require that TSC control both the Sandercock quarry land and the adjoining impacted rural residential property as well as the Kinnears and Singh quarry sites.

5.3 ARD Control Techniques

Techniques that are commonly used to minimize and control acid drainage before treatment with chemicals are discussed below in the context of the Kinnears site:

Table 4: ARD MINIMISATION AND CONTROL TECHNIQUES FOR KINNEARS QUARRY

ARD Control or Treatment Solution	Description	Efficacy of Use at Kinnears Quarry
Minimise PAF rock exposure	▪ Geological assessment and methods of mining/quarrying to reduce exposure or oxidizing potential of exposed PAF materials	Relevant if further geological investigation and subsequent integrated quarry development occurs; if no further quarrying occurs, then other control measures discussed below are needed.
Dilution	▪ Discharge of acid drainage into a local waterway with relatively high flows is sometimes regarded as a suitable control measure provided there are no detrimental impacts on the environmental values of the receiving or downstream environment; ▪ Strictly dependent upon local hydrological factors, environmental values, relative locations of discharge and compliance points	Not considered a viable, single ongoing solution for the low pH water in sediment ponds, given the environmental values of the creek and downstream waters. In practice, dilution with creek flows is the only presently available method for ARD treatment from the site. During periods of heavy rainfall, any containment system that could be constructed by expanding and deepening the existing sediment ponds would be expected to inundate and overflow, so dilution during high rainfall events is likely to remain part of the suite of ARD remediation methods, albeit it is unlikely to be sufficient to prevent harm to the aquatic eco-system of the creek. Chemical testing and biological assessment of downstream creek waters (at say Kin 3) would be necessary to determine the effectiveness of this method.
Diversion	▪ Fundamental control method; ▪ Divert unimpacted runoff away from acidic materials and acidic water; ▪ Concept is to minimize the volume of acidic water generated;	Whilst there are some existing drainage controls at the site to divert surface water flows from NAF materials away from the sediment ponds, further improvements to diversion controls are recommended. This remains one of the cheapest and most effective methods to minimize the amount of water to be treated. Improvements include profiling of benches and existing diversion drains to divert uncontaminated water,
Containment and evaporative discharge	▪ Containment of the water for internal processes and use is recommended; ▪ Evaporative disposal is suitable only in drier climates;	Neither present as particularly viable solutions for shorter term remediation of ARD. There are no quarrying processes currently occurring on site and the climate and rainfall is not conducive to evaporative discharge. During dry periods, the ARD seepage is confined to relatively small flows of groundwater seepage and minor quantities of remobilized surface water and the sediment ponds do dry up. But the method is not controllable in rain conditions.

ARD Control or Treatment Solution	Description	Efficacy of Use at Kinnears Quarry
Selective handling (Segregation; waste blending)	▪ Store or locate waste rock to minimize the generation of acid; ▪ Usually involves handling and placing the waste rock to limit its exposure to air and water; ▪ Can involve the blending or mixing of acid producing and acid neutralizing waste to minimize acid release	PAF materials in the exposed rock faces are relatively easy to identify and occur in a discrete lens. Low PAF or NAF (non-acid forming) materials from the quartzite and shale beds can be selectively quarried and blended as required. Selective handling and subsequent encapsulation of high PAF materials is a primary control method under a future quarry development scenario.
Encapsulation or covers	▪ Range from simple clay barriers to complex, composite multi-layer, organic bearing covers	Under the future quarry development scenario, high PAF material (typically the pyritic carbonaceous shale material from the discrete lens) would be encapsulated in a clay lined void constructed within the quarry workings. The are of encapsulation would be selected having regard to host rock type and the degree of fracturing and jointing. Clay and argillaceous materials that could be used to enclose the high PAF material are apparent at the Singh's and Sandercock quarries. If exposed benches at Kinnears were to remain as they are here is a scope to attempt to seal the exposures with an impregnated clay material and shotcrete. In essence, loose, friable high PAF material would be carefully removed from the PAF rock face exposures (faces 1 and 2) and shotcrete to provide an air and water seal could be applied. The effectiveness of this measure would rely on sealing or controlling ingress from uncontaminated surface water and the extent to which PAF exposures in benches 2 and 3 are sealed by their current roadbase cover from air and water ingress. Some dental treatment using a reactive alkaline material could be applied with this technique. ARD seepages with some initial alkaline amendment from the reactive cover, would continue to flow to the treatment ponds.
Sub aqueous deposition of waste (submergence)	▪ PAF materials are largely unreactive when stored underwater due to reduced availability of oxygen	This is possible if a permanent water body were to be established within the quarry workings. At this stage, selective handling and encapsulation in a clay/shale cover is probably the most viable long-term strategic re-burial option.

5.4 Recommended ARD Controls and Treatment at Kinnears Quarry

Table 4 sets out the various control techniques available and their pros and cons for use at the Kinnears Quarry site.

To date the ARD management and control emphasis at the site has been to avoid extracting and exposing more PAF material, diverting surface water away from the potentially acid forming carbonaceous shale exposure, and reliance on dilution of low pH water with higher pH receiving waters to mitigate adverse ARD effects.

In addition to these controls, it is recommended that the following sequence of additional ARD mitigation controls be generally adopted. These controls are superimposed on the Site Layout from figure 1 of the Geobas report (Refer **Figure 4: Recommended ARD Controls**).

The recommended controls (shown on Figure 4) are listed below in order of approximate ease of implementation and cost.

1. Re-profile diversion drains to minimize the flow of uncontaminated surface water into the existing sediment ponds; during this stage attempt to recover any obviously PAF rock which might have become scattered in the workings.

2. Application of a low cost alkaline material such as the cement waste washout from concrete plants to the base around the PAF rock face exposures at faces 2 and 3. Also use this material to form a low bund wall around known ARD seepage points and the two sediment dams.

3. Monitor water quality in sediment ponds before and after these initial treatments are implemented. Conduct laboratory testing of sediment pond water and receiving waters in creek to establish the efficacy of various alkaline chemical treatments of impacted water on the quality of the creek water. Estimates of flow rates and dosage rates of impacted water can then be made. A hydrology model would be required for the quarry. The cost benefit implications of various chemical treatment options can then be assessed. Some ongoing chemical treatment of ARD seepage is likely, so modest dosing plants should be considered at this stage.

4. Conduct sub-surface drilling and testing of drill samples to establish geochemistry of rock mass underlying the existing sediment ponds. If rock is NAF (to low PAF) then extend the sediment ponds laterally and at depth to create sufficient storage capacity to treat impacted water. The pond configuration would allow for chemical dosing of impacted water, and recovery or storage of metal sludges which precipitate when pH is increased. The rock recovered from excavation of the ponds could be used by TSC for quarry products.

5. Extend the sediment ponds with drill and blast operations. A new primary and secondary pond configuration would be created to allow chemical treatment and sludge recovery.

6. Option - the existing PAF rock exposures in faces 2 and 3 could be dug out to a depth of say 2m if possible (dental treatment) and infilled with an alkaline material and clay cover. The treated area and immediate surrounds could then be shotcreted to provide an airseal against future oxidation from air. Whether this measure would alleviate existing ARD groundwater flows is less likely and it doesn't provide any protection to PAF material that might be exposed in the benches and covered by roadbase, but if incident surface water flows over the PAF rock exposures are a major contributing factor in the ARD, then shotcreting might be effective in reducing long-term water treatment costs.

7. Once the more immediate ARD controls are in place and being monitored, undertake a feasibility study into future quarrying options for the site and surrounds with a view to removing PAF rock exposures through selective quarrying and encapsulation in clay/shale covers in quarry voids.

8. The timing and form of the post-extractive landform can then be determined having regard to the costs and benefits of the various ARD mitigation options.

9. We also recommend that after treatment recommendations i) to iii) that TSC officers responsible for the ARD operational and environmental management visit some other quarry sites who are managing similar ARD problems. These site visits can be arranged with other quarry operators who are willing to share their practical ARD remediation solutions.

10. In the implementation of the ARD control and mitigation recommendations we suggest TSC make reference to the ACMER (2003) Guide to the Application of the ANZECC/ARMCANZ Water Quality Guidelines in the Minerals Industry, Australian Centre for Mining Environmental Research.

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July 2009

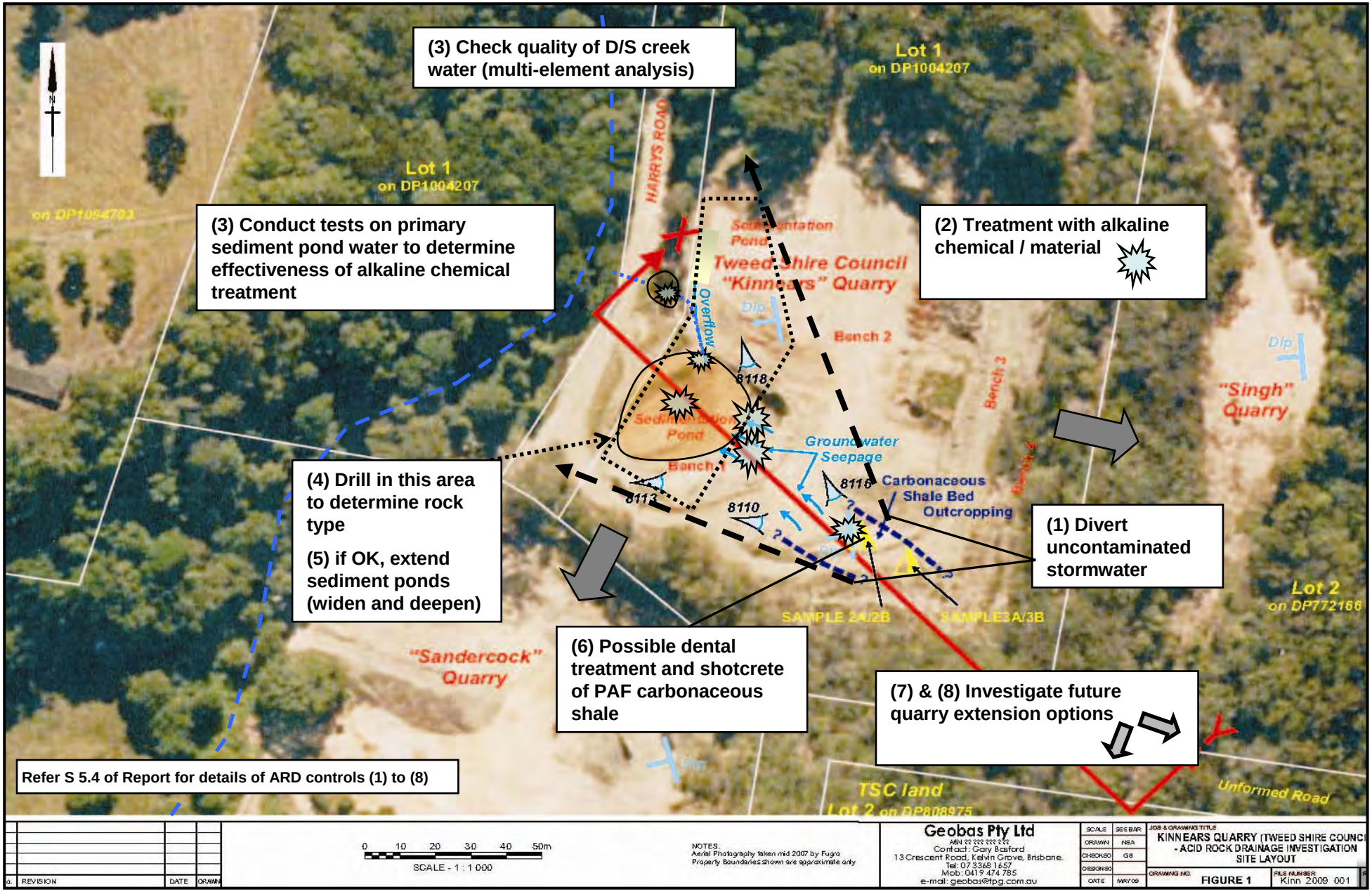


Figure 4: Recommended ARD Controls from Ecoroc ARD Report July 2009

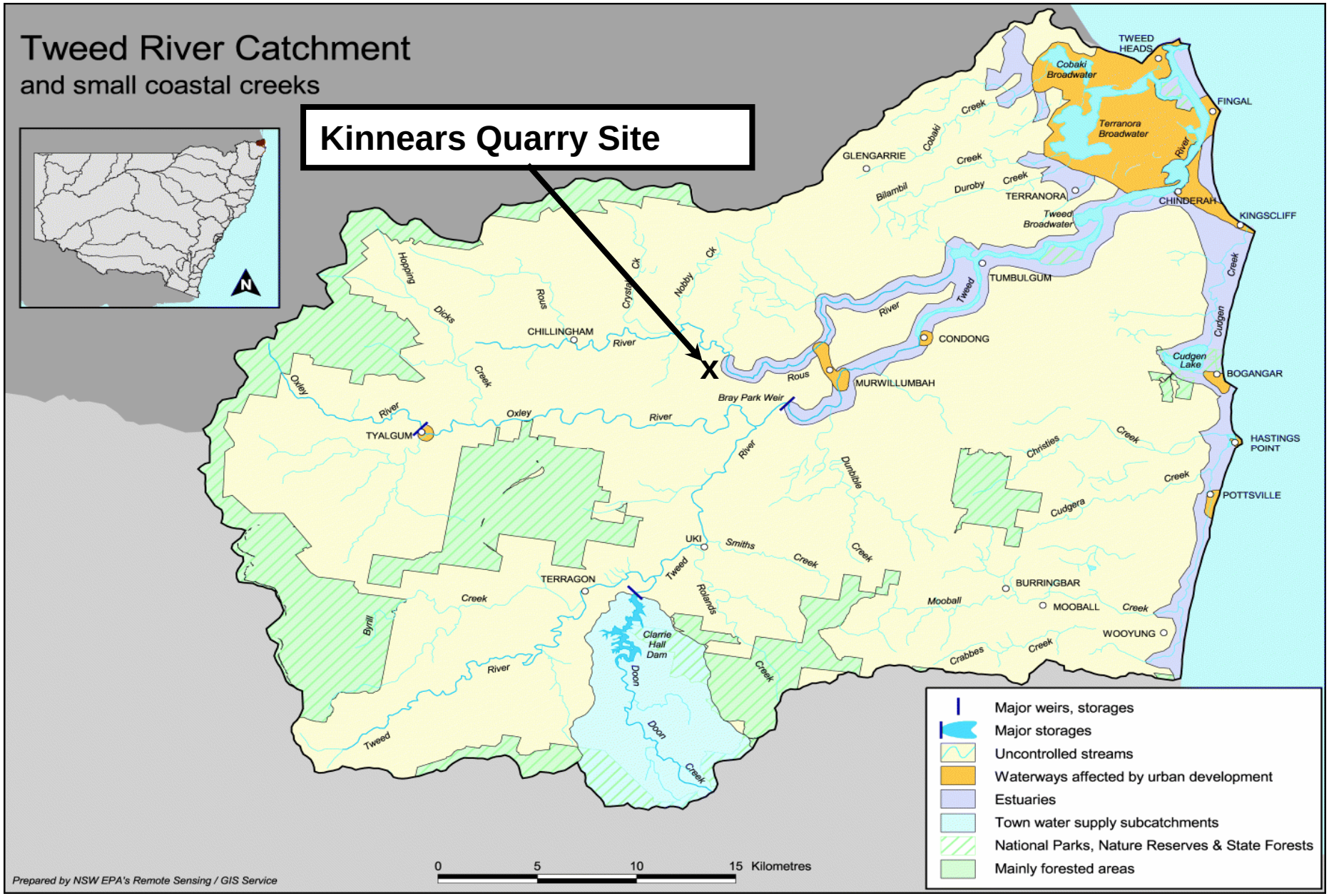
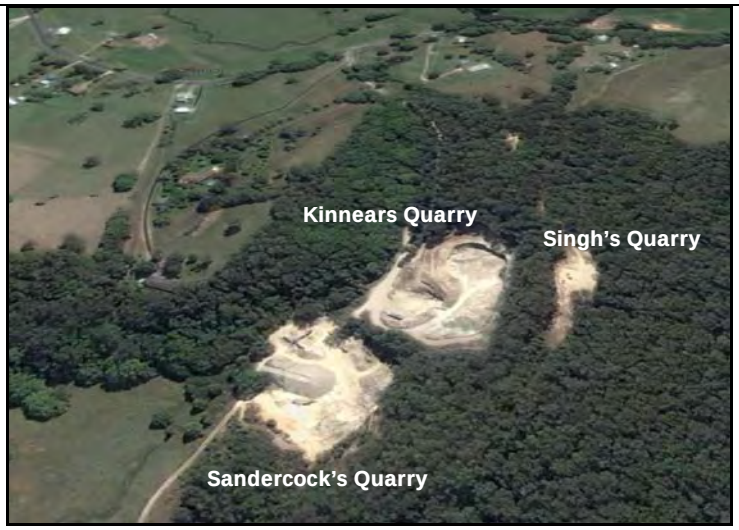


Figure 5: Quarry Location on Tweed Catchment Map

Table of Photos

Description	Photograph
1. **Three (3) quarry sites at Harry's Rd, off North Arm Road;** The centre working is Kinnears Quarry. All three quarries work quartzites and argillites of the Neranleigh Fernvale Beds. Photo Source Google Earth	
2. **Aerial view (looking northwest) of Kinnears Quarry and surrounding sites** Photo Source Google Earth	
3. **View looking south from Harry's Rd of entrance to Kinnears Quarry (on left)** Sediment pond 1 is located just behind the vegetated bund wall to the left of frame. Some seepage from sediment pond 1 is evident in table drain beside the road.	

Description	Photograph
4. **Kinnears Quarry – northern section of quarry, upper benches** View north along haul road on Bench 2 that provides access to Singh's Quarry, behind tree-line, top right of frame. The rock exposures in the northern section of the quarry consist of non-acid forming quartzites and argillites.	
5. **Kinnears Quarry – southern portion of quarry** The rock consists of folded and faulted quartzites and argillites of the Neranleigh Fernvale metasediments, with a bed of graphitic, carbonaceous shale exposed. Acid forming carbonaceous shale is exposed in faces 2 and 3.	
6. **Kinnears Quarry – exposure of high PAF carbonaceous shale** View east of quarry faces 3 (upper) and 2 (lower) showing grey, pyrite-rich clay and shale. This is the primary source of ARD from the quarry.	

Description	Photograph
7. **Sampling face 3 above Bench 3 (circa RL 42m AHD)** This appears to be the highest elevation of the exposure of the PAF carbonaceous shale. The graphitic, friable clay-shale material here (Sample 3B) showed the highest acid forming potential of the four rock samples tested.	
8. **View looking south east towards Face 1** showing distinctive iron staining from acid drainage through joints and fractures from faces and benches 2 and 3 above. Intensely cleaved (NAF) argillite outcrops on LHS of frame.	
9. **Sediment pond 1 in Bench 1 at base of Kinnears Quarry** This pond receives most of the acid drainage from the PAF rock in benches and faces 2 and 3. Sandercock quarry processing plant can be seen in top left of frame. Un-named creek which receives the overflow water from the sediment pond(s) flows at rear of frame, left to right.	

Description	Photograph
10. **Sediment pond 2 (in foreground) with sediment pond 1 in background.** Water from sediment pond 2 discharges via under road pipe to un-named creek beside Harry's Rd. Entrance to Sandercocks quarry is seen at rear of photo.	
11. **Embankment between sediment ponds 1 and 2 showing signs of leakage** Sediment ponds 1 and 2 have similar water chemistry – both highly degraded, low pH (2.5 in May 09). Soluble metals (Al, Fe, Cu, Mn, Ni) and sulphate exceed ANZECC livestock drinking water guidelines.	
12. **Close-up of un-named creek flowing in deep gully beside Harry's Rd** close to where discharge water from Kinnears Quarry enters. The pH of the water here was averaging about pH 2.9 during testing in 2007. The pH of the water upstream of Kinnears Quarry after flowing past Sandercock's quarry averages about 4.1	

Description	Photograph
13. **Upstream side of bridge over Harry's Rd, downstream from Kinnears Quarry** This is the location of TSC sample location KIN 3. Average pH (from 2007 to 2009) is 3.4	
14. **Swampy land downstream of bridge over Harry's Rd.**	
15. **Creek on northern side of North Arm Road (near Harry's Rd) flowing to Rous River.** This creek receives the water from the un-named creek and surrounding drainage lines.	

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Appendix 1

Geological Assessment and Quarry Development Report,
Geobas, June 2009

GEOBAS CONSULTING PTY LTD

ABN 73 061 919 355

Kinnears Quarry – Tweed Shire Council
Acid Rock Drainage Investigation

Geological Assessment and Quarry Development Report

Regional Geology & Topography

Kinnears Quarry and the contiguous Sandercocks and Singhs Quarries are located on the steep slopes of a major N-S strike ridge. It is one of several impressive ridges formed in a deeply incised terrain typical of this region of hard resistant rocks and high rainfall. Significant surface runoff and groundwater regimes persist in this terrain which contributes to the subject of this Kinnears Quarry investigation. The local draining creeks contain permanent flows and seeps and during the commonly occurring intense rain events of the region they can flood flow readily.

The regional geology is dominated by the Neranleigh Fernvale sequence and has been folded and aligned to the regional structural trend. A strong north to north-westerly strike (320 - 360 degrees) with west to south-westerly dips ranging from moderate to steep angles are developed. Major folding of the rocks in the region is evident such that east and north easterly dips are also present in the overall structural trend.

The Neranleigh - Fernvale Beds, which are of Upper Devonian to Carboniferous age, in this region, consist of hardened and recrystallised sedimentary rocks. The geological history of the sequence is one of offshore marine deposition of land-derived sediments forming mainly sandstones (predominantly greywacke), siltstones, shales and mudstones. These were interbedded with chemically precipitated chert beds. The whole sequence has been deeply buried, hardened and recrystallised, uplifted, folded and steeply inclined to the regional structural trend.

The rocks comprising this geological formation are best described as “meta-sedimentary” with the dominant rock types of the region and their descriptions as follows:

- **Quartzite** - derived from recrystallised chert beds. The quartzite range in colour from white, grey to black with various pinks, reds, yellows, etc. They are generally very fine grained and characteristically very hard, tough and abrasive. When black with little recrystallisation, the quartzites are more truly the original chert rocks. They range from banded to massive and blocky. Those closely fractured are heavily influenced by groundwater, ironstaining

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and weathering processes. These fractured quartzites (versus massive) are preferred for quarrying because of lesser degree of difficulties with extraction, raw feed size, crushing, processing, equipment wear, etc

- **Argillite** - derived from hardened and slightly recrystallised mudstones, shales and siltstones. Argillite is generally dark grey to black in colour, very fine grained and commonly with well developed thin bedding or banding. It can often be sheared to a poor quality slate where it has been affected by greater degrees of metamorphism. The other rock names often used in the Neranleigh Fernvale Beds viz shale, mudstone and siltstone, are inclusive in this broad "argillite" terminology. Argillite (or really meta-argillite) is a dominant quarry source rock in the Ballina to Coffs Harbour region.
- **Metagreywacke** - derived from hardened and slightly recrystallised coarse grained sediment mainly sandstone of quartz and feldspar composition (which is greywacke). It generally is a greenish grey to dark grey colour, hard and durable. It consists of fine to coarse sand grains and commonly shale clasts. Some areas of the metagreywacke have extensive angular clasts of carbonaceous shale, which are often mildly foliated. The metagreywacke is generally massive and thickly bedded but some lenses of highly foliated metagreywacke occur. Metagreywacke is a dominant quarry source rock in the Northern NSW and SEQ regions.

The rocks in the Murwillumbah area of this investigation are dominantly quartzite.

Site Geology

Kinnears Quarry is a typical hillside quarry which has been worked for many decades commencing from the Harry's Road entry level and gradually working back into the slope and upwards with a series of faces and benches to its current quarry development.

The dominant source rock of the current Kinnears Quarry is quartzite. It is of moderate to high quality in terms of strength and durability as an extractive construction material for TSC, particularly its main usage in roadbases and drainage materials.

This similar quality source rock should also extend into future quarry workings on the Kinnears site as well as into the adjoining neighbouring Quarries if the lands were amalgamated.

The quarry is located on a steep western slope of a major N-S ridge. This highlights the geological structure of a strong north to north-westerly strike (320 - 360 degrees) with west to south-westerly dips of the quartzite beds. This dominant N-S strike ridge has in effect directed the orientation and shape of the quarry and its development strategies over the years.

To understand the more detailed site geology, the issues and the investigation intent, the quarry layout should be considered adopting the following nomenclature:

- **Bench 1** - floor level at approx. RL 24 – includes the small sedimentation pond.
- **Face 1** - moderate sloping face of 7m height to Bench 2.
- **Bench 2** – fairly wide and open continuous operational bench used for the more recent extraction and stockpiling and handling materials – still contains significant accessible rock reserves – approx. RL 31
- **Face 2** - varying low to steep face of 8-9m height to Bench 3.
- **Bench 3** – very narrow continuous 5 to 8m wide bench at approx, RL 39 - 40 with low angle toe abutting next face above.
- **Face 3** - very steep and high face of approx. 18m height overall to Bench 4– face shows reasonable stability but would attract Mines Dept inspector's attention. In future quarry development a face split should be a mandatory requirement.
- **Bench 4** – narrow "5m" bench restricted at approx. RL 58 extending over a short lateral extent of approx. 30-40m with a difficult north to south access/haul road
- **Face 4** – the final low to moderate angle sloping face which daylights on natural slope at approx. 10m vertical height (approx. RL 68).

As a general statement in this quartzite deposit, as well many other similar quartzite deposits and outcrops in the Neranleigh Fernvale Beds, the geological structural characteristics in terms of the bedding, folding, faulting, cleavage, etc can be complex and can be difficult to map in quarry faces with any confidence over extensive areas, without a large degree of effort and time. However, it seems that overall in Kinnears Quarry, that the thin bedding in the quartzite is fairly well developed with a northerly strike direction and bedding planes dipping westerly at moderate to high angles (with occasional lower angle bedding/cleavage dips in sympathy with the folding (refer photos). This bedding structure can at times be disrupted with local faulting, shearing and local minor tighter folding. There is plenty of evidence of this in Kinnears Quarry and the adjoining Sandercock Quarry.

The quartzites are multi coloured often brown, white, black, pink and blue. Blue and dark grey to black chert beds are visually present within the quartzite. The rock mass has been fractured to generally a close to medium defect spacing with the main fracture orientation following the bedding within the rock. Other superimposed joint sets cause the blocky nature of the quartzite. All this fracturing leads to the intense ironstaining particularly prevalent in this quarry with shades of yellow, brown, orange and red penetrating deeply throughout the quartzite and chert source rock. Such intense mottling and discolouration can often lead to false conclusions regarding source rock quality where this material in actual fact may be of higher quality, particularly roadbase materials, than the unstained blue-grey quartzite/chert which may still contain active clay traces along the joint planes due to the lack of water penetration and migration of the fines.

Due to the dominance of quartzite over argillites (including mudstones, shales and siltstones), weathering is shallow with overburden depths generally very thin and only occasional shallow pockets of gravelly clayey soil. This can prove very difficult to strip and preserve for later rehabilitation due to its thinness and tree root development.

Carbonaceous Shale

Inherently in the Neranleigh Fernvale beds, particularly the quartzites, are occurrences of a material termed "carbonaceous shale". It represents discrete beds, lenses, pods, etc of generally black, very soft, graphitic, clay shale often heavily mineralised with finely disseminated sulphides (predominantly iron pyrites). These occurrences are the result of highly organic muds depositing in generally thin layers or depressions in the coarser sandier sediments and from their very inception may have been present as discontinuous deposits. Being in an anaerobic (oxygen free) environment where only certain organisms could thrive was perfect for the generation of sulphide mineralisation. Following deep burial and hardening/recrystallization of the sediments followed by very complex tectonic processes including uplifting we have the Neraneigh Fernvale Beds in our landscape and now weathering and eroding in an oxygen and free water environment. It is these carbonaceous shale occurrences which are very weak, graphitic, clayey, often sulphide mineralised which when exposed degenerate rapidly to produce acid mine drainage (ARD).

Within quarry rock situations, these acid forming rocks often occur as quite discontinuous structures which have at times been remobilised with faulting, folding, etc and commonly occur in association with argillite and chert bands.

The occurrence of potentially acid forming rocks in Kinnears Quarry is typical of similar quarry sites within similar units of the Neranleigh Fernvale beds and is presenting the attendant problem of very low pH and iron concentrated water releasing from the quarry to the natural drainage system. Also, a small isolated and structurally unrelated deposit of carbonaceous shale was observed in the adjoining and upstream Sandercock Quarry and this presents the same water quality risks as those being addressed in Kinnears Quarry.

It should be noted that disseminated pyrites can and often does occur throughout the general rock masses of the Neranleigh Fernvale Beds particularly the quartzites and cherts. This is generally not as visibly obvious as the distinct black carbonaceous shale occurrences. Weathering processes of the rock mass as a whole can also therefore lead to lower than normal pH water. This could explain the higher acid environment (lower pH) present just as background ambient conditions.

Carbonaceous Shale Exposed in Kinnears Quarry

Currently exposed in the south east sector of Kinnears Quarry is a significant carbonaceous "bed" present in Bench 2, Face 2, Bench 3 and Face 3. Refer site layout and cross-section (Figures 1 and 2 and the marked up photographs). Although it is present as a structural "bed" that is very difficult to establish with any lateral continuity, its immediate semi-continuous extent is a shown on Figures 1 and 2 as a 5

to 8m thick bed outwardly dipping from the face (towards the SW) at a medium dip angle. Due to the present folding, a flanking fault, a shear zone and possible remobilisation of the soft clayey material comprising the bed, interpretation of its continuation into the quarry source rocks behind existing faces is difficult without exploratory work such as drilling.

Even with this uncertainty of continuation over distance, there is sufficient evidence to allow prediction of the carbonaceous shale stratum being present behind Face 1 within Bench 2, this being a big part of the source (PAF) for the acid charged groundwater from Face 1 seepage through the highly fractured quartzites. The exposure of this PAF stratum in the rear of Bench 2, Face 2, Bench 3 and base of Face 3, all contribute to the ARD in terms of surface runoff as well as the more serious longer term groundwater seepages from all Faces 1, 2 and 3. In particular, Face 1 seepage need serious controls as it is really the receiver of all the groundwater emanating from all these rearward faces. Refer Figures and photos showing the outcrop and seepage areas associated with the carbonaceous shale.

Samples of the pyritic (high acid forming potential) carbonaceous shale material and associated chert source rock were taken for chemical testing by others from Face 2 (samples 2A and 2B respectively) and Face 3 (samples 3A and 3B respectively). Refer to the figures and photos for the approximate location of these samples.

Certainly in the short term, extraction from the SW benches, management of the PAF material and the ARD treatments suggested, will be critical. From site observations, it does not appear that other carbonaceous shale materials are outcropping which is somewhat positive in terms of site ARD management. However, one should not presume that in the long term extraction deeper into the current face exposures that other laterally discontinuous beds, bands, lenses or pods of similar PAF carbonaceous shales will not be encountered.

Future Quarry Development and Opportunities

Referring to the cross-section (Figure 2), it becomes obvious that even in Kinnears Quarry there has not been a lot of the resource extracted and a suggested long term development with the adoption of a 20m standard stand-off from freehold boundaries, followed by a series of 15m faces, 10m benches and 2 further floor drops over the full north to south extent of Kinnears Quarry, would conceptually provide very significant reserves. Obviously the haul road designs would require careful planning. The undertaking of such a quarry development would also allow drop cuts to be staged and constructed such that large and effective sedimentation ponds for the ARD could be purposefully constructed with appropriate control measures.

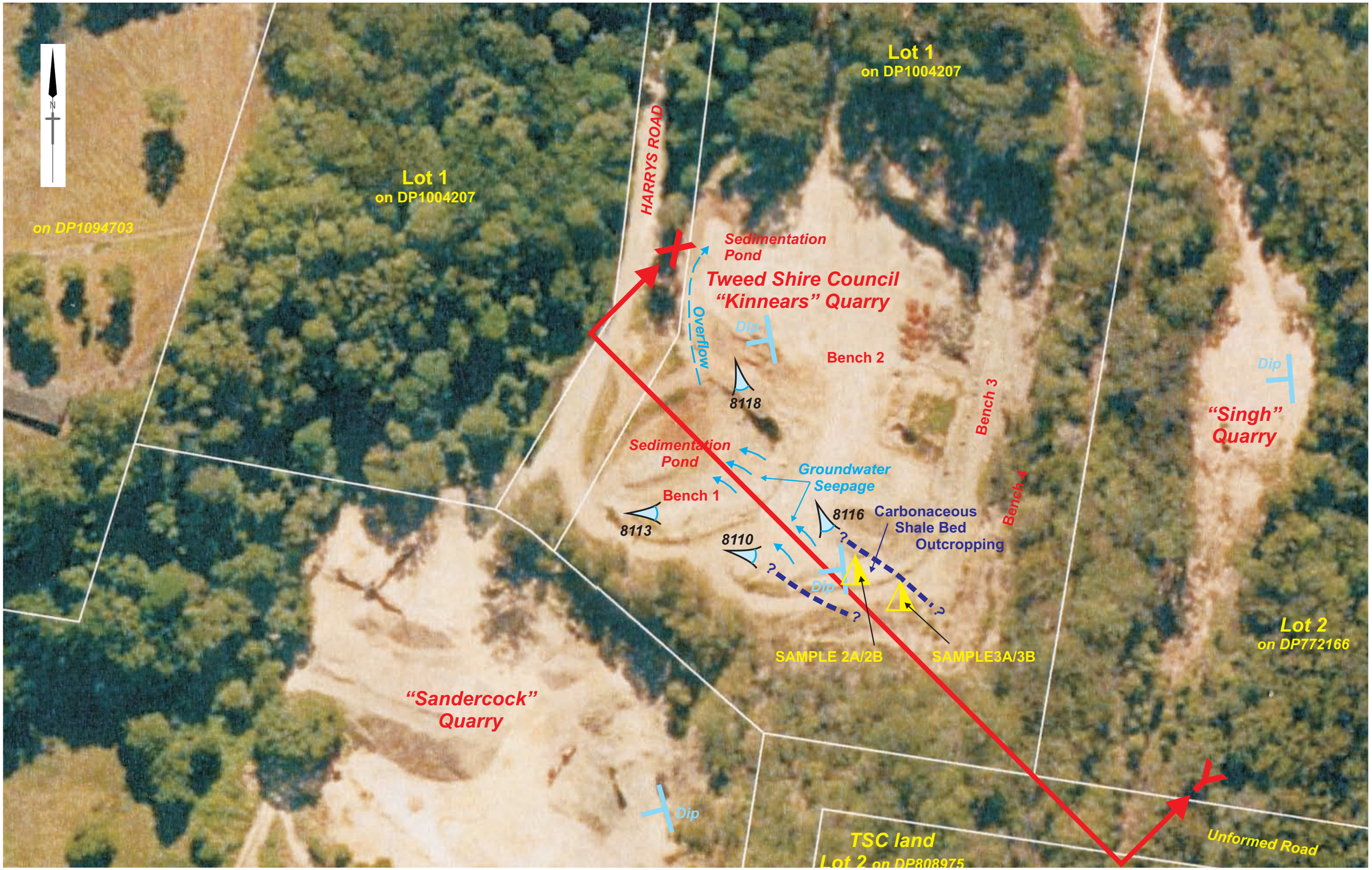
Sandercock Quarry with its present development constraints is approaching the last years of its reserves life. A Sandercock Quarry land acquisition by TSC would offer some extra reserves in terms of taking out the current buffer zone between both the quarries. Then, longer term floor drops cuts, as conceptually proposed in Kinnears Quarry, would add significantly to the rock reserves. Provided environmental amenity issues (noise, dust etc) can be appropriately managed, most importantly the Sandercock Quarry offers an alternative site for crushing and processing, stockpiling

of quarry products and space for sedimentation pond controls (or storage areas) for the PAF waste materials extracted from Kinnears Quarry.

This option could form part of a wider integrated quarry development concept involving an amalgamation of Kinnears Quarry with the 3 contiguous land holdings, which are the current Sandercock and Singhs Quarries land and the block to the SE which is understood to also be TSC land. A major receding rim quarry could then be effectively planned along with ARD management and controls. The resource evaluation, planning, land acquisitions, road reserve closures, approvals, etc for such a major quarry development would be a comprehensive and extensive exercise.

Gary Basford

19 June 2009



No.	REVISION	DATE	DRAWN

0 10 20 30 40 50m

SCALE - 1 : 1 000

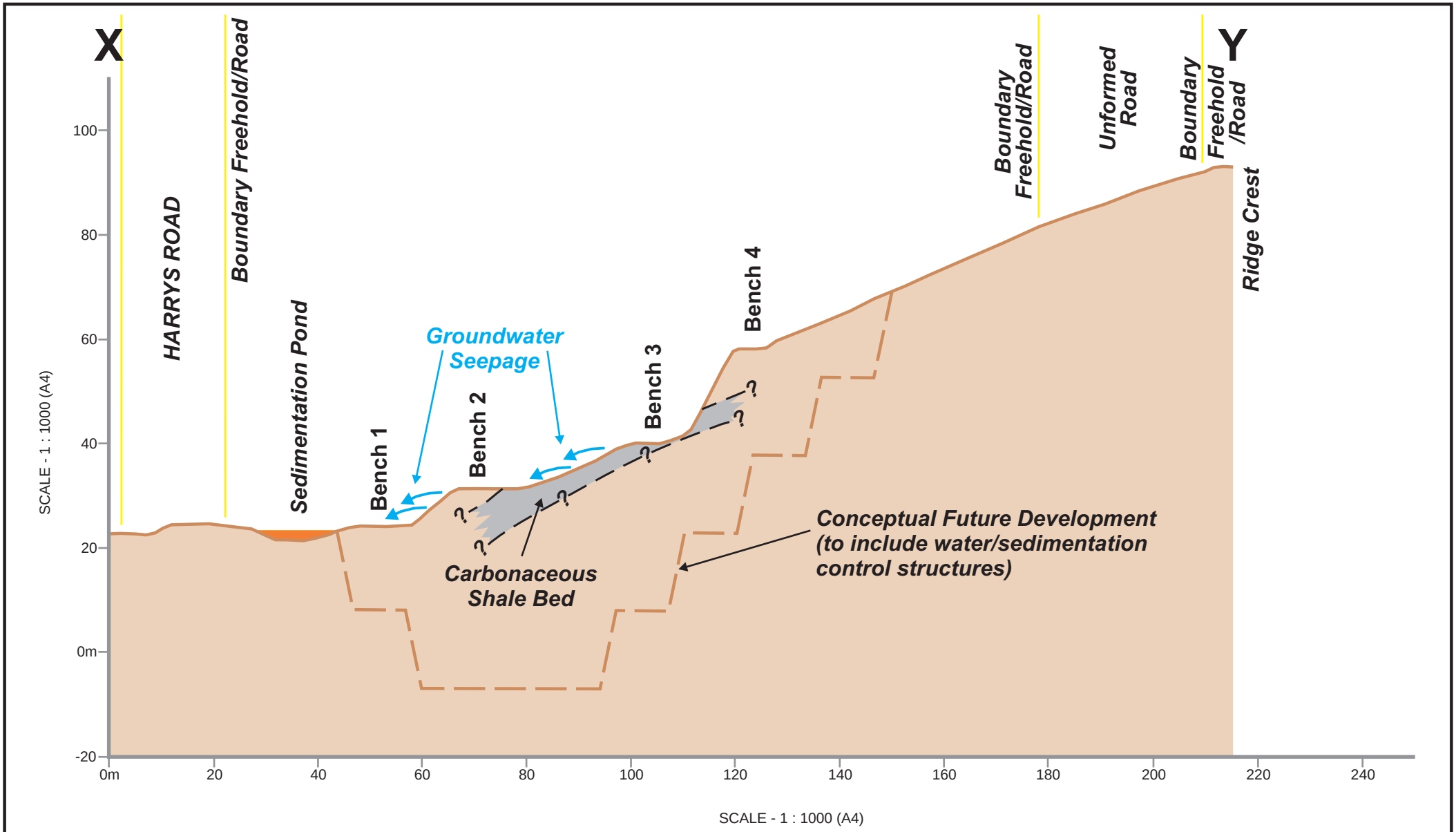
NOTES:
Aerial Photography taken mid 2007 by Fugro
Property Boundaries shown are approximate only

Geobas Pty Ltd
ABN ?? ??? ??? ???
Contact: Gary Basford
13 Crescent Road, Kelvin Grove, Brisbane.
Tel: 07 3368 1657
Mob: 0419 474 785
e-mail: geobas@tpg.com.au

SCALE	SEE BAR
DRAWN	NEA
CHECKED	GB
DESIGNED	
DATE	MAY 09

JOB & DRAWING TITLE
KINNEARS QUARRY (TWEED SHIRE COUNCIL) - ACID ROCK DRAINAGE INVESTIGATION SITE LAYOUT

DRAWING NO.	FILE NUMBER	REV.
FIGURE 1	Kinn_2009_001	**A**



NOTES:
For Cross Section location refer Figure 1
Level Datum from Fugro mid 2007 aerial survey

Geobas Pty Ltd
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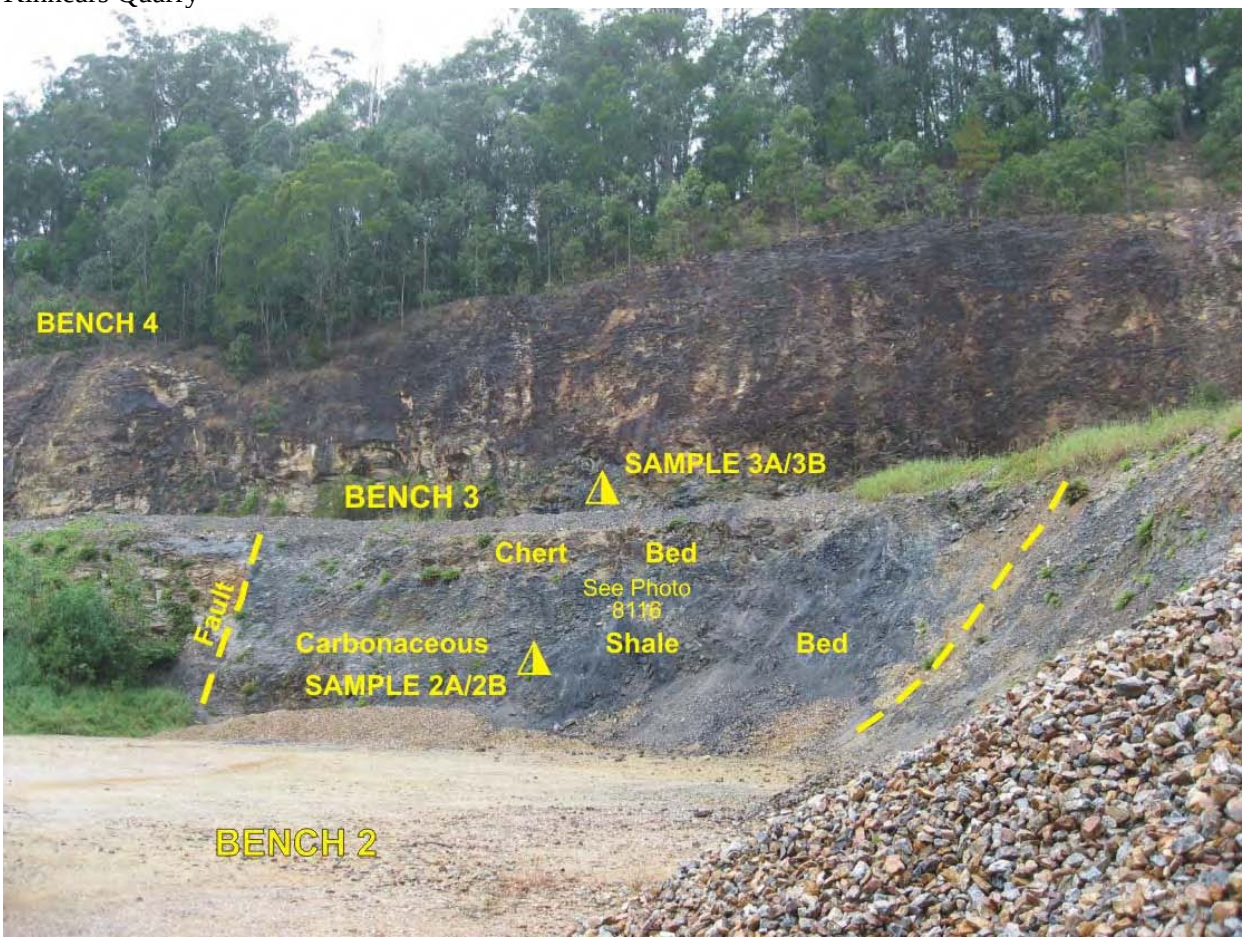
SCALE	SEE BAR
DRAWN	NEA
CHECKED	GB
DESIGNED	
DATE	MAY 09

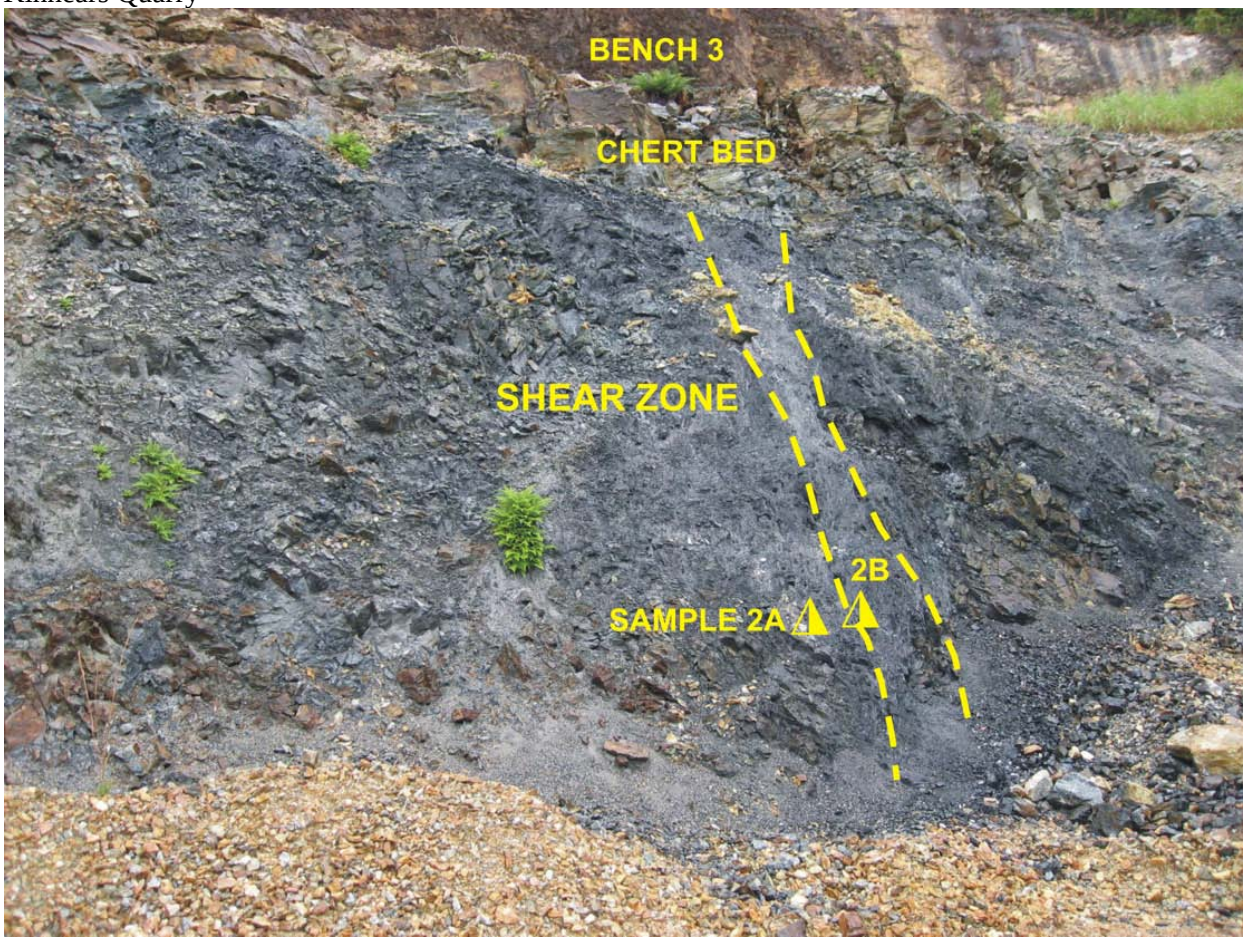
JOB & DRAWING TITLE
KINNEARS QUARRY (TWEED SHIRE COUNCIL) - ACID ROCK DRAINAGE INVESTIGATION CROSS SECTION XY

DRAWING NO. **FIGURE 2**
FILE NUMBER Kinn_2009_002
REV. **A**



Face 2/3 Carbonaceous Shale Bed Outcropping (Photo 8110 – 18/5/09)

Bench 1 Acid Drainage Seepage Exposure (Photo 8113 – 18/5/09)



Close up of Carbonaceous Shale Bed showing Complex Geological Structure (Photo 8116 – 18/5/09)

Face 1/2 Staining (Photo 8118 – 18/5/09)

Appendix 2

Acid Rock Chemistry and Water Quality Test Results

Table A2-1: Acid Rock Chemistry - NAG Test Results

Table A2-2: Water Quality Tests

Table A2-3: Multi-Element Analysis of Sediment Pond Water

Table A 2-1

Acid-Base and NAG Test Results for Rock Samples from Kinnears Quarry

Sample Number	Sample Date	Sample Type	Description	pH[1]	Acidity (to pH 8.3)	Alkalinity (to pH 5.5)	EC[1]	Total Sulfur	Sulfate Sulfur	MPA[2]	ANC[2]	NAPP[2]	NAG[2] Capacity (pH 4.5)	NAG[2] pH	Sample Classification Non-Acid Forming (NAF) Potentially Acid Forming (Low Capacity) Potentially Acid Forming (High Capacity)
					(kg H_2SO_4/t)		(µS/cm)	(%)		(kg H_2SO4/t)					
2A	18-May-09	Rock	Dark Grey Quartzite	4.4		NP	200	0.03	<0.1	0.97	NP	0.97	23.0	4.3	Potentially Acid Forming (Low Capacity)
2B	18-May-09	Rock	Carbonaceous Shale	4.3		NP	1,300	0.02	<0.1	0.67	NP	0.67	19	4.3	Potentially Acid Forming (Low Capacity)
3A	18-May-09	Rock	Dark Grey Quartzite	5.0		5.0	186	<0.01	<0.1	0.27	NP	0.27	6.0	4.4	Non Acid Forming
3B	18-May-09	Rock	Carbonaceous Clay	2.3		NP	12,160	0.14	0.40	4.14	NP	4.14	78	2.0	Potentially Acid Forming (High Capacity)

Notes:

1. Natural pH and EC provided for 1:5 sample:water extracts

2. ANC = Acid neutralising capacity; MPA = Maximum potential acidity; NAPP = Nett acid producing potential; NAG = Net acid generation

3. Samples classified as Non-Acid Forming if NAPP is zero or negative. Samples classified as Potentially Acid Forming (PAF) if NAPP is positive and NAG pH is less than or equal to pH 4 (low capacity if NAG capacity is less than or equal to 5 kgH_2SO_4/t and high capacity if NAG capacity is greater than 5 kgH_2SO_4/t).

4. NP = not produced

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FINAL CERTIFICATE OF ANALYSIS

Client: Works Unit (Quarries)
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PO Box 816
MURWILLUMBAH
NSW 2484

Lims1 Report No: 09/1628-C
Attention: Athol Kiem
Client Reference:
Copy To: David Hannah & Tanya Fountain
Date of Report: 5/06/2009

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Taken By:	Laboratory Staff	**No of Samples:**	4
Date Taken:	18/05/2009	**Date Testing Commenced:**	18/05/2009
Date Received:	18/05/2009	**Date Testing Completed:**	5/06/2009

Sample Description: Kinnears Quarry - ARD - Soil Samples

Sample/Site No	Sample/Site Description
1	Bench 2/A
2	Bench 2/B
3	Bench 3/A
4	Bench 3/B

COMMENTS:
Samples have been taken in accordance with AS5667:98 - Water Quality - Sampling.
Additional testing requested by David Hannah. HSR
NP = Not Present.

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Accreditation No: 12754 & 13538

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NSW 2484

Attention: Athol Kiem

Lims1 Report No: 09/1628-C
Date Testing Completed: 5/06/2009
Date of Report: 5/06/2009

Sample Description: Kinnears Quarry - ARD - Soil Samples

Sample Identification:			1	2	3	4
Date Taken:			18/05/2009	18/05/2009	18/05/2009	18/05/2009
Date Received:			18/05/2009	18/05/2009	18/05/2009	18/05/2009
Date Testing Commenced:			18/05/2009	18/05/2009	18/05/2009	18/05/2009
Test	Method	Units	09/1628-C/1	09/1628-C/2	09/1628-C/3	09/1628-C/4
pH	P1	pH units	4.4	4.3	5.0	2.3
Alkalinity as $CaCO_3$	C10	kg/H_2SO_4/t	NP	NP	5	NP
Conductivity @ 25°C	P2	μScm^{-1}	200	1,300	186	12,160
Sulphur as Sulphate (Total)	M8	%	<0.1	<0.1	<0.1	0.4
Sulphur (Total)	M8	%	0.03	0.02	<0.01	0.14
Maximum potential Acidity		kg/H_2SO_4/t	0.97	0.67	0.27	4.14
Acid Neutralising Capacity		%$CaCO_3$	NP	NP	NP	NP
Net Acid Producing Potential		kg/H_2SO_4/t	0.97	0.67	0.27	4.14
Net Acid Generation (pH 4.5)		kg/H_2SO_4/t	23.00	19.00	6.00	78.00
Net Acid Generation pH		pH units	4.30	4.30	4.40	2.00

Table A 2-2

Kinnears Quarry and Environs - Water Quality Test Results

							Date Sampled		20/05/2009	31/03/2009	11/02/2009	29/01/2009	26/11/2008	18/11/2008	5/11/2008	5/09/2008	18/08/2008	21/07/2008	23/06/2008	26/05/2008	28/04/2008	31/03/2008	3/03/2008	4/02/2008	10/12/2007	14/11/2007	20/08/2007
							Rainfall Data	Previous day	2.0	50.0	0.0	5.0	86.0	11.0						0.0		0.0		25.0			0.0
								Previous week	45.0	91.5	1.0	171.0	206.5	56.5						32.0		44.0		81.5			55.0
								Weather	rain	overcast, rain	hot/humid	showers/sunny	showers	rain						fine		fine		showers			raining
KIN 1	**Upstream Sandercocks quarry**																												
Test		**Units**	**No. of samples**	**Mean**	**Std. Dev.**	**High**	**Low**																						
pH			18	6.2	0.5	7.3	5.3		6.2	5.3	6.0	6.0	5.7	6.0	6.3	5.8	6.2	6.7	6.3	6.9	6.0	6.6	5.4	5.7	7.3	6.4	
Conductivity @ 25 C		µS/cm	18	179	215	940	44		44	110	121	96	110	132	130	103	72	96	90	108	111	940	512	60	203	189	
Suspended Solids		mg/L	18	13	23	93	1.4		93	4.6	3.2	5.3	4.6	11	10	7	2	2.2	3	1.4	2.3	2.1	1.9	30	39	4.4	
Chloride		mg/L	18	18	7	38	5.6		5.6	16	15	12	15	14	18	13	24	15	18	16	15	19.5	16	25	28	38	
Sulphur as Sulphate		mg/L	18	7	4	23	4.0		23	6.1	4.9	5.6	6.4	7.2	7	7.5	6	6	6.7	6.7	5.9	5.6	7.4	4	9.1	9.2	
Iron (Total)		mg/L	18	0.3	0.2	0.6	0.02		0.38	0.26	0.23	0.22	0.37	0.59	0.6	0.19	0.02	0.23	0.18	0.03	0.02	0.02	0.13	0.53	0.59	0.17	
KIN 2	**Upstream Kinnears at Outlet Pipe from Sandercocks**								Was KIN 4 pre Nov 07																		
Test		Units																									
pH			32	4.1	1.1	7.0	2.2		4.7	5.6	3.5	3.6	3.7	4.1	5.8	4.6	5.5	5.9	4.3	7.0	4.8	5.3	4.1	3.7	3.1	3.0	4.6
Conductivity @ 25 C		µS/cm	32	561	459	2200	87		87	356	400	211	305	278	170	212	124	180	330	161	260	268	688	282	930	853	778
Suspended Solids		mg/L	32	1153	2666	11200	3		2155	69	37	60	27	28	31	86	72	38	34	16	27	3	28	1230	11200	5750	344
Chloride		mg/L	32	22	15	80	4		3.6	11	14	9	12	13	15	9	23	16	17	15	14	17.9	14	8	50	21	13
Sulphur as Sulphate		mg/L	32	252	258	1120	15		15	118	97	65	103	121	45	82	48	71	104	46	79	98	68	94	406	344	284
Iron (Total)		mg/L	32	27.4	45.5	190.0	0.0		0.44	1.46	21	5.12	12	11	8.96	0.82	0.03	5.53	9.93	3.02	6.79	9.4	6.23	3.85	11	14	5.07
KIN 3	**Upstream of Bridge over Harry's Rd near entrance**								Was KIN 6 pre Nov 07																		
Test		Units																									
pH			33	3.4	1.1	7.9	2.2		6.6	3.3	3.2	2.8	3.5	3.0	2.2	3.0	2.8	3.4	3.2	3.5	3.2	2.9	3.4	3.9	7.9	3.0	4.6
Conductivity @ 25 C		µS/cm	33	904	555	2700	77		77	360	664	407	469	377	2450	791	1624	470	590	530	681	462	1068	377	2700	955	914
Suspended Solids		mg/L	33	22	44	253	2		253	11	11	12	5.8	5.3	3.4	14	4.8	3	7.4	6	51	5.6	3.3	22	4.2	5.6	16
Chloride		mg/L	33	23	19	114	5		5.6	18	14	9	14	11	50	4.9	13	16	17	16	13	16.9	114	10	18	19	18
Sulphur as Sulphate		mg/L	33	588	964	5331	39		39	109	169	119	142	144	1348	263	1460	180	224	186	208	154	148	129	5331	442	326
Iron (Total)		mg/L	33	17.2	33.0	151.0	0.3		0.25	4.45	2.69	1.3	2.85	2.79	151	37	130	3.0	2.72	2.86	2.77	1.86	2.2	5.87	12	12	8.24
KIN 4	**Primary sediment pond**																										
Test		Units																									
pH			18	3.0	0.9	5.6	2.0		3.9	2.4	2.5	2.0	2.6	2.4	2.1	3.7	2.7	2.7	2.6	2.5	2.5	5.6	2.6	4.4	3.1	2.8	
Conductivity @ 25 C		µS/cm	18	1714	795	3200	173		173	1822	2555	1516	2039	944	1976	182	1553	1915	1980	3200	2360	2300	1810	640	2180	1698	
Suspended Solids		mg/L	18	15	18	59	2		59	2.6	1.8	4	35	5	2	10	8.3	2	42	8.8	28	7.1	3.4	42	5.6	5.2	
Chloride		mg/L	18	11	7	27	2		1.9	11	7	5	27	4	25	13	14	8	7	9	6	8.9	9	10	20	14	
Sulphur as Sulphate		mg/L	18	939	500	1940	52		100	642	1191	500	950	442	1223	52	1320	1099	1144	1940	947	1131	1394	332	1429	1066	
Iron (Total)		mg/L	18	95.4	71.9	258.0	1.8		1.84	72	166	61	150	55	24	3.54	50	142	183	258	108	113	167	9.36	111	43	
KIN 5	**Secondary sediment pond**								Was KIN 1 pre Nov 07																		
Test		Units																									
pH			28	3.1	0.5	4.7	2.3		3.8	2.9	2.6	2.3	2.8	2.7	3.0	3.9	3.5	2.7	2.7	2.7	2.7	3.7	2.8	4.0	2.9	3.0	4.7
Conductivity @ 25 C		µS/cm	28	1431	1213	6400	137		314	590	2252	933	1321	645	600	221	387	1890	1890	2690	1885	1216	6400	285	1648	1140	137
Suspended Solids		mg/L	28	32	44	192	1		2.5	19	8.7	7.7	20	3.3	21	15	2.1	145	26	36	43	4.8	6.4	90	15	1	36
Chloride		mg/L	28	16	9	35	3		3.1	8	7	7	22	5	32	35	24	8	7	14	6	10.3	15	10	20	12	15
Sulphur as Sulphate		mg/L	28	685	533	1900	25		27	152	928	283	481	254	168	82	195	1186	1057	1900	773	523	1324	104	808	631	25
Iron (Total)		mg/L	28	52.9	82.5	352.0	0.2		3.59	5.67	77	12	40	15	123	0.4	1.4	50	116	258	66	42	151	4.59	38	11	0.2
Sample Points																											
OLD	NEW																										
KIN 1	KIN 5																										
KIN 2	discontinued																										
KIN 4	KIN 2																										
KIN 6	KIN 3																										
Outlet from Pit across road (Old KIN 2)					check what this was (outlet pipe or in the creek?)																						
Test		**Units**	**No. of samples**	**Mean**	**Std. Dev.**	**High**	**Low**																				
pH			14	2.9	0.4	3.9	2.2																				3.9
Conductivity @ 25 C		µS/cm	14	1344	428	2000	700																				937
Suspended Solids		mg/L	14	7	5	17	1																				12
Chloride		mg/L	14	34	26	117	13																				14
Sulphur as Sulphate		mg/L	14	702	326	1140	109																				335
Iron (Total)		mg/L	14	25.2	13.1	51.0	7.2																				7.19

25/07/2007	28/05/2007	14/05/2007	2/04/2007	8/03/2007	5/03/2007	5/02/2007	8/01/2007	4/01/2007	5/12/2006	13/11/2006	9/11/2006	16/10/2006	18/09/2006
	0.0	32.0	3	33.5			0	23	56				
	2.0	35.0	7	55			41.5	39	60				
	fine		fine	fine	fine	rain	fine	fine	rain	fine				fine

Table A 2-3

Multi-Element Concentration in Water Samples from Kinnears Quarry

				Soluble Concentration (mg/L unless otherwise stated)	
				Sample Number (Description)	
				Primary Sediment Pond Sample ID KIN 4 Sample Date 18/5/2009	Secondary Sediment Pond Sample ID KIN 5 Sample Date 18/5/09
			pH (no units)	2.5	2.5
			EC (μS/cm)	3,170	3,060
			Acidity (mg/L $CaCO_3$)	1,170	1,280
Major Elements	**Detection Limit**	**ANZECC Guidelines[1]**	**NEPM Guidelines[2]**		
Al	0.1	5	5	**26**	**52**
Ca	1	1000	1000	139	138
Cu	0.01	0.4 to 5	0.5	**1.20**	**1.57**
Fe	0.01	-	1 (irrigation)	**216**	**202**
K	1	-	-	<1	<1
Mg	1	-	-	99	102
Mn	0.01	-	2 (irrigation)	**72**	**79**
Na	1	-	-	3.8	4.1
Ni	0.01	1	1	**2.10**	**2.29**
SO_4	1	1000	-	**1720**	**1760**
Zn	0.01	20	20	4.11	4.49
Minor Elements					
As	0.005	0.5	0.5	0.005	<0.005
B	0.1	5	5	<0.01	<0.01
Cd	0.005	0.01	0.01	**0.018**	**0.022**
Cl				1.7	1.0
Co	0.01	1	1	0.79	0.93
Cr	0.01	1	1	0.07	0.09
Hg	0.0001	0.002	0.002	<0.0001	<0.0001
Mo	0.01	0.15	0.01	<0.01	<0.01
Pb	0.01	0.1	0.1	<0.01	<0.01
Sb	0.01	-	-	<0.001	<0.001
Se	0.01	0.02	0.02	<0.01	<0.01

Notes:

< indicates concentration less than the detection limit;

1. Australian and New Zealand Environment and Conservation Council (ANZECC). Australian Water Quality Guidelines for Fresh and Marine Waters (Livestock Drinking Water). October 2000.

2. National Environment Protection Measure (Assessment of Site Contamination) Measure (NEPM). Guideline on Investigation Levels for Soil and Groundwater (Livestock). December 1999.

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FINAL CERTIFICATE OF ANALYSIS

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Lims1 Report No: 09/1627-C
Attention: Athol Kiem
Client Reference: A4930.7049
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Taken By:	Laboratory Staff	**No of Samples:**	2
Date Taken:	18/05/2009	**Date Testing Commenced:**	18/05/2009
Date Received:	18/05/2009	**Date Testing Completed:**	11/06/2009

Sample Description: Kinnears Quarry - ARD - A4930.7049 - Chemical

Sample/Site No	Sample/Site Description
KIN 4	Primary Sediment Pond
KIN 5	Secondary Sediment Pond

COMMENTS:

Samples have been taken in accordance with AS5667:98 - Water Quality - Sampling.

Tide: Low. Weather: Fine/Showers.
Rainfall previous day/week: Nil/Nil.
The accreditation of this Report does not include Total Acidity.

NATA ACCREDITED FOR TECHNICAL COMPETENCE

This document is issued in accordance with NATA's accreditation requirements. Accredited for compliance with ISO/IEC 17025.
Accreditation No: 12754 & 13538

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Client: Works Unit (Quarries)

Address: Tweed Shire Council
PO Box 816
MURWILLUMBAH
NSW 2484

Attention: Athol Kiem

Lims1 Report No: 09/1627-C
Date Testing Completed: 11/06/2009
Date of Report: 11/06/2009

Sample Description: Kinnears Quarry - ARD - A4930.7049 - Chemical

Sample Identification:			KIN 4	KIN 5
Date Taken:			18/05/2009	18/05/2009
Date Received:			18/05/2009	18/05/2009
Date Testing Commenced:			18/05/2009	18/05/2009
Test	Method	Units	09/1627-C/1	09/1627-C/2
pH	P1	pH units	2.5	2.5
Conductivity @ 25°C	P2	μScm^{-1}	3,170	3,060
Suspended Solids	P4	mg/L	<1	4.3
Chloride	C20	mg/L	1.7	1.0
Cobalt (Soluble)	M8	mg/L	0.79	0.93
Cadmium (Soluble)	M7	mg/L	0.018	0.022
Mercury (Soluble)	M5	mg/L	<0.0001	<0.0001
Lead (Soluble)	M8	mg/L	<0.01	<0.01
Antimony (Soluble)	M7	mg/L	<0.001	<0.001
Selenium (Soluble)	M7	mg/L	<0.01	<0.01
Iron (Total)	M8	mg/L	217.00	206.00
Total Acidity	APHA 2310	mg/L $CaCO_3$	1,170.0	1,280.0

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Sample Identification:			KIN 4	KIN 5
Date Taken:			18/05/2009	18/05/2009
Date Received:			18/05/2009	18/05/2009
Date Testing Commenced:			18/05/2009	18/05/2009
Test	Method	Units	09/1627-C/1	09/1627-C/2
Manganese (Soluble)	M8	mg/L	72.00	79.00
Sodium (Soluble)	M8	mg/L	3.8	4.1
Potassium M8 (Soluble)	M8	mg/L	<1	<1
Calcium (Soluble)	M8	mg/L	139.00	138.00
Magnesium (Soluble)	M8	mg/L	99.0	102.0
Aluminium (Soluble)	M8	mg/L	26.00	52.00
Arsenic (Soluble)	M7	mg/L	0.005	<0.005
Boron (Soluble)	M8	mg/L	<0.01	<0.01
Iron (Soluble)	M8	mg/L	216.00	202.00
Copper (Soluble)	M8	mg/L	1.20	1.57
Chromium (Soluble)	M8	mg/L	0.07	0.09
Molybdenum (Soluble)	M8	mg/L	<0.01	<0.01
Nickel (Soluble)	M8	mg/L	2.10	2.29
Silicon (Soluble)	M8	mg/L	7.5	11.0
Sulphur as Sulphate (Soluble)	M8	mg/L	1,720.0	1,760.0
Zinc (Soluble)	M8	mg/L	4.11	4.49

Appendix 3

Paper on Overview of AMD Treatment with Chemicals,
West Virginia University

Overview of Acid Mine Drainage Treatment with Chemicals

West Virginia University Extension Service

Jeff Skousen, Tiff Hilton, and Ben Faulkner

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Acid Mine Drainage Formation

Acid mine drainage (AMD) forms when sulfide minerals in rocks are exposed to oxidizing conditions in coal and metal mining, highway construction, and other large-scale excavations. There are many types of sulfide minerals, but iron sulfides common in coal regions, pyrite and marcasite (FeS_2), are the predominant AMD producers. Upon exposure to water and oxygen, pyritic minerals oxidize to form acidic, iron and sulfate-rich drainage. The drainage quality emanating from underground mines or backfills of surface mines is dependent on the acid-producing (sulfide) and alkaline (carbonate) minerals contained in the disturbed rock. In general, sulfide-rich and carbonate-poor materials are expected to produce acidic drainage. In contrast, alkaline-rich materials, even with significant sulfide concentrations, often produce alkaline conditions in water.

Acidity in AMD is comprised of mineral acidity (iron, aluminum, manganese, and other metals depending on the specific geologic setting and metal sulfide) and hydrogen ion acidity. Approximately 20,000 km of streams and rivers in the United States are degraded by AMD. About 90% of the AMD reaching streams originates in abandoned surface and deep mines. Since no company or individual claims responsibility for reclaiming abandoned mine lands (AML), no treatment of the AMD occurs and continual contamination of surface and groundwater resources results. In a previous Green Lands

article (Winter 1996 edition), Ziemkiewicz and Skousen reviewed strategies used to control AMD at its source. In this article, chemical treatment alternatives are discussed.

Chemical Treatment of Acid Mine Drainage

Since the passage of the Surface Mining Control and Reclamation Act (SMCRA) in 1977, coal mine operators have been required to meet environmental land reclamation performance standards established by federal and state regulatory programs. Operators must also meet water quality standards established in the Clean Water Act of 1972 (CWA), which regulates discharges into waters of the U.S. Control of AMD is a requirement imposed on operators by both SMCRA and CWA. In addition to the surface mining permit, each mining operation must be issued a National Pollutant Discharge Elimination System (NPDES) permit under CWA. Allowable pollutant discharge levels are usually determined by the U.S. Environmental Protection Agency's (EPA) technology-based standards, or the discharge levels may be based on the more stringent water quality-based standards where discharges are being released into streams with designated uses. If AMD problems develop during mining or after reclamation, a plan to treat the discharge must be developed. Treatment of AMD includes neutralization of acidity and precipitation of metal ions to meet the relevant effluent limits. In most cases, a variety of alternative treatment methods can be employed to meet the limits specified.

NPDES permits on surface mines usually require monitoring of pH, total suspended solids (TSS), and iron and manganese concentrations. Other parameters may be requested by the regulatory authority in a particular mining situation. However, in order for an operator to make a selection of an AMD treatment system, one must determine (in addition to the above parameters) the flow rate, the receiving stream's flow and quality, availability of electrical power, the distance from chemical addition to where the water enters a settling pond, and the settling pond's volume for water retention time. After evaluating these variables over a period of time, the operator can consider the economics of different chemicals and alternative AMD treatment systems. Most AMD chemical treatment systems consist of an inflow pipe or ditch, a storage tank or bin holding the treatment chemical, a means of controlling its application rate, a settling pond to capture precipitated metal oxyhydroxides, and a discharge point. The latter is the point at which NPDES compliance is monitored. The amount of chemical needed for neutralization can be calculated by multiplying the flow (gpm), the AMD's acidity (mg/l), and a factor of .0022. The product is the tons of acid that require neutralization per year (calcium carbonate equivalent). This value (tons of acid/yr) can then be multiplied by a conversion factor for each chemical to determine the amount of the chemical needed.

Overview of Chemicals Available to Treat AMD

Six primary chemicals have been used to treat AMD (Table 1). Each chemical has characteristics that make it more or less appropriate for a specific condition. The best choice among alternatives depends on both

technical and economic factors. The technical factors include acidity levels, flow, the types and concentrations of metals in the water, the rate and degree of chemical treatment

needed, and the desired final water quality. The economic factors include prices of reagents, labor, machinery and equipment, the number of years that treatment will be needed, the interest rate, and risk factors.

Table 1. Chemical Compounds used in AMD treatment.

Common Name	Chemical Name	Formula	Conversion Factor[1]	Neutralization Efficiency[2]	1996 Cost[3] $ per ton or gallon Bulk	<Bulk
Limestone	Calcium carbonate	CaCO3	1	30%	$10	$15
Hydrated Lime	Calcium hydroxide	Ca(OH)2	0.74	90%	$60	$100
Pebble Quicklime	Calcium oxide	CaO	0.56	90%	$80	$240
Soda Ash	Sodium carbonate	Na2CO3	1.06	60%	$200	$320
Caustic Soda (solid)	Sodium hydroxide	NaOH	0.8	100%	$680	$880
20% Liquid Caustic	Sodium hydroxide	NaOH	784	100%	$0.46	$0.60
50% Liquid Caustic	Sodium hydroxide	NaOH	256	100%	$1.10	$1.25
Ammonia	Anhydrous ammonia	NH3	0.34	100%	$300	$680

[1] The conversion factor may be multiplied by the estimated tons acid/yr to get tons of chemical needed for neutralization per year. For liquid caustic, the conversion factor gives gallons needed for neutralization.

[2] Neutralization Efficiency estimates the relative effectiveness of the chemical in neutralizing AMD acidity. For example, if 100 tons of acid/yr was the amount of acid to be neutralized, then it can be estimated that 82 tons of hydrated lime would be needed to neutralize the acidity in the water (100(0.74)/0.90).

[3] Price of chemical depends on the quantity being delivered. Bulk means delivery of chemical in a large truck, whereas <Bulk means purchased in small quantities. Liquid caustic prices are for gallons. Others in tons.

Metal Precipitation and pH

Enough alkalinity must be added to raise water pH and supply hydroxides (OH^-) so dissolved metals in the water will form insoluble metal hydroxides and settle out of the water. The pH required to precipitate most metals from water ranges from pH 6 to 9 (except ferric iron which precipitates at about pH 3.5). The types and amounts of metals in the water therefore heavily influence the selection of an AMD treatment system. Ferrous iron converts to a solid bluish-green ferrous hydroxide at pH $\geq$8.5. In the presence of oxygen, ferrous iron oxidizes to ferric iron, and ferric hydroxide forms a yellowish-orange solid (commonly called yellow boy), which precipitates at pH $\geq$3.5. In oxygen-poor AMD where iron is primarily in the ferrous form, enough alkalinity must be added to raise the solution pH to 8.5 before ferrous hydroxide precipitates. A more efficient way of treating high ferrous AMD is to first aerate the water (also outgassing CO_2), causing the iron to convert from ferrous to ferric, and then adding a neutralizing chemical to raise the pH to 6 or 7 to form ferric hydroxide. Aeration after chemical addition is also beneficial. Aeration

before and after treatment usually reduces the amount of neutralizing reagent necessary to precipitate iron from AMD. Aluminum (Al) hydroxide generally precipitates at pH $\geq$ 5.0 but also enters solution again at a pH of 9.0. Manganese precipitation is variable due to its many oxidation states, but will generally precipitate at a pH of 9.0 to 9.5. Sometimes, however, a pH of 10.5 is necessary for complete removal of manganese. As this discussion demonstrates, the appropriate treatment chemical can depend on both the oxidation state and concentrations of metals in the AMD (U.S. Environmental Protection Agency 1983). Interactions among metals also influence the rate and degree to which metals precipitate. For example, iron precipitation will largely remove manganese from the water at pH 8 due to co-precipitation, but only if the iron concentration in the water is much greater than the manganese content (about 4 times more or greater). If the iron concentration in the AMD is less than four times the manganese content, manganese may not be removed by co-precipitation and a solution pH of $\geq$9 is necessary to remove the manganese. Because AMD contains multiple combinations of acidity and metals, each AMD is unique and its treatment by these chemicals varies widely from site to site. For example, the AMD from one site may be completely neutralized and contain no dissolved metals at a pH of 8.0, while another site may still have metal concentrations that do not meet effluent limits even after the pH has been raised to 10.

Chemicals

Limestone

Limestone has been used for decades to raise pH and precipitate metals in AMD. It has the lowest material cost and is the safest and easiest to handle of the AMD chemicals. Unfortunately, its successful application has been limited due to its low solubility and tendency to develop an external coating, or armor, of ferric hydroxide when added to AMD. In cases where pH is low and mineral acidity is also relatively low (low metal concentrations), finely-ground limestone may be dumped in streams directly or the limestone may be ground by water-powered rotating drums and metered into the stream. These applications have been tried recently in West Virginia in AMD-impacted streams with great success. Limestone has also been used to treat AMD in anaerobic (anoxic limestone drains) and aerobic environments (open limestone channels). These latter two techniques are especially useful in situations where specific discharge limits do not have to be met. They are both being installed on abandoned mine land reclamation projects and by operators wishing to reduce chemical treatment costs and improve compliance (Faulkner 1996).

Hydrated Lime

Hydrated lime is a commonly-used chemical for treating AMD. It is sold as a powder that tends to be hydrophobic, and extensive mechanical mixing is required to disperse it in water. Hydrated lime is particularly useful and cost effective in large flow, high acidity situations where a lime treatment plant with a mixer/aerator is constructed to help dispense and mix the chemical with the water (Skousen and Ziemkiewicz 1995). However, due to the kinetics of lime dissolution and its neutralization efficiency, increasing the lime rate above that required for acid neutralization increases the volume of unreacted lime that enters the metal floc settling pond. Hydrated lime can be purchased in 50-pound bags or in bulk. Bulk lime is preferred by mine operators due to cost and handling advantages. It can be delivered by barge, truck, or train to many sites and handled pneumatically. Proper storage of hydrated lime is important in order to maintain its flow characteristics and thus ensure efficient use. The appropriate silo volume depends on the daily lime requirement, but should be large enough to hold the amount of hydrate needed to last between scheduled deliveries with a safety margin to cover periodic unexpected delivery delays. The length of time that the system will be in operation is a critical factor in determining the annual cost of a lime treatment system due to the large initial capital expenditure that can be amortized over time. The topography of the site is also an important cost factor with design and structural costs increasing as the slope of the site increases.

Pebble Quicklime

CaO, has been recently used in conjunction with the Aquafix Pebble quicklime, Water Treatment System utilizing a water wheel concept (Jenkins and Skousen 1993). The amount of chemical applied is dictated by the movement of the water wheel, which causes a screw feeder to dispense the chemical. The hopper and feeder can be installed in less than an hour. This system was initially used for small and/or periodic flows of high acidity because calcium oxide is very reactive. Recently, however, water wheels have been attached to large bins or silos for high flow/high acidity situations. Preliminary tests show an average of 75% cost savings over caustic systems and about 20 to 40% savings over ammonia systems.

Soda Ash

Soda ash is generally used to treat AMD in remote areas with low flow and low amounts of acidity and metals, but its use is declining. Selection of soda ash for treating AMD is usually based on convenience rather than chemical cost. Soda ash comes as solid briquettes and is gravity fed into water by the use of hoppers mounted over a basket or barrel. The number of briquettes to be used each day is determined by the flow and quality of the water to be treated. One problem with the basket-hopper system is that the briquettes absorb moisture, causing them to expand and stick to the corners of the hopper. This hinders the briquettes from dropping into the AMD stream. For short-term treatment at isolated sites, some operators use a much simpler system employing a box or barrel with holes that allows water inflow and outflow. The operator fills the box or barrel with briquettes on a regular basis and places the box or barrel in the flowing water. This system offers less control of the amount of chemical used.

Caustic Soda

Caustic soda is often used in remote locations (e.g., where electricity is unavailable), and in low flow, high acidity situations. It is commonly the chemical of choice if manganese concentrations in the AMD are high. The system can be gravity fed by dripping liquid caustic directly into the AMD. Caustic is very soluble in water, disperses rapidly, and raises the pH of the water quickly. Caustic should be applied at the surface of ponded water because the chemical is more dense than water and sinks. The major drawbacks of using liquid caustic for AMD treatment are high cost and dangers in handling.

Tanks housing caustic soda can range in volume from 500 to 8,000 gallons. Large tanks are usually placed on a cement platform to limit the tendency for the tank to slip or twist as the ground swells and contracts with temperature changes. The discharge line is fixed at the bottom of the tank and transports the caustic solution to the seep, ditch, or pond. The rate of flow is controlled by a gate valve placed at the end of the discharge line.

Liquid caustic can freeze during winter months, but there are several options available to deal with the freezing problem. These include burying the caustic tank, installing a tank heater, switching from a 50 percent to a 20 percent caustic solution, using a freeze-proof solution containing some potassium hydroxide (KOH), and utilizing solid caustic. Burying a caustic tank is expensive because the operation must then comply with stringent EPA underground storage tank regulations. Heaters must be replaced often because of the corrosive effects of caustic. Of these options, the three most economical solutions are switching to the 20 percent caustic solution, adding some KOH, and switching to solid caustic. Switching from a 50 percent to a 20 percent caustic solution lowers the freezing point from 0^{o}C to about -37^{o}C. The addition of KOH (35% of the solution) also lowers the freezing point. Solid caustic, which may be delivered in 70-pound drums, beads, or flakes, has been used with good success. It is possible to regulate the rate at which solid caustic dissolves by metering the flow of water into the drum. Solid caustic can be used to make liquid caustic. A 20% solution of caustic requires 1.8 pounds of solid caustic to be dissolved in a gallon of water. Making a liquid solution from solid caustic is not cost effective when liquid caustic can be purchased, but the use of solid caustic for treating AMD is cost effective when compared to soda ash briquettes.

Ammonia

Ammonia, the common term for anhydrous ammonia, is a material that must be handled carefully (Hilton 1990). A gas at ambient temperatures, ammonia is compressed and stored as a liquid but returns to the gaseous state when released into water. In the gaseous state, ammonia is extremely soluble and reacts rapidly. It behaves as a strong base and can easily raise the pH of receiving water to 9.2. At pH 9.2, it buffers the solution to further pH increases, and therefore very high amounts of ammonia must be added to elevate the pH beyond 9.2. Injection of ammonia into AMD is one of the quickest ways to raise water pH. It should be injected into flowing water at the entrance of the pond to ensure good mixing because ammonia is lighter than water. The most promising aspect of using ammonia for AMD treatment is its cost, especially compared to caustic soda. A cost reduction figure of 50% to 70% can be realized when ammonia is substituted for caustic if the target pH for metal precipitation is <9.8 (Skousen et al. 1990). Major disadvantages of using ammonia include: 1) hazards associated with handling the chemical, 2) potential biological implications, and 3) the consequences of excessive application rates (Faulkner 1990). Specialized training and experience are important for the safe use of ammonia. Operators using ammonia are required to conduct additional analyses of discharge water where it is released into the stream and to monitor the biological conditions downstream. The extra analyses include temperature, total ammonia-N, and total acidity.

Operators must be careful to inject the appropriate amount of ammonia due to the potential consequences of excessive ammonia application. While ammonia can be effective for manganese removal in many cases, this requires careful monitoring and attention. Therefore, in situations where manganese is the ion of primary concern (low iron, high manganese water), a different chemical may be more appropriate. Low flow in the receiving stream may also require the substitution of another neutralizing chemical during dry conditions due to ammonia's toxic un-ioned state under these conditions (Faulkner 1990).

Costs of Treating AMD

Costs have been developed for five AMD treatment chemicals under four sets of flow (gpm) and acid concentration (mg/l) conditions (Table 2). These conditions are: (1) 50 gpm and 100 mg/l; (2) 1000 gpm and 100 mg/l; (3) 250 gpm and 500 mg/l; (4) 1000 gpm and 2500 mg/l. These conditions represent a sufficiently wide range for valid comparison of the treatment systems.

The costs for each technology were divided into two broad categories: installation cost and variable cost. Each of these can be broken down into several sub-categories. For example, installation cost includes materials, equipment, and labor. Materials consist of piping, extra material for the system foundation, and additional site preparation. Equipment includes conventional machinery and/or actual system hardware. Labor costs are based on man hours at a current union wage scale of $27 an hour. Variable cost includes reagent cost, annual labor, and maintenance. The amount of reagent was computed using acid neutralization formulas presented in Skousen and Ziemkiewicz (1995), but neutralization efficiencies were not included in the reagent calculation. Annual labor is estimated man-hours to run the system for one year multiplied by the current union scale of $27 an hour. Other variable costs include repair costs and electricity (Phipps et al. 1991).

The prices for the reagents, equipment, and labor were based on actual costs to mining operators in West Virginia in May 1996. All dollar values are in 1996 U.S. dollars. The net present value (NPV) is the value of the total treatment system plus annual operating and chemical expenses over the specified duration of treatment. A rate of 6% per year was used to devalue the dollar during future years of the treatment period. The annualized cost was obtained by converting the total system cost (NPV) to an equivalent annual cost so that each system could be compared equally on an annual basis. The parameters used in the analysis were entered in a spreadsheet and can be varied to conform to local conditions.

Use of soda ash has the highest labor requirements (10 hours per week) because the dispensers must be filled by hand and inspected frequently (Table 2). Caustic soda has the highest reagent cost per mole of acid- neutralizing capacity and soda ash has the second highest. But remember, soda ash is much more inefficient in treating water than caustic. Hydrated lime treatment systems have the highest installation costs of the four technologies because of the need to construct a lime treatment plant and install a pond aerator. However, the cost of hydrated lime is low. The combination of high installation costs and low reagent cost make hydrated lime systems particularly appropriate for long term treatment of high flow/high acid situations.

For a five-year treatment period, ammonia has the lowest annualized costs for the low flow/low acid situation (Table 2). Pebble quicklime was similar to ammonia in cost, and caustic was third. Soda ash is fourth because of its high labor and reagent costs, and hydrated lime is fourth because of its high installation costs. With the intermediate flow and acid cases, ammonia is the most cost effective, with pebble quicklime second. Hydrated lime and soda ash were next. Caustic soda is the most expensive alternative with these intermediate conditions. In the highest flow/acidity category, pebble quicklime and

hydrated lime are clearly the least costly treatment systems, with an annualized cost of $260,000 less than ammonia, the next best alternative. The use of soda ash and caustic is prohibitively expensive at high flow and high acidity.

Other Aspects of AMD Treatment Technologies

Other Neutralizing Chemicals

While the primary AMD chemicals and applications have been discussed, particular circumstances may require a different chemical, a combination of chemicals, particular management patterns to implement the most cost effective method, or to meet more stringent effluent limits. Several operators have used potassium hydroxide, magnesium hydroxide, and magna lime with good results (Table 3). Potassium hydroxide is used because it is safer to use than caustic and reduces the potential for over treatment, but it is more expensive than caustic. Magnesium hydroxide and magna lime are dispensed in a manner similar to and behave like calcium hydroxide, but tend to be more expensive.

Table 2. Costs in 1996 of six chemicals to treat acid mine drainage in West Virginia. The analysis is based on a five-year operation period and includes chemical reagent costs, installation and maintenance of equipment, and annual operating costs. The "<Bulk" chemical prices in Table 1 were used to calculate the reagent costs for only the 50 gpm flow. The "Bulk" prices were used for higher flows. Neutralization efficiencies were not included in the reagent cost calculation.

Flow and Acidity Conditions				
Flow (gpm)	50	1000	250	1000
Acidity (mg/l)	100	100	500	2500
CHEMICAL				
Soda Ash				
reagent costs	$3,731	$44,000	$58,300	$1,166,000
repair costs	0	0	0	0
annual labor	14,040	14,040	14,040	14,040
installation costs	229	229	229	229
salvage value	0	0	0	0
Net present value	75,052	244,679	245,774	4,911,804
Annualized cost	$17,817	$58,086	$58,346	$1,166,046
Ammonia				
reagent costs	$2,543	$22,440	$28,050	$561,000
repair costs	495	495	495	495
tank rental	480	1,200	1,200	1,200
annual labor	7,020	7,020	7,020	7,020
electricity	600	600	600	600
installation costs	1,936	6,357	6,357	6,357
salvage value	0	0	0	0
Net present value	48,547	139,117	162,749	2,407,725
Annualized cost	$11,525	$33,026	$38,636	$571,586
Caustic Soda (20% Liquid)				
reagent costs	$5,174	$79,341	$99,176	$1,983,520

repair costs	0	0	0	0
annual labor	7,020	7,020	7,020	7,020
installation costs	283	5,478	5,478	5,478
salvage value	0	0	0	0
Net present value	51,601	368,398	451,950	8,389,433
Annualized cost	$12,250	$87,457	$107,292	$1,991,636
Pebble Quicklime				
reagent costs	$1,478	$9,856	$12,320	$246,400
repair costs	500	2,500	2,500	10,000
annual labor	6,500	11,200	11,200	11,200
electricity	0	0	0	0
installation costs	16,000	80,000	80,000	120,000
salvage value	0	5,000	5,000	20,000
Net present value	49,192	162,412	172,790	1,127,220
Annualized cost	$11,678	$38,556	$41,020	$267,600
Hydrated Lime				
reagent costs	$814	$9,768	$12,210	$244,200
repair costs	1,000	3,100	3,500	10,500
annual labor	6,500	11,232	11,232	11,232
electricity	3,500	11,000	11,000	11,000
installation costs	58,400	102,000	106,000	200,000
salvage value	5,750	6,500	7,500	25,000
Net present value	94,120	228,310	242,809	1,313,970
Annualized cost	$22,344	$54,200	$57,642	$311,932

Flocculants and Coagulants

Other chemicals used sparingly in AMD treatment include flocculants or coagulants, which increase particle settling efficiency (Table 3). These materials are usually limited to cases where unique metal compositions require a specialized treatment system, or where aeration and/or residence time in settling ponds are insufficient for complete metal precipitation. Coagulants reduce the net electrical repulsive forces at particle surfaces, thereby promoting consolidation of small particles into larger particles. Flocculation aggregates or combines particles by bridging the space between particles with chemicals. Bridging occurs when segments of a polymer chain absorb suspended particles creating larger particles (Skousen et al. 1993).

The most common coagulants/flocculants used in water treatment are aluminum sulfate (alum) and ferric sulfate. These materials are also called polyelectrolytes and produce highly charged ions when dissolved in water. Anionic polymers dissolve to form negatively-charged ions that are used to remove positively-charged solids. The reverse occurs with cationic flocculants. Polyampholytes are neutral, but when dissolved in water release both positively- and negatively-charged ions. Flocculants may be added to water as a liquid, or more commonly, placed in water as a gelatinous solid ("floc" logs).

Oxidants

Aeration is the process of introducing air into water. Oxidation occurs when oxygen in air combines with metals in the water. If the water is oxidized, metals generally will precipitate at lower pH values. For this reason, aeration of water can be a limiting factor in many water treatment systems. If aeration and oxidation were incorporated or improved in

the treatment system, chemical treatment efficiency would increase and costs could be reduced. Oxidants (Table 3) are sometimes used to aid in the completion of the oxidation process to enhance metal hydroxide precipitation and reduce metal floc volume. The hypochlorite products, hydrogen peroxide, and potassium permanganate are used in AMD situations and have demonstrated very effective oxidation. Calcium peroxide has been shown to oxygenate AMD as well as neutralize acidity (Lilly and Ziemkiewicz 1992).

Residence Time in Ponds and Floc Generation

After chemical treatment, the treated water flows into sedimentation ponds so metals in the water can precipitate. Dissolved metals precipitate from AMD as a loose, open-structured mass of tiny grains called "floc". All chemicals currently used in AMD treatment cause the formation of metal hydroxide sludge or floc. Sufficient residence time of the water, which is dictated by pond size and depth, is important for adequate metal precipitation. Hilton (1993) found pond size to be too small on most AMD treatment sites to result in complete treatment of the water and precipitation of dissolved metals. The amount of metal floc generated by AMD neutralization depends on the quality and quantity of water being treated, which in turn determines how often the ponds must be cleaned. Knowing the chemical and AMD being treated will help determine the general floc properties and will provide an estimate of the stability of the various metal compounds in the floc.

Ackman (1982) investigated the chemical and physical characteristics of AMD floc and concluded that each floc varied depending on the nature of the AMD, the neutralization chemical, and the mechanical mixing or aeration device used during chemical treatment. He stated the most important physical property is the floc's settleability, which includes both the settling rate and final floc volume. Ackman found that calcium hydroxide and sodium carbonate produced a granular, dense floc versus a more gelatinous, loose floc generated by sodium hydroxide and ammonia. The chemical compositions of flocs were generally composed of hydrated ferrous or ferric oxyhydroxides, gypsum, hydrated aluminum oxides, calcium carbonate and bicarbonate, with trace amounts of silica, phosphate, manganese, copper, and zinc.

Payette et al. (1991) found that AMD neutralized by calcium hydroxide resulted in the formation of crystalline gypsum as well as various amorphic metal hydroxides. AMD floc was mostly amorphous at 1 hour after formation, while crystals were observed in the floc 24 hours after formation. In a series of experiments on floc generation and stability, Brown et al. (1994 a, b, c) found:

1. More floc was produced as the pH of the AMD solution was increased by chemical addition.

2. Using four AMD types, each was unique in its reaction to four neutralization chemicals.

3. The amount of floc produced as a function of the amount of chemical added (termed its "efficiency") remained about the same across all pH ranges for calcium hydroxide, sodium hydroxide, and sodium carbonate. Ammonia became less efficient at high pH.

4. Sodium carbonate was needed in the highest amount to raise water pH to 7.5 or greater.

5. Floc volumes were lowest with sodium carbonate and highest with calcium hydroxide after 1 week of settling.

6. Greater settling time caused floc consolidation.

7. Flocs were composed of metals in ratios similar to the metal ratios of the AMD from which it was generated.

8. Flocs were primarily amorphic (having no crystalline structure), except for sodium carbonate flocs.

9. Flocs collected from ponds on mined areas showed little similarity in composition to flocs generated with the same AMD and chemical in the laboratory. The field flocs had soil particles mixed with the chemical floc.

10. Aging of AMD flocs caused them to be more stable, thereby decreasing their likelihood of releasing metals (Watzlaf and Casson 1990). The greater stability of aged flocs remained even after re-introducing the flocs into acidic solutions. Aging in a dry environment resulted in better floc stability than flocs aged under water. Aging also caused floc consolidation.

Floc disposal options include: 1) leaving the floc submerged in a pond indefinitely, 2) pumping or hauling floc from ponds to abandoned deep mines or to pits dug on surface mines, and 3) dumping floc into refuse piles. Flocs pumped or dumped onto the surface of land or mixed with overburden during backfilling and allowed to age and dry is a good strategy for disposal. In its oxidized and dried condition, AMD flocs can become crystalline and become part of the soil. Injecting stable floc containing excess alkalinity into acidic deep mine pools has the potential to improve the quality of the discharge from those pools. Injection into abandoned mine works is cost-effective where field conditions allow its safe disposal.

Lovett and Ziemkiewicz (1991) estimated ammonia chemical costs for a site in West Virginia at $72,000 per year and floc handling costs of $486,000 per year. Based on a flow of 100 gpm for this site, Brown et al. (1994b) estimated that this site generated approximately 77,900 cubic yards of floc per year. Dividing $486,000 by 77,900 cubic yards of floc yields a cost of $6.25 per cubic yard for floc handling and disposal on this site. Several mine operators observed that floc handling and disposal may cost up to $15 per cubic yard. Due to their high water content and the sheer volume of material, floc handling costs frequently exceed chemical costs by several times.

Each AMD is unique and the chemical treatment of any particular AMD source is site specific. Each AMD source should be tested with various chemicals by titration tests to evaluate the most effective chemical for precipitation of the metals. The costs of each AMD treatment system based on neutralization (in terms of the reagent cost and capital

investment and maintenance of the dispensing system) and floc volumes and disposal should be evaluated to determine the most cost effective system.

Table 3. Chemicals for acid neutralization, coagulation/flocculation, and oxidation.

NAME	CHEMICAL FORMULA	COMMENTS
Acid Neutralization		
Limestone	$CaCO_3$	Used in anoxic limestone drains and open limestone channels.
Hydrated Lime	$Ca(OH)_2$	Cost effective reagent, but requires mixing.
Pebble Quick Lime	CaO	Very reactive, needs metering equipment.
Soda Ash Briquettes	Na_2CO_3	System for remote locations, but expensive.
Caustic Soda	NaOH	Very soluble, comes as a solid in drums, beads, or flakes, or as a 20% or 50% liquid. Cheaper in the liquid form.
Ammonia	NH_3 or NH_4OH	Very reactive and soluble; also purchased as aqua ammonia.
Potassium Hydroxide	KOH	Similar to caustic.
Magnesium Hydroxide	$Mg(OH)_2$	Similar to hydrated lime.
Magna Lime	MgO	Similar to pebble quicklime.
Calcium Peroxide	CaO_2	Used as a neutralizer and oxidant; either powder or briquettes.
Kiln Dust	CaO, $Ca(OH)_2$	Waste product of limestone industry. Active ingredient is CaO with various amounts of other constituents.
Fly Ash	$CaCO_3$, $Ca(OH)_2$	Neutralization value varies with each product.
Coagulants/Flocculants		
Alum (aluminum sulfate)	$Al_2(SO_4)_3$	Acidic material, forms $Al(OH)_3$.
Copperas (ferrous sulfate)	$FeSO_4$	Acidic material, usually slower reacting than alum.
Ferric Sulfate	$Fe_2(SO_4)_3$	Ferric products react faster than ferrous.
Sodium Aluminate	$NaAlO_2$	Alkaline coagulant.
Anionic Flocculants		Negatively-charged surface.
Cationic Flocculants		Positively-charged surface.
Polyampholytes		Both positive and negative charges on surface based on pH.
Oxidants		
Calcium Hypochlorite	$Ca(ClO)_2$	Strong oxidant.
Sodium Hypochlorite	NaClO	Also a strong oxidant.
Calcium Peroxide	CaO_2	Trapzene, an acid neutralizer.
Hydrogen Peroxide	H_2O_2	Strong oxidant.
Potassium permanganate	$KMnO_4$	Very effective, commonly used.

Summary

Acid mine drainage occurs when geologic materials containing metal sulfides are exposed to oxidizing conditions. Subsequent leaching of reaction products into surface waters pollute over 20,000 km of streams in the U.S. Chemicals used for treating AMD after formation are hydrated lime, pebble quicklime, caustic soda, soda ash briquettes, and ammonia. Each chemical has advantages for certain water conditions and treatment. Under low flow situations, pebble quicklime and ammonia are the most cost effective. Under high flow situations, hydrated lime and pebble quicklime are the most cost effective due to their low reagent cost compared to the other chemicals. Each chemical reacts differently with a specific AMD. Therefore, it is essential that each AMD source be treated and evaluated with each chemical to determine which is most environmentally sound, efficient and cost effective. Coagulants and flocculants may be used in water treatment where retention time in sedimentation ponds is insufficient for metal precipitation. Oxidants can be used to meet more stringent effluent limits and to make chemical treatment more efficient. Floc, the metal hydroxides collected in ponds after chemical treatment, are disposed of in abandoned deep mines, refuse piles, or left in collection ponds. Studies show that flocs are relatively stable materials and metals contained therein do not resolubilize after disposal, especially if aged and dried.

Acknowledgments

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Appendix 4

Glossary of Acid Drainage Terms

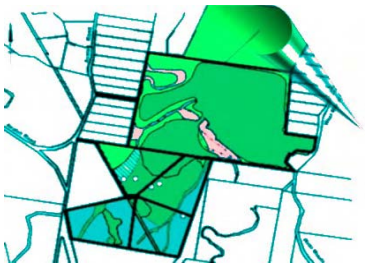
Glossary of Acid Drainage Terms

Term	Abbrev.	Explanation
Acid Base Accounting	ABA	A static test that defines the amounts and relative balance of potentially acid-generating and acid-neutralising minerals in a sample.
Acid Drainage	AD	Low pH drainage derived from the oxidation of sulfidic materials. In mining, AD typically occurs as runoff or seepage from excavations, waste rock stockpiles, tailings impoundments or coal rejects.
Acid Neutralization Capacity	ANC	The bulk capacity of a sample to neutralize acidity determined as part of the Acid Based Accounting (ABA) procedure. Units are kg H_2SO_4 per tonne of sample.
Acid Mine Drainage	AMD	Refer acid drainage ... Acidic drainage produced from mining components resulting from oxidation of sulfidic materials.
Acid Rock Drainage	ARD	A variation on Acid Mine Drainage (AMD) that may include natural acidic drainage from rock not directly connected with mining activity (eg quarrying, civil construction excavations).
Chromium Reducible Sulfur	CRS	A test whereby only the oxidisable sulfide sulfur content of a sample is measured. The test is used to replace the NAG test particularly when a sample also contains organic matter and organic sulfur, neither of which will oxidize in air to yield acid.
Maximum Potential Acidity	MPA	Total sulfur content of a sample with stoichiometric conversion to disulfide as part of the ABA procedure. Units kg H_2SO_4 per tonne of sample.
Net Acid Generating Potential	NAGP	NAG test. This test rapidly and forcibly oxidizes a pulverized rock sample with hydrogen peroxide to generate the full potential acid yield of the sample. Any intrinsic minerals with acid neutralizing capacity react with the acid as it is produced. The result is the net acid generating capacity for the sample expressed in kg H_2SO_4 per tonne of sample. The test can over estimate acid generating potential of a sample if it contains significant organic matter.
Net Acid Producing Potential	NAPP	NAPP = MPA – ANC. Units kg H_2SO_4 per tonne of sample. Determined as part of the ABA procedure.
Non Acid Forming	NAF	An environmental risk based assessment term to indicate the low risk of a sample of earth material to generate unacceptable acid drainage or unacceptable quality of near neutral drainage.
Potentially Acid Forming	PAF	An environmental risk based assessment term to indicate the moderate to high risk of a sample of earth material to produce unacceptable acid drainage.

Appendix 5

Ecoroc Pty Ltd – Capability Statement

ECOROC Company Profile



ECOROC Pty Ltd is a specialist consultancy firm providing strategic and operational management and engineering services to organizations with interests in the aggregates and extractive industry sectors.

ECOROC has a track record of success in providing a range of extractive industry consultancy services to both the public and private sector.

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- Economic and industry profiling
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- Market analysis and strategy
- Operational improvements
- Project management
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- Recycling. secondary aggregate and fly-ash markets and opportunities
- Royalty advice
- Strategic advice and scenario planning
- Sustainable development strategies for quarries

ECOROC was established in 2000 by Dugald Gray, a mining engineer with wide-ranging business and project management skills in quarrying, construction materials and civil infrastructure development.

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