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The Department of Communications, Energy and Natural Resources

Feasibility Study for Management and Remediation of the Avoca Mining Site

Feasibility Study

December 2008

Report

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Contents

Section 1 Study Objectives and Scope of Work

Section 2 Site Description

Section 3 Remedial Action Objectives

Section 4 General Response Actions, Remedial Technologies, and Process Options

Section 5 Development of Preliminary Remedial Action Alternatives

Section 7 Comparative Analysis of Combined Alternatives

Section 8 References

Appendices

Figures

Tables

Acronyms

µg/l	micrograms per liter
$1x10^{-6}$	one in one million
ADTs	articulated dump trucks
AET	actual evapotranspiration
AMD	acid mine drainage
AR	available recharge
ARD	acid rock drainage
BAFs	bioaccumulation factors
BERA	Baseline Ecological Risk Assessment
BMI	benthic macroinvertebrates
CDM	Camp Dresser & McKee Inc.
CEC	cation exchange capacity
cms	cubic metres per second
COC	contaminants of concern
CSF	cancer slope factors
CSM	Conceptual Site Model
EAs	exposure areas
EMP	electronmicroprobe
ETP	Emergency Tailings Pond
EPA	Environmental Protection Agency (Ireland)
EPC	exposure point concentration
ERA	Ecological Risk Assessment
ERFB	Eastern Regional Fisheries Board
ES	Ecological Solids
EW	Ecological Water
FD	frequency of detection
FS	feasibility study
GRAs	general response actions
GSI	Geological Survey of Ireland
HDPE	high density polyethylene
HHRA	Human Health Risk Assessment
HHS	Human Health Solids
HHW	Human Health Water
HI	hazard index
HQ	hazard quotient
IEUBK	Integrated Exposure Uptake Biokinetic
IQ	Intelligence Quotient
kg/day	kilograms per day
km	Kilometers
km^2	square kilometers
l/s	Litres per second
m	Metres
m^2	square metres
m^3	cubic metres

mg/kg	milligrams per kilogram
mg/l	milligrams per liter
mm	Millimeters
mm/yr	millimetres per year
Mt	million tones
NA	not applicable, not analyzed, or not available
P	Precipitation
PET	potential evapotranspiration
PH	Physical Hazards
PRGs	preliminary remediation goals
RAOs	remedial action objectives
RfD	reference dose
RME	reasonable maximum exposure
SCEM	site conceptual exposure model
SHA	Seán Harrington Architects
Site	Avoca Mine Site
TDS	total dissolved solids
TRV	toxicity reference values
TSS	total suspended solids
UCL	Upper Confidence Level
USEPA	United States Environmental Protection Agency
ZOC	zone of contribution

Section 1
Study Objectives and Scope of Work

1.1 Background

The Avoca River watershed above Arklow, County Wicklow, is situated in a rural, residential, agricultural, tourist, and, to a lesser extent, industrial area. Mining for copper and pyrite (iron sulfide, FeS_2) occurred in the Avoca district for over 230 years and ceased in 1982. Historic mining, milling, and smelting at the East Avoca and West Avoca mining sites, and tailings disposal at the Shelton Abbey site, have left contaminated waste materials (spoils) on the surface and in the waters; surface waters and waterways have been impacted by high metal concentration acid drainages and discharges; and unsafe conditions exist as a result of abandoned shafts and adits, unstable piles and pit walls, and potential subsidence. In addition, the area contains many historic structures of industrial archaeological, heritage, and cultural importance including engine houses, the Tramway Arch, and the Tigroney Ore Bins. Some of the structures (e.g., the Ore Bins) are unsafe and need repair.

In order to address the concerns associated with the historic mining areas and Avoca River watershed, the Minister for Communications, Energy and Natural Resources appointed Camp Dresser & McKee Inc. (CDM) to conduct a feasibility study (FS) for management and remediation of the Avoca Mining Site including the Shelton Abbey tailings facility (the Site). The work was conducted under the direction of the Geological Survey of Ireland.

1.2 Objectives of Feasibility Study

The overall objective of the feasibility study was to prepare a realistic, cost-effective, and achievable integrated management plan for the Site that addresses the many issues at the Site including human and ecological concerns, safety and physical hazards, heritage, future uses, and long-term site management.

This objective was achieved by conducting investigations and evaluations in the following two phases:

Phase 1

- Conduct a safety audit and physical hazard assessment of the Site in its present state.
- Review existing information and documentation for the Site and identify any additional information required.
- Conduct preliminary risk assessments based on existing information of the Site in relation to the potential risks posed to human health, animal health, and the wider environment. The preliminary risk assessments will assist in the identification of deficiencies in existing information and will help identify suitable remediation options for the Site.

- Provide a preliminary evaluation on the range of potential options for remediation and management of the Site, together with the major advantages and disadvantages of each, and the principal constraints that will affect the choice of solutions.
- Identify sites of industrial archaeological importance.
- Identify and interact with key stakeholders.

Phase 2

- Conduct the approved programme of sampling, data collection, and analysis from Phase 1 to supplement and confirm the information collected in Phase 1.
- Update the preliminary risk assessments carried out in Phase 1, with data and analysis collected during Phase 2, including the development of a conceptual site model, which identifies all possible significant sources, pathways, and receptors as well as the processes that are likely to occur along each of the linkages. The results from this work will assist in identifying management and/or remediation options for the Site.
- Consult with interested and affected parties.
- Prepare management and/or remediation options for the Site and the component sub-sites (e.g., open pits, tailings impoundments, waste piles, mine discharges, contaminated streams, and sediments), including where appropriate alternative management and/or remediation options for different sub-sites identifying the advantages and disadvantages and commenting on the long-term effectiveness of each option.
- Provide cost estimates, both capital and operating, at feasibility level and timescales for implementing those options.
- Develop a scheme to monitor the environmental status of the Site.
- Prepare and present a final report and recommendations to the Department of Communications, Energy and Natural Resources.

1.3 The Feasibility Study Approach

The feasibility study was conducted following the approach shown in Figure 1-1. During preliminary (Phase 1) evaluations conducted in May 2007, existing data and limited new data collected in April 2007 were used to prepare the following evaluations:

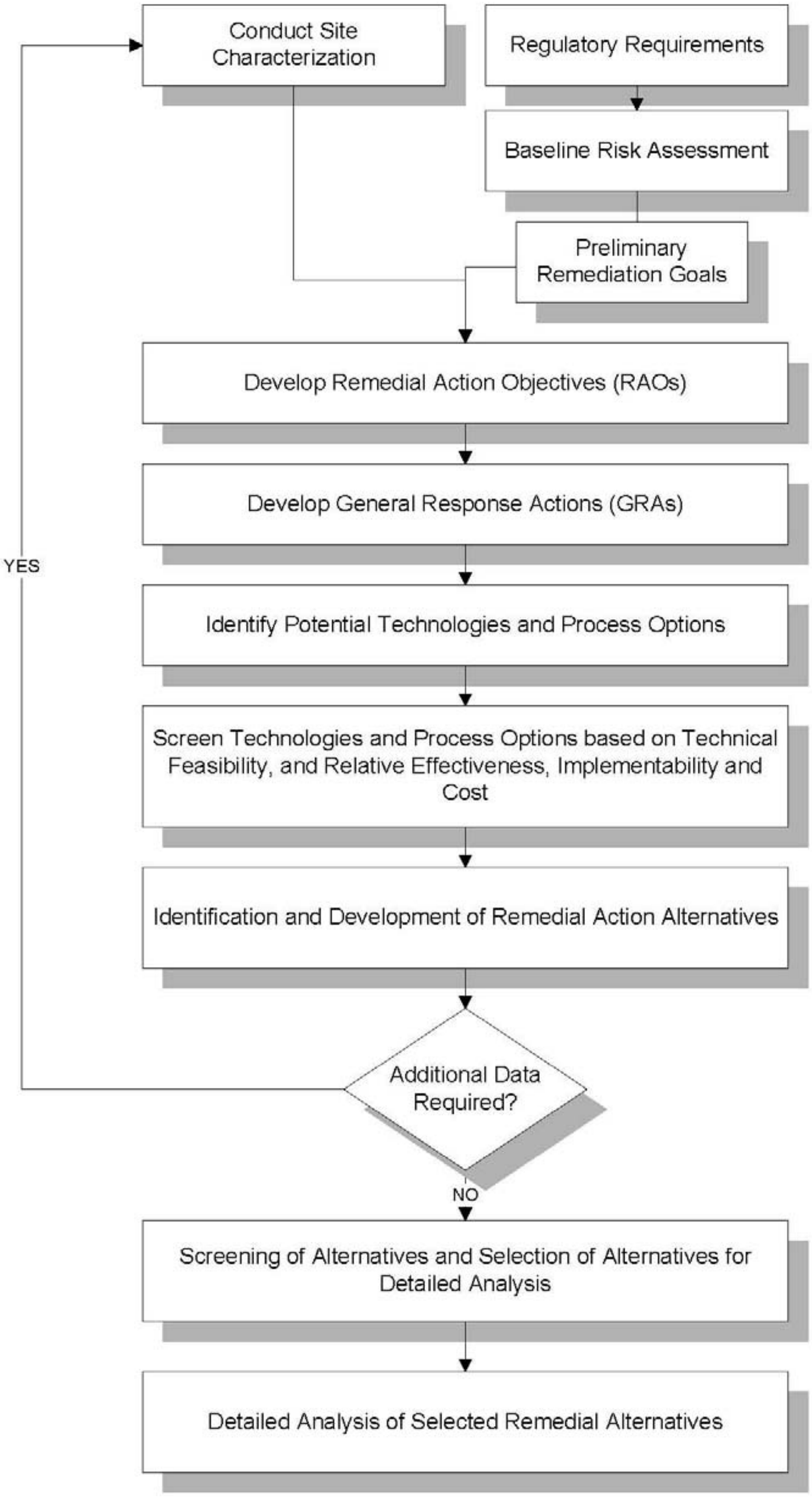


Figure 1-1 General Feasibility Study Approach

- Preliminary site conceptual hydrogeological and geochemical model
- Preliminary human health risk assessment
- Preliminary ecological risk assessment
- Preliminary remedial alternative evaluation

Based on these evaluations, data gaps were identified and then investigated during field studies conducted in July/August and November 2007 and February 2008. The Phase 1 evaluations included a preliminary identification and assessment of potential remedial alternatives. This evaluation followed the process outlined in Figure 1-1 and was the precursor to this document. As shown in Figure 1-1, the identification and evaluation of management and remediation alternatives is performed in conjunction with other studies (e.g., human health risk assessment) and follows the feasibility study approach of developing remedial action objectives and identifying potential treatment, containment, removal, and disposal technologies that satisfy the remedial action objectives. The technically feasible technologies are evaluated based on effectiveness, implementability, relative cost, and site compatibility. The retained technologies and process options are subsequently assembled into remedial action alternatives, intended to satisfy the remedial action objectives. The remedial action alternatives provide the combinations of technologies and process options most suited for overall site remediation.

1.4 Report Organization

The information presented in this report, *Feasibility Study for Management and Remediation of the Avoca Mining Site*, is organised as follows:

- Section 1 – Study objectives, scope of work, and feasibility study approach

- Section 2 – Site description, background information, nature and extent of contamination, physical hazard summary, human health risk assessment summary, and ecological risk assessment summary

- Section 3 – Summary of the process and information used in determining remedial action objectives and quantitative preliminary remediation goals for the site

- Section 4 – Selection of general response actions and corresponding technologies and process options, and evaluation of the technologies and process options

- Section 5 – Development, description, and evaluation of preliminary remedial action alternatives

- Section 6 – Development of two site-wide combined alternatives

- Section 7 – Comparative analysis of the two site-wide combined alternatives

Section 2
Site Description

2.1 Background Information

2.1.1 Location and Topography

The Avoca mining area is located in the eastern foothills of the Wicklow Mountains some 55 kilometres (km) south of Dublin. The Vale of Avoca, which is considered to be of outstanding scenic beauty, divides the mine sites into East and West Avoca mining areas (see Figure 2-1). The Avoca River flows along this north-south trending steep sided valley, which rises from 30 metres (m) at its base to 180 m on its margins and eventually to 500 m in the mountains to the west. The Avoca River is formed by the confluence of the Avonmore and Avonbeg rivers, 1.5 km upstream of the mining area at the Meeting of the Waters. It is joined by the Aughrim River at Woodenbridge and various small streams in the vicinity of the mine sites, and flows into the Irish Sea at the town of Arklow, 10 km to the southeast of the mining area.

Figure 2-1 provides a map of the Site showing major features. The Site includes the East and West Avoca mining areas, the Shelton Abbey Tailings Facility, and the surface waters in the vicinity of these mining and disposal areas. The study area includes from above the Meeting of the Waters to below Shelton Abbey Tailings Facility. Figures 2-2 and 2-3 provide more detailed maps of the East and West Avoca areas, respectively, and show all features discussed in this document.

The East and West Avoca mine sites cover 0.34 square kilometres (km^2) and 0.29 km^2, respectively, extending from the Avoca River onto the higher ground on either side of the valley to the northeast and southwest. The surface water and groundwater drainage from the Site has been heavily modified and groundwater levels are depressed as a result of mining. The East Avoca area mainly drains through the 19th Century Deep Adit and flows into the Avoca River through a short surface channel. There are also a few smaller higher-level discharges that either return underground or flow into small streams. West Avoca is drained by the 19th Century Road Adit beside the main Avoca/Rathdrum Road and flows through a ditch and pipe into the Avoca River.

Outside the mine sites, the land is a mixture of forestry and pasture with scattered farms and some small groups of houses. The mine sites themselves contain entrances to shafts and adits (mainly sealed), several open-pits, and numerous waste piles with limited vegetation. There are various other mining features such as ochre pits and engine houses, some of which are of heritage interest. The former Pond Lode Pit (Ballymurtagh) open pit was used as a domestic landfill operated by Wicklow County Council. The landfill is now closed and has been rehabilitated.

Fig 2-1 Site Map

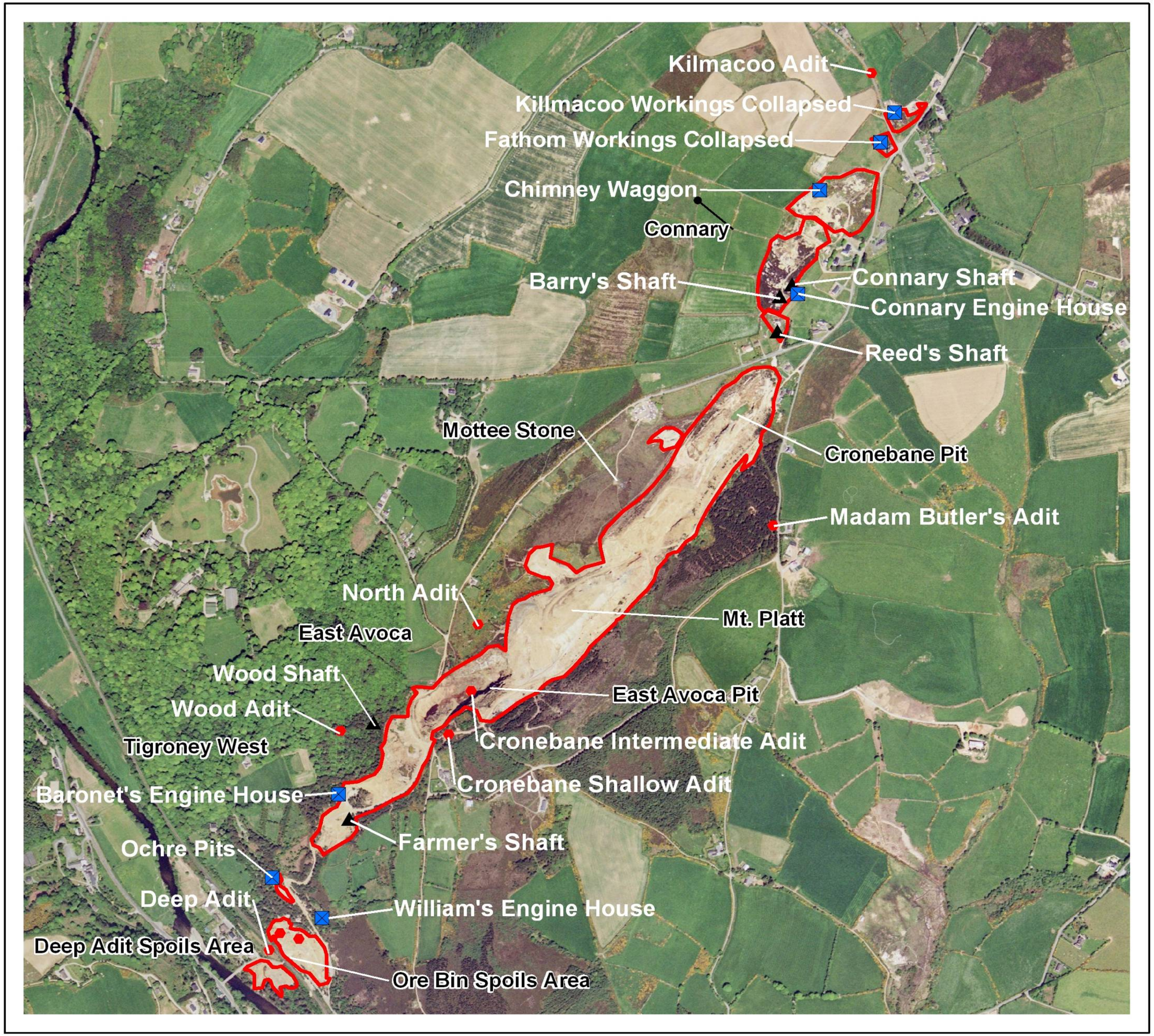


Figure 2-2
Site Features - East Avoca

OSI Licence No - EN 0047 207

Legend

- ▭ Spoils and Mining Areas
- ● Adits
- ▲ Shafts
- ■ Mine Features

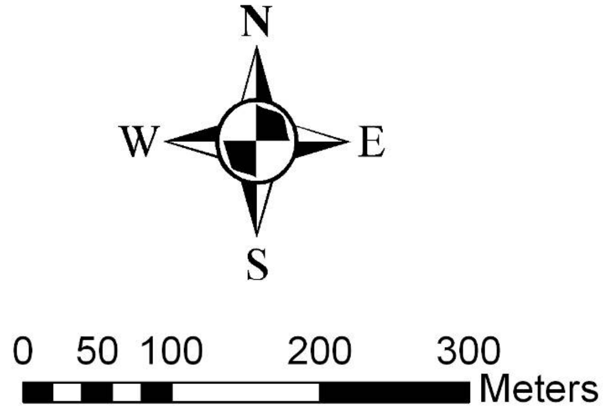


Figure 2-3
Site Features - West Avoca

OSI Licence No - EN 0047 207

2.1.2 Geology

The mineralised zone at Avoca is hosted in the Ordovician Avoca Formation that consists of tuffs (consolidated volcanic ash) and felsites (volcanic or extrusive igneous rocks) interbedded with slaty mudstones. The rocks trend northeast/southwest and are generally steeply-dipping to the southeast, but there are tight folds a few hundred metres wide. The main ore zones, from which copper and pyrite (FeS_2) were extracted, occur as generally stratiform lenses up to a few tens of metres thick at the top of a sequence of tuffs and felsites.

There are numerous shear zones and a series of north-south trending faults, one of which (the Great Fault) runs close to the Avoca River and displaces the western orebodies southward relative to the eastern ones.

There are three main ore types:

- Banded sulphides with more than 95 percent pyrite (FeS_2) accompanied by chalcopyrite ($CuFeS_2$), sphalerite (ZnS), and galena (PbS)
- Vein or disseminated ore invariably associated with silicification and containing pyrite and chalcopyrite
- Lead-zinc ore (galena and sphalerite) with banded pyrite

All three have minor quantities of arsenic and bismuth minerals.

The uppermost 30 to 60 m of the deposits have been oxidised. The most important minerals include iron oxides, chalcocite (Cu_2S) and covellite (CuS) together with various copper and iron oxides.

The higher parts of the area, including the mining areas outside the river valley, are generally covered by less than one metre of superficial deposits. The lower-lying areas are blanketed by glacial tills and sands and gravels derived from Lower Palaeozoic lithologies in the area, except in the Avoca River valley, which is covered by more than 10 m of Recent alluvium.

2.1.3 Mining History

Mining has taken place at Avoca since the early 18th Century. The first phase, which lasted until the mid-19th Century, consisted mainly of small-scale underground extraction of narrow high-grade copper veins yielding up to a few thousand tonnes of ore a year. This produced a large number of small interconnecting shafts and levels throughout the 4 km length of the Avoca mining area. Pyrite extraction became significant during the 19th Century, when 1.5 million tonnes (Mt) was produced, mainly from underground, but also from some surface workings (most from the North Lode open pit). By 1888, the mines were abandoned.

Limited exploration and some ochre production occurred in the late 1940s and early 1950s by the State mining company, Mianraí Teoranta. In addition, a new access shaft was started in 1955. Since that time, there have been two periods of large-scale mining production. The first, by St. Patrick's Copper Mines, lasted from 1958 to 1962. A new decline (inclined tunnel) was driven into West Avoca and a new level into East Avoca, both from the river valley. Mining was by open-stoping, sometimes with caving that extended to the surface, and 3.1 Mt of ore grading 0.74 percent copper together with 120,000 tonnes of pyrite, were extracted. The operation was not financially successful and the company went into receivership.

The mine was re-opened in 1969 by Avoca Mines Ltd. In addition to continuing underground extraction in West Avoca using open stoping with backfilling, three open-pits were worked:

- Pond Lode Pit (West Avoca) covering 64,000 square metres (m^2) and up to 50 m deep; 1 Mt of ore was extracted.
- East Avoca Pit covering 20,400 m^2 and with a maximum depth of 40 m; 900,000 tonnes were mined.
- Cronebane Pit (East Avoca) covering 62,000 m^2 and up to 40 m deep; 500,000 tonnes were mined. The pit was 40 percent backfilled.

A total of 8.9 Mt of ore grading 0.73 percent copper, plus 540,000 tonnes of pyrite was mined before closure in 1982.

The estimated remaining resources in the area, based on calculations by Avoca Mines Ltd. (the last operators) are 4.6 Mt grading 0.68 percent Cu in West Avoca and 14.4 Mt grading 0.6 percent Cu, 0.33 percent Pb and 1.19 percent Zn in East Avoca. No figures are available for pyrite but there are substantial tonnages. Mineralisation occurs over a wide area in the district. Prospecting licenses are currently held over the area.

2.1.4 Milling and Tailings Disposal

Ore mined during both the last two periods was treated by conventional flotation producing copper and pyrite concentrates. The resultant tailings (waste materials) were mainly disposed of in a facility located beside the Avoca River at Shelton Abbey 8 km downstream from the mining area. The initial tailings impoundment was constructed in 1955. The dam was formed from sand fraction cycloned tailings in a series of lifts and encloses a 30 ha site. The tailings impoundment was developed on the broad flat alluvial floodplain of the Avoca River. Once the tailings impoundment was constructed, the floor of the valley was artificially raised approximately 20 m above the river. Its elevation has had a significant influence in altering the local hydrological patterns and the vegetation in the area. The tailings impoundment at Shelton Abbey was designed to last for approximately 10 years, at a capacity of 3,000 tonnes per day. However, as mining operations continued into the 1970s, its capacity was extended several times by raising the berms (dam walls). Tailings were transported to the impoundment by pipeline, and on a number of occasions the line was breached, resulting in escape of tailings into the surrounding woodland. No evidence of impact from the spilled tailings has been observed. The ultimate volumes of tailings storage was 7,547,000 cubic metres (m^3).

The main tailings area was remediated by the Receiver to Avoca Mines Ltd. in 1984. The tailings were covered by 200 to 300 millimetres (mm) of shale, overlain by 75 to 100 mm of soil. This was revegetated with conventional agricultural grasses. The site is now generally unmanaged grassland with trees and scrubs on the berms. There is also a pheasant/duck farm on the tailings impoundment.

About 200,000 m^3 of tailings were disposed in a 19th Century open-pit in West Avoca (the North Lode open pit). This disposal area is covered with fine spoil and about a third is vegetated. In addition to disposal in the North Lode open pit, an area on the west bank of the Avoca River just north of the current Wicklow County Council maintenance yard was used as an emergency tailings disposal area. This area is shown on Figure 2-3 and is estimated to contain 129,300 m^3 of tailings. Some tailings were also disposed in the Pond Lode Pit (Ballymurtagh).

Prior to construction of the Shelton Abbey tailings impoundment, the tailings were reported to have been discharged directly into the Avoca River. No evidence of these tailings was observed in the river sediments near or downgradient of the mining area.

Substantial surface dumps of waste rock (spoil piles) were created during surface mining, particularly in East Avoca. The main pile, known locally as "Mount Platt," contains approximately 700,000 m^3 and five other piles total 280,000 m^3. The remaining 31 piles, mainly dating from the 18th to 19th Century, consists of low grade ore left after the limited beneficiation then carried out. They contain about 60,000 m^3 in total. These spoil piles cover some 180,000 m^2, of which 70,000 m^2 is accounted for by Mount Platt. There are eight spoil piles in West Avoca, dating mainly from the 19th Century, covering 70,000 m^2 and containing 190,000 m^3, of which 150,000 m^3 is contained in two of these. More detailed information on the chemical composition and volumes is provided in Section 2.3.3.2. The larger spoil piles consist dominantly of waste rock from open-cast mining.

2.1.5 Acid Rock Drainage from Avoca

The quality of the water in the Avoca River is not documented prior to the commencement of mining in the 18th Century, but acid waters from the mines reduced its quality. The river continues to be significantly contaminated by acid waters with elevated concentrations of heavy metals, which enter the water from adits draining both East and West Avoca. Acid rock drainage (ARD) generated in waste piles and underground workings contribute to these flows.

From 1994 to 1997, discharges varying from 10 l/s to 72 l/s from East Avoca and 8 l/s to 37 l/s from West Avoca were recorded under various monitoring programmes of the two principal drainage adits; the Deep Adit in East Avoca and the Road Adit in West Avoca. The discharges have low pH values and high levels of Fe, Cu, Zn, and Al. More detailed information on the chemical composition is provided in Section 2.3.3.4.

2.1.6 Industrial Archaeology

As previously discussed in Section 2.1.3, Mining History, industrial-scale mining began at Avoca in the early 18th Century and continued intermittently until the mines were closed in 1982, by which time some 12 Mt of ore had been extracted, much of it through open-cast mining. A considerable legacy of this long period of mining activity remains around Avoca in the form of heritage features and industrial archaeology sites. Consideration of this important legacy in the overall context of the remediation options developed for the Avoca Mining Area was very important. To assist with interpretation of the industrial archaeology, Seán Harrington Architects (SHA) updated and reinterpreted their previous work for the Avoca Mining Heritage Trust evaluating the environment in and around the Avoca Mining Area (SHA 2007). The industrial archaeology sites consist of two general types of features:

- Buildings and structures (chimneys, ore bins, etc.)
- Mining landscape features (spoil piles, open pits, etc.)

In summary, the visible important buildings/structures identified by SHA follow:

- The Williams Engine House
- The Tigroney Ore Bins
- The Baronet's (or Farmer's) Engine House
- The Chimney to the former Waggon Engine House at Connary
- The Tramway Engine House Chimney at Ballygahan
- The Twin Shafts Engine House
- The Hodgson's Tramway Arch
- The Ballygahan Engine House Chimney
- The Mines Office in West Avoca

The visible mining landscape features identified by SHA follow:

- The Open Cast (open pit) Mines at Cronebane, East and West Avoca
- Adits, Shafts, and Underground Mines (many features are not visible)
- Mount Platt (only mentioned by SHA and not identified specifically)

The condition of many of these features was addressed in detail in the *Health & Safety Audit Avoca Mining Site* prepared by GWP Consultants (see Section 2.2). SHA provided descriptions and photography of the features and evaluated the significance of the various features (the SHA report is provided in the *Investigative Reports, Data*

Report, CDM 2008). SHA concluded that "There are serious issues regarding pollution, destabilisation, and general health and safety hazards on the Site." SHA specifically recommends that Williams Engine House, the Ore Bins at Tigroney West, Baronet's (Farmer's) Engine House, and Twin Shaft Engine House be repaired and made safe and accessible to the public. The "serious health and safety hazards" of the open pit mines also need to be addressed.

Wicklow County Council's most recent Development Plan (*Wicklow County Development Plan 2004-2010*) contains a chapter on Heritage and Landscape Conservation (Chapter 10). The Council's heritage objectives are guided by the following principles:

- Avoid negative impacts upon heritage
- Promote enhancement of heritage as a key principle to every development
- Ensure that all developments include adequate provisions regarding mitigation of impact upon heritage

Specifically, the Development Plan maintains a Record of Protected Structures. Protected Structures at the Site include:

- Ballymurtagh (old mining office, Tramway Arch, Western Whim Engine House, Twin Shafts Engine House and Chimney, Tramway Engine House Chimney, Ballygahan Engine House, spoils heaps and associated disturbed ground, etc.)
- Connary (Waggon Shaft Engine House, spoils heaps and associated disturbed ground)
- Cronebane (Cronebane and East Avoca open pits, volcanogenic massive sulphide mineralisation and host rock sequences)
- Tigroney West (Williams Engine House and Chimney, Baronet Engine House and Chimney, spoil heaps and associated disturbed ground, etc.)

Wicklow County Policy HL47 states that "The Council will have regard to structures, sites, and objects which are part of the county's industrial heritage, in particular features which relate to former mining and/or transport activities."

2.1.7 Ecology

The main flora habitats in the mine area include pine/birch scrub, pine-dominated woodland, acid grassland, and heathland with oak woodlands adjacent to the mines. Plant species from habitats near the mine site are the principal colonising species of ground disturbed by mining activity. A detailed survey of the area was performed and is summarised in Section 2.6.11.

Fauna recorded at the Site include the following:

- Mammals – Rabbit, badger, fox, hare, brown rats, stoat, mink
- Bats – Pipistrelles, Lusler's bat, Daubenton's bat, Natterer's bat
- Birds – Pheasant, wren, robin, blackbird, rook, jackdaw, wood pigeon, red kite, falcon
- Fish – salmon, sea trout, eel, brook-lamprey, river lamprey, sea lamprey

A more detailed discussion is provided in Section 2.6.11.

2.2 Health and Safety Concerns from Physical Hazards

A detailed health and safety audit in relation to the physical hazards at the Avoca Mine site was performed by GWP Consultants LLP (GWP 2008). The report documents the conditions and physical hazards of 15 rock faces and pits, 19 spoil piles, six tailings impoundments (lagoons), 28 adits, 44 shafts, and 25 buildings and structures. These features are identified in the following areas: Connary (CO), Cronebane/Mt. Platt (CR), East Avoca (EA), Tigroney West (TI), West Avoca (WA), and Shelton Abbey (SA). The following sections summarise the major safety concerns at the Site.

2.2.1 Rock Faces and Pits

Stability

The steep, high rock faces at Cronebane and East Avoca pits are not stable and are a major physical hazard. Major slides have occurred on the northwestern wall of Cronebane and will probably continue as the slopes age. The potential for failure of the northwestern and southeastern walls of East Avoca pit is also a major physical hazard.

The faces with the greatest consequences as a result of failure are the southwestern wall and southern end of the northwestern wall of East Avoca pit. The upper parts of both are cut in spoil backfilling old workings. It appears that only the ferricrete cementation of this backfill is holding these faces up. Over time the cementation is likely to degrade or erode resulting in failure. In the underlying rockfaces, undercut discontinuities could slide into the pit. Because the crest of the slope is only one metre away from the public road through the Site in places, failure could have serious consequences.

In West Avoca, all the pits have already been partially backfilled. The risk of failure of these faces is greatly reduced. A problem exists with the southern faces of Weaver's Lode open pit, where the remaining rock faces, although low, are overhanging. A small slab slide from the faces of Pond Lode pit seems to have occurred during 2007 (GWP 2008).

Rockfall

Rockfall from the high rock faces and also from undercut spoil slopes is apparent in many locations in the Avoca site (GWP 2008). Rockfall, by its frequency, is the major cause of injury in quarries if people are constantly present. The ragged nature of some of the rock faces causes the trajectories to be quite erratic. Rockfall analysis of potential trajectories indicates that in both Cronebane and East Avoca pits, the danger zones constitute the entire pit floor.

The danger of rockfall from the residual faces of pits at the West Avoca site is generally lower. The remaining northern face of the Pond Lode Pit is still 20 m high and County Wicklow staff periodically conduct inspections in the area, although not for any great length of time. Overall, the risk is relatively low.

Falling Hazard

The other main risk from the high rock faces is of people and animals falling over them. No evidence exists for any such incidents having occurred over the past few years, but the risk will always be present when access may be obtained to the crest of the rock faces.

Pit Lake Water

The Cronebane Pit and the East Avoca Pit are partially blocked by embankments. Mine water from upgradient workings flows into the pits, thereby creating acid water ponds. These ponds constitute serious physical hazards to any human or animal that may fall into or otherwise enter the ponds.

2.2.2 Spoil Piles and Tailings Impoundments

Tailings Impoundments

The main Shelton Abbey tailings impoundment appears to have been constructed primarily of tailings. The initial starter bank for the impoundment appears to have been the flood defence bank along the Avoca River. Currently, the dam appears to be stable. However, a rise in internal water table (consequent, for example, on increased infiltration) could lead to failure. The current drains on the top surface of the impoundment allow infiltrating water into the body of the tailings rather than removing it from the surface.

The drain across the top of the emergency tailings pond promotes infiltration into the tailings.

There is also a small possibility of the tailings within the North Lode Pit infill washing into underground cavities, causing subsidence at the surface.

Spoil Piles

Many smaller spoil piles generally show little, if any, signs of major instability. Where undercut by subsequent excavation (or possibly shaft collapse), small scale failures are apparent (especially at Tigroney and West Avoca). The stability is enhanced by the ferricrete cementation of the outer faces. However, this does allow some large blocks of rocklike material to fall out.

The steepness of the slopes and height of Mount Platt call for caution regarding its apparent stability. The current condition is temporary as evidenced by a relatively large slope failure on the southwest side of Mount Platt that has occurred in the past. There are a number of factors including likely large precipitation events that could alter its current condition resulting in slope failure. In addition, surface erosion is a problem. Erosion of the finer material allows larger blocks to roll down the slope, with potential harmful consequences. Some large gullies have formed on Mount Platt. The debris from one of these blocks drainage channels. The gully has also allowed large angular rock boulders to roll down slope, one at least impacted the boundary fence, being stopped by a concrete fence post from running onto the road.

The West Avoca spoil pile above the Road Adit has many angular boulders that could reach the road if disturbed. The trees may stop some of the rocks.

The spoil pile in the Connary area appears to be periodically removed for fill or aggregate. This could be a hazardous procedure because of the probable presence of open shafts beneath the spoil. If the excavation forming the builder's yard is extended any further, it could intersect two shafts.

2.2.3 Adits

There are two partially open adits with easy access from a public road and no fencing at the Tigroney Ore Bin part of the Site. These are the 850 Adit, accessing the last underground workings at Tigroney mine, East Avoca, and the nearby Inclined (Branch) Entry to the Deep Adit (see Figure 2-2 for locations). Both were originally walled up and (apparently) covered with spoil. In both cases, the spoil has been dug away and the concrete block walling partially broken down, allowing easy access to the interior of the adit.

Both Wood Adit and North Adit (see Figure 2-2) are open, and, although partially flooded, can be entered. However, neither is easy to find or close to areas to which the public have access.

Examination of the mouth of the Deep Adit in the Tigroney area indicates the possibility of collapse of the portal. It appears to have been infilled where it passes beneath the main Rosslare to Dublin railway line. It is also the main drain to the entire eastern side of the Avoca mines; hence, its condition is important. Blockage of the pipe drain through the infill could give rise to contaminated water emerging at other sites up the hillside.

The Cronebane Shallow adit is close to a publicly used road. Entry would be difficult due to the depth of water. However, rotting timbers may give way, precipitating inquisitive explorers into the acidic mine water.

2.2.4 Shafts

Two shafts were found to be open; Air Shaft (at West Avoca) and Farmers (at East Avoca) (see Figures 2-2 and 2-3 for locations). Since initial inspection, Farmers Shaft has had a steel grate placed over it.

While many shafts have been capped, the condition of some of the caps appears doubtful. The worst is Whelan's shaft, West Avoca (see Figure 2-3 for location). Here poor quality materials appear to have been used. At Connary, the Reed's shaft cap was seen to have a void developing alongside. This appeared to be due to inadequate depth of founding of the cap, allowing soils to slip into the shaft void beneath the cap foundation. The Site is accessible to children (indeed, from the holes made in the fence, appears to be considered a play area). At least two other shaft caps, Barry's and Wheatley (see locations in Figures 2-2 and 2-3), appear to be only just wide enough to cover the shaft opening and hence could be vulnerable to similar void formation should the lining collapse.

Many shafts appear to have collapsed, leaving circular depressions. This includes several possible shafts, not shown on the maps. At least one shaft (associated with Baronets Engine House, see Figure 2-2) has not been located and appears to be buried in spoil. This may be a source of considerable risk (see below). Two shafts west of Connary Engine shaft appear to be actively collapsing – the depressions appear to have grown slightly between April and October 2007.

2.2.5 Void Migration

Over considerable areas, the waste appears to have ferricrete cement on the outer surface (a product of evaporation of iron rich water). This cementation may give a false sense of security in places. At one location in West Avoca (see Figure 2-3, Open Void), a cavity has formed in the waste (probably due to internal erosion of spoil into underground cavities), and has reached the surface. It appears to have increased in size over the past year. Such voids pose a serious threat to human and animal health, as their presence within an area of open ground may be completely unexpected.

In the same general area of fill in West Avoca, two circular depressions have been noted. These may be crown holes, a type of feature due to progressive collapse of the roofs of workings meeting the surface. The Connary area also has examples of probable collapse of workings. The large depression probably reflects collapse of the underlying 9 Fathom (see Figure 2-2) workings, some 11 m below. The depression could also be a collapse into the Kilmacoo North (9 Fathom) adit (see Figure 2-2), although its shape makes it more likely that it is an uncharted shaft collapse.

The feature now known as Wood Shaft (see Figure 2-2) is also possibly a collapsed structure and not a proper shaft. No shaft is shown at this location on any mine plan. The Wood shaft shown on mine plans was some 90 m to the east, and destroyed in the stope collapses of the 1970s.

Other cavities could pose risks of sudden collapse, especially if water levels rise and fall. The large area of backfilled stopes downhill of East Avoca pit is a potential location for such void migration ("weak area"). The Baronets Engine House shaft (see Figure 2-2), located in this area, would be a particular concern.

Although all shafts and adits with records have been shown on plan maps, many unrecorded mine entrances, now buried in spoil, may exist. There is one adit (WA35, see Figure 2-3), now blocked with a wall, that does not appear on any plan that has been reviewed. Neither the mine plans nor the OS plans are comprehensive. For example, three shafts are shown on the plan that Weavers produced with his paper of 1819, which appear on no other plan. One of these shafts certainly disappeared in the progressive collapses of the Tigroney mine stopes c1864, but the other two, adjacent to the Deep Adit, must still exist. It is possible that the cavities in spoil piles visible at TI49 and EA161 (see Figure 2-3) are a consequence of collapse of these shafts.

Shafts and adits do not always appear in the same place on different plans. The biggest discrepancy is 74 m for the Kilmacoo South Adit. As this adit is no longer visible, it is not possible to be certain of its exact position. When compared with the positions shown on the mine plans with those accurately surveyed in October 2007, errors of 8 m or more were found in the relative positions of some shafts (e.g., Farmers shaft and Reeds shaft). Thus the position of shafts now buried in spoil could also be in error by many metres.

2.2.6 Structures

Many of the 19th Century engine houses and tramway remains have been conserved by recent works, although some appear to require further attention and all will require ongoing maintenance. Williams Engine House (see Figure 2-2) contains a number of dangerous sections. The risks imposed by this structure are high because there is easy access – the gate in the surrounding fence has been removed. The lower western window arch on the northern side has a missing keystone, leading to loose stones and potential instability of the wall. There are several unprotected drops. The worst is above what is believed to be the stoking hole to the boilers. This is partially covered by a thin rotting piece of plywood and constitutes a serious risk.

There are no parapets to the Tramway Arch (see Figure 2-3). This constitutes a risk of falling to anyone on top of the arch.

The remains of the 20th Century ore storage bins (ore bins) in the Tigroney West mine area are in far worse condition than the 19th Century remains. One of the main steel support beams for the southern bin has serious corrosion damage, as have several other structural components. This damage appears to have occurred mainly where water that has become acid laden from passage through the ore in the bins has dripped onto the steelwork. The wooden crib wall alongside the bins also shows signs of decay. It also appears to be leaning forwards. The roadside location makes failures potentially dangerous.

2.3 Nature and Extent of Contamination

2.3.1 Sources of Water Contamination

The contamination source for water media is the acid mine drainage (AMD) generated in the abandoned underground mine workings, and the acid rock drainage (ARD) generated from the mines, mine spoils, mill tailings, and exposed rock surfaces. AMD/ARD results from oxidation of reduced minerals such as pyrite and dissolution of metals. The AMD discharges at the surface via the old drainage tunnels or other adits, or seeps into nearby groundwater. The Deep Adit and Road Adit produce substantial metal laden discharges to the Avoca River. Contaminated groundwater also impacts the Avoca River as "diffuse" flow; i.e., water that enters the river via subsoil, soil, aquifer, or bedrock transport in general rather than at a discrete location such as an adit or other point source. The ARD from spoil heaps and tailings normally percolates into the groundwater but occasionally discharges at the surface, and then typically seeps into the soil or backfill beneath it. In either case it discharges to underground mine workings and/or groundwater aquifers and eventually to the river.

2.3.2 Solids Contamination

The contaminated solids media resulted from mining, milling/ore processing operations, and, to a lesser extent, historic small scale smelting operations. These contaminated solids include the mine spoils (waste rock) deposited on the ground at East and West Avoca; spoils and slag (smelter waste) at the Connary site; and tailings at the Shelton Abbey facility, portions of the North Lode Pit and Pond Lode Pit (Ballymurtagh), and the emergency tailings ponds at West Avoca. The exposed faces of the pit highwalls are also contaminated solid materials. Locations of the various areas are shown in Figures 2-2 and 2-3. These solid materials typically contain elevated metal concentrations.

2.3.3 ARD Sources

Sources of ARD within the Avoca site include the following:

- Pit walls
- Spoil piles
- Tailings
- Adits
- Underground workings

Each source of ARD is described below.

2.3.3.1 Pit Walls

The pits located at the Avoca site consist of the following:

- Cronebane (open - partially filled with spoil materials)
- East Avoca (open)
- Pond Lode/Ballymurtagh (filled with municipal waste and tailings)
- North Lode (filled with tailings and spoils)
- Weaver's Lode (partially filled with debris and spoils)

The pits likely contribute to the loading of ARD to the Avoca River in a number of ways, including the following:

- ARD is generated directly as precipitation (rainfall) flows along the pit walls and through spoil piles located within the pits

- The pits can collect ARD from overland flow or interflow from surrounding areas or from direct underground mine opening (e.g., adits, stopes) discharge (in the cases of the Cronebane and East Avoca Pits)

- All of the pits are in contact with the underground workings to one degree or another and provide pathways to transport ARD to adit discharges and diffuse flow to the Avoca River

2.3.3.2 Spoil Piles

Spoils at the Avoca site were generated both during the historical (1720-1888) and modern (1958-1982) periods. In general, the spoils consist of sand to pebble-sized material contained in a fine-grained matrix. The spoils are generally oxidised to a red-brown color, but still contain unreacted pyrite.

The volume of spoils material in each area of the Site considered for reclamation is provided in Table 2-1. These volumes were based on review of recent aerial photographs (Lidar Survey, July 24, 2007) and recent site observations. In some cases, the volumes are different from the original estimates by Gallagher and O'Connor (1997). The reclamation volumes in Table 2-1 do not account for spoil material already in place in pits throughout the Avoca site because these materials will be remediated in place and not moved. Estimates by Gallagher and O'Connor included these volumes.

Table 2-1 Summary of Spoils and Tailings Areas and Volumes

	Area (m^2)	**Volume (m^3)**
Spoils		
Connary	41,100	47,800
Cronebane/Mount Platt	85,600	659,800
East Avoca/Tigroney West (Not including Deep Adit Site)[1]	51,100	124,800
West Avoca (Not including SP39)[1]	83,600	65,200
Deep Adit Site[1]	3,800	6,300
SP39 (adjacent to Avoca/Rathdrum Road)[1]	14,300	51,800
East/West Avoca Spoils Totals	279,600	955,800
Tailings		
Shelton Abbey Tailings	446,500	7,547,000
Emergency Tailings Pond	34,900	129,300

[1] See Figures 2-2 and 2-3 for locations.

The spoils contain significant concentrations of copper (56-11,344 milligrams per kilogram [mg/kg]), zinc (44-7,404 mg/kg), lead (112-41,353 mg/kg), and arsenic (18-3,903 mg/kg). Analyses of seepage from the Mount Platt spoils indicate that the spoils are acid generating resulting in seeps with low pH (typically < 3) and very high concentrations of copper, zinc, iron, and aluminum, as shown in Table 2-2. Concentrations of arsenic and lead were typically low compared to other metals (see Section 2.4.7 for a further discussion). These seeps are typically low flow (<0.1 l/s) or flow only periodically (e.g., after rainfall events).

Table 2-2 Water Quality Data for Seepage from Mt. Platt (August 2007)[1] (mg/l)

Parameter[2]	**East Seep**	**West Seep**
Iron	723	348
Aluminum	1032	314
Copper	88.8	39.5
Zinc	133	113

[1] CDM Data Report (2008)
[2] Units in milligrams per liter (mg/l) unless noted otherwise

2.3.3.3 Tailings

Tailings are known to be present at the following locations:

- Shelton Abbey Impoundment
- North Lode Pit
- Along the West bank of the Avoca River north of Wicklow County Council yard (Emergency Tailings Pond)
- Pond Lode Pit (Ballymurtagh)
- Spill areas along pipelines

Of these locations, Shelton Abbey is by far the most significant tailings deposit at the Site, with an estimated volume of 7,547,000 m^3.

In general, the Shelton Abbey Tailings had lower concentrations of copper (67-1,372 mg/kg), zinc (69-2,141 mg/kg), lead (39-3,651 mg/kg), and arsenic

(26-198 mg/kg) than the spoils. The Emergency Tailings Pond had similar lower concentrations of copper (254-3,850 mg/kg), zinc (113-3,446 mg/kg), lead (57-2,649 mg/kg), and arsenic (58-1,562 mg/kg). Typically lower concentrations would result in less potential impact to the environment.

Review of aerial photographs show no areas near the pipeline route where tailings were present or where tailings had impacted vegetation. Ground surveys along the pipeline route also revealed no observable tailings (only dense vegetation).

2.3.3.4 Adit Discharges

The adits with active discharge for at least a portion of the year include the following:

- Kilmacoo Adit (seasonal flow)
- Madam Butler's Adit (no direct discharge)
- Wood Adit (seasonal flow)
- Intermediate Adit
- Cronebane Shallow Adit
- Deep Adit
- Road Adit
- Ballygahan Adit
- Spa Adit

A summary of the water quality for the adit discharges that have been analysed and the estimated or measured flows are presented in Table 2-3. Discharge from Madam Butler's Adit has been piped to an area where the water does not discharge directly to the surface; therefore, no sample was collected during field investigation (July/August 2007). Only standing water was present at Wood Adit during the field investigations.

Table 2-3 Summary of Adit Water Quality (mg/l) [1]

Parameter	Intermediate	Cronebane Shallow	Deep	Road	Spa	Ballygahan	Kilmacoo
Average Flow (l/s)	8.5	0.2	16	19	0.02	0.06	0.4
Iron	10.77	22.64	72.34	150.7	15.42	10.8	0.46
Aluminum	71.36	36.7	102.6	20.93	21.73	99.1	4.0
Copper	3.198	8.921	0.845	0.268	8.39	5.24	0.3
Zinc	33.03	85.9	47.62	10.95	14.3	21.68	2.66
Lead	1.352	1.334	1.717	0.308	0.102	0.24	2.18
Sulfate	799	3,215	NM[2]	NM	2,044	2,072	63
pH (su)	4.31	3.92	3.55	4.08	3.5	3.80	4.62

[1] CDM Data Report (2008); data for July/August 2007

[2] NM = Not measured (only metals analysed; sulfate was measured at discharge to the Avoca River)

The loads of metals discharged from each adit were calculated by multiplying the measured flow by the concentration of each metal and making the appropriate conversions (to kg/day). The Intermediate, Deep, and Road Adits had significant metal discharge loads compared to the other adits. For example, loads of zinc were 24, 68, and 12 kg/day for the Intermediate, Deep, and Road Adits, respectively, compared to values of 0.03 - 1.6 kg/day for the other adits. The load from the Intermediate Adit is significant and should be addressed along with the Deep and Road Adits.

2.3.3.5 Avoca River Water Quality

Both direct and diffuse discharges of metals impact the water quality in the Avoca River. The impact is the greatest during low flow conditions in the river. Table 2-4 summarises Avoca River quality for samples collected during the summer of 2007. Note that the concentrations in Table 2-4 are in micrograms per liter (µg/l) versus concentrations in Table 2-2 and 2-3 are in mg/l (1,000 times greater). Historic low flow typically occurs in late July or early August; however, the July/August flows during the 2007 sampling period were approximately 1.5 times more than low flow observed in June 2007. The June 2007 samples better represent low flow (higher concentration) conditions. As shown, the Avoca River has increased concentration of metals throughout the mining area and downgradient of adit discharges when compared to upgradient locations. Water quality improves further downgradient (Avoca Bridge and downgradient of the Aughrim confluence), but elevated concentrations of metals are still present (e.g., zinc concentrations were 378 µg/l at Avoca Bridge on June 14, 2007; 219 µg/l upstream of the Aughrim on August 2, 2007; and 136 µg/l downstream of the Aughrim on August 2, 2007). No increases in metal concentrations were observed between the upgradient and downgradient samples at Shelton Abbey during August 2007.

Table 2-4 Summary of Avoca River Water Quality (dissolved concentrations, µg/l)

Parameter	Avonmore[1] June 14, '07	Avonmore[2] Aug 2, '07	Below Deep Adit[3] June 13, '07	Below Deep Adit[4] July 30, '07	Below Road Adit[3] June 13, '07	Below Road Adit[5] July 31, '07
Iron	<1	72	321	162	75	250
Aluminum	<1	59	17,380	197	4,705	208
Copper	<0.5	4	298	12	69	24
Zinc	16	26	9,167	143	1,159	267
Lead	<0.5	2	239	4	15	7
Sulfate	9,000	5,000	133,000	9,000	105,000	31,000

[1] 100m above Meeting of the Waters, GSI data
[2] Lions Bridge, CDM data
[3] Mixing Zone, GSI data
[4] T2 mixed composite immediately downgradient of Deep Adit River discharge, CDM data
[5] T5 grab (across from abandoned coal yard), CDM data

2.3.3.6 Runoff Water Quality

Samples of runoff (overland flow) from spoil piles during precipitation events were collected by both CDM and the GSI during 2007 and 2006, respectively. High metal concentrations and low pH values were observed. The concentrations are summarised in Table 2-5.

Table 2-5 Water Quality of a Runoff Collected from the Surface of Spoil Piles Near the Deep Adit (µg/l)

Parameter	Result[1] (Collected by CDM August 5, 2007)	Result (Collected by GSI November 20, 2006)
Copper	4,549	1,563
Zinc	2,806	45,190
Iron	39,930	23,840
Aluminum	22,980	98,200
Lead	108	2,009
pH (su)	2.93	3.12

[1] µg/l unless noted otherwise, dissolved concentrations

The runoff entered directly into the Avoca River.

2.3.3.7 Underground Workings

The underground workings at the Avoca mine site are extensive, with an aggregate of 30 km of shafts, adits, and levels in East Avoca, and 16-21 km in West Avoca. The total does not include stopes, the extent of which is unknown. The flooded portions of the workings, while in contact with large quantities of sulphide minerals, probably do not produce as much ARD as the workings that receive only periodic flow from infiltration water.

2.4 Hydrogeological and Geochemical Conceptual Site Model

A hydrogeological and geochemical Conceptual Site Model (CSM) was created using existing site data and the results of site investigations to perform an evaluation of the geochemical and hydrological processes that result in ARD input to the Avoca River. The CSM was used to help select appropriate remedial and management alternatives at the Site.

A detailed evaluation of the nature and extent of the contamination and CSM is provided in the *Investigative Reports, Conceptual Site Model* (CDM 2008). The following paragraphs summarise information from the report.

2.4.1 Hydrological Summary

The Avoca River catchment drains eastward from the Wicklow Mountains to Arklow on the coast. It covers an area of approximately 645.6 km^2, and includes the Avonbeg and Avonmore Rivers, which form the Avoca River at their confluence at the Meeting of the Waters, approximately 1.5 km north of the mine area. The Avoca River subsequently merges with the Aughrim tributary about 5 km to the south of the mine area. Several tributaries empty into the Avoca River in the vicinity of the mine area. The important tributaries include Vale View, Red Road, and Sulphur Brook (see Figure 2-1).

2.4.1.1 Precipitation

There is a significant rainfall gradient from west to east across the Avoca River catchment. Median annual rainfall (1961-1990) ranges from greater than 2,000 millimetres per year (mm/yr) in the mountains to 990 mm/yr on the coast. Median annual rainfall at the mine site is approximately 1,100 mm/yr, while potential evapotranspiration (PET) is estimated to be approximately 540 mm/yr (Met Eireann 2007).

2.4.1.2 River Flow

While a permanent gauging station does not exist at the Avoca mine site, flows were estimated from rainfall-runoff modeling as part of the Eastern River Basin District project (CDM 2007). Calibrating initially to measured flows at Station 10002 on the Avonmore River and Station 10028 on the Aughrim River, the estimated flow in cubic metres per second (cms) just downstream of the Avoca mine site for the period 1993–2005 is depicted in Figure 2-4. The wide range of estimated flow conditions implies a rapid response to rainfall that in turn is a function of the physical characteristics of the Avoca catchment (high rainfall, steep topography, thin soil cover, low permeability bedrock). The estimated flow for the period on Figure 2-4 ranged from 1.12 to 144.5 cms with a mean of 15.6 cms. The estimated Q95 (flow exceeded 95 percent of the time) was 0.97 cms.

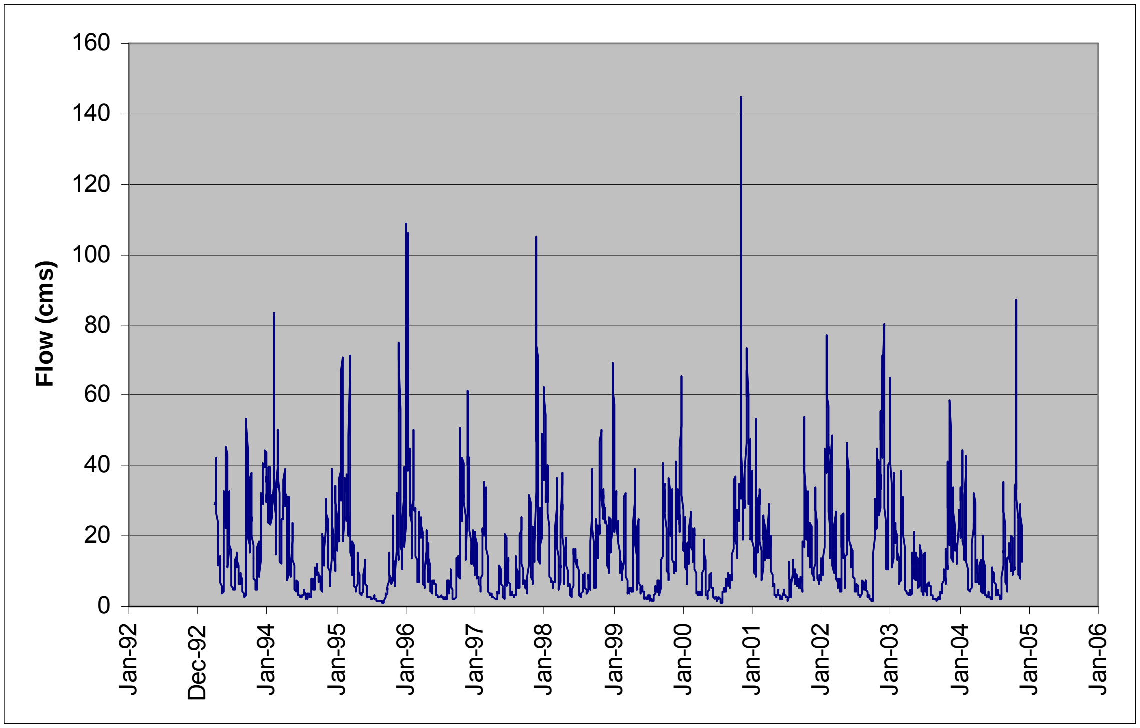


Figure 2-4 Net Estimated Flow of the Avoca River Near the Avoca Mines

2.4.2 Conceptual Hydrogeologic Model

The Avoca mine site is underlain by dark grey slates and rhyolitic volcanics. The bedrock is overlain by subsoils derived from glacial till and weathering of bedrock. Subsoils are thin (<2 m) or absent on hilltops and thicker (>2 m) along valley floors. The Avoca River valley itself comprises a thick (10-30 m) sequence of coarse-grained alluvial sediments.

In terms of groundwater yield, the GSI classifies the bedrock in the Avoca mines area as poorly productive. Movement of water, and groundwater pathways specifically, are difficult to decipher in this hydrogeological setting due to a lack of monitoring wells and paucity of groundwater data in the Avoca area. However, the following section explores potential pathways based on observations of similar rock types elsewhere in Ireland and specific knowledge of groundwater conditions in other parts of County Wicklow.

Water movement in poorly productive bedrock is broken down into three primary pathways:

- Surface runoff (overland flow)
- "Interflow" (flow in subsoils and/or along the top of bedrock)
- "Deep" groundwater

These pathways are shown schematically in Figures 2-5 and 2-6 and discussed in the following sections. Figure 2-6 is a more detailed drawing of the pathways near the Avoca River.

2.4.2.1 Surface Runoff

Surface drainage follows topography. Within the mines area, surface drainage is influenced by the spoil piles and open pits on both sides of the river. The open pits collect rainwater (directly) and runoff (indirectly). The water that collects within the pits infiltrates into the bedrock and underground systems of the mine workings or flows directly into underground workings. Surface runoff that is not captured by the pits flows overland towards other localised topographic depressions (where it partly infiltrates) and the Avoca River valley (where it discharges into the Avoca River).

2.4.2.2 "Interflow"

"Interflow" is defined as the flow that takes place at the very top of bedrock, near or at the contact with the overlying subsoils. The interface between the top of bedrock and subsoil materials is chemically weathered and comprises a dense network of shallow fractures that is more interconnected than fractures at greater depth. As such, "interflow" represents a transition zone between subsoils and underlying bedrock. The transition zone may be only a few metres thick, and is regarded as being more permeable or transmissive than deeper bedrock. Interflow in the mine area is typically captured by the open pits or underground workings. Near the Avoca River, interflow will enter the alluvium and the Avoca River or emerge as seeps or springs.

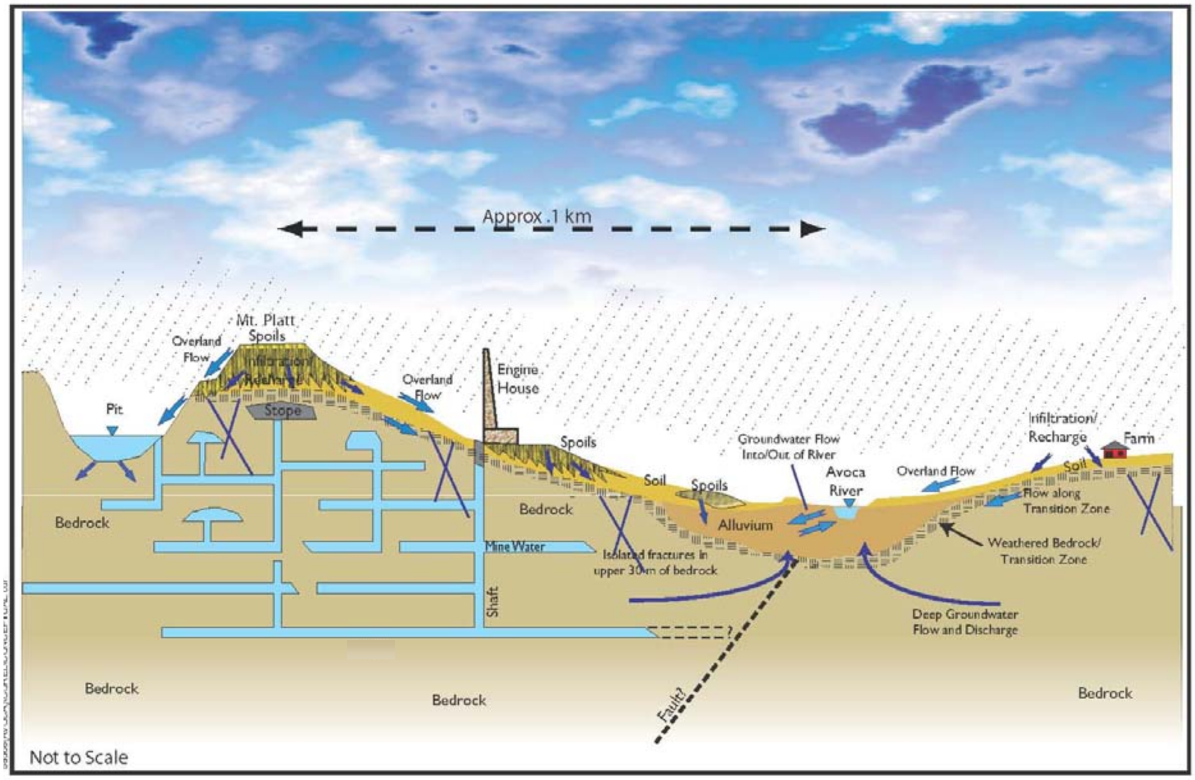


Figure 2-5 Schematic Cross-Section of Flow Components Influencing the Avoca River

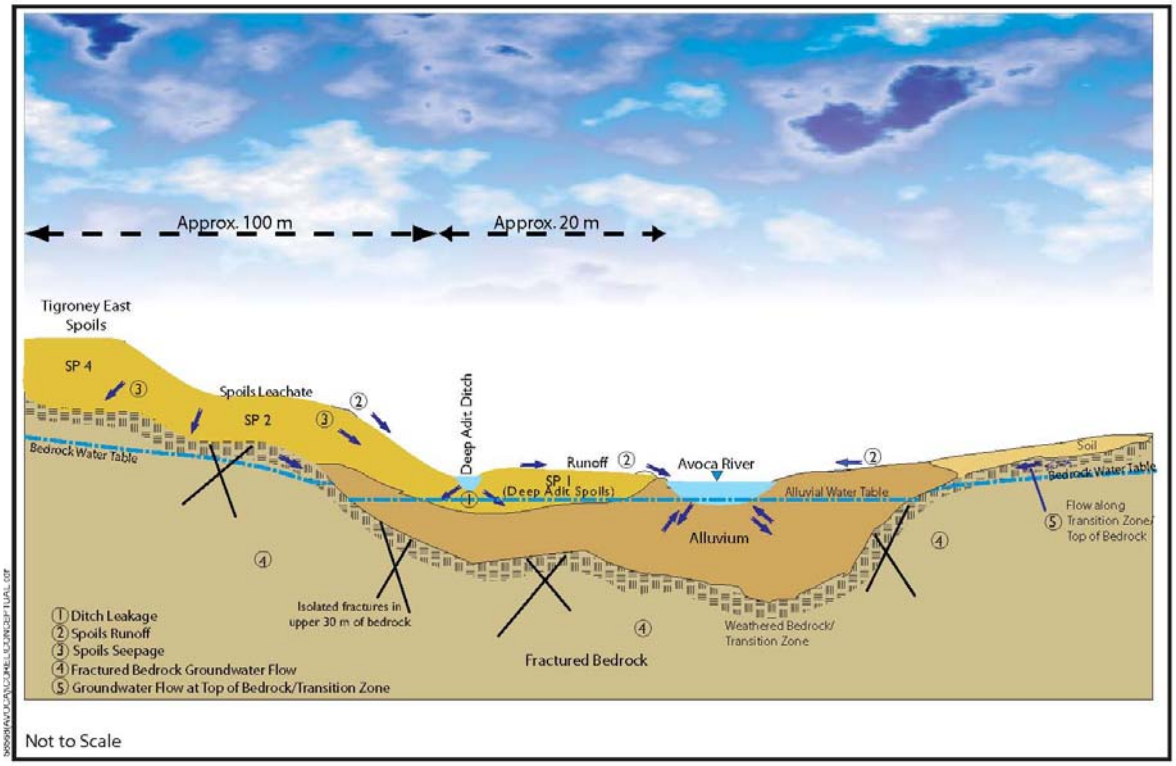


Figure 2-6 Schematic Cross-Section of the East Avoca Area Upgradient of the Deep Adit

2.4.2.3 "Deep" Groundwater

"Deep" groundwater is considered to be groundwater flow in bedrock proper, beneath the transition zone with interflow. "Deep" groundwater flow at Avoca occurs in discrete fractures or fracture zones that represent zones of enhanced permeability. Varying degrees of rock deformation can be observed in the open pits on both sides of the Avoca River, and these deformations influence bedrock permeability. Bedrock is deformed by both folding and faulting; both of which are associated with fracturing and permeability development. Thus, "deep" groundwater flow is heterogeneous, following lines of structural geologic weakness. Deep groundwater will also be captured by underground mine workings in the mine area. Near the Avoca River, deep groundwater will also enter the alluvium.

2.4.3 Recharge and Groundwater Flow

Recharge from rainfall to bedrock is expected to occur quickly as a function of the limited soil and subsoil thicknesses in upland areas. Bedrock has a finite ability to accept recharge on account of its low storage and transmissive properties. A maximum recharge limit or "cap" of approximately 100 mm/yr has been suggested for areas underlain by poorly productive rocks (GSI 2005; National Working Group on Groundwater 2005; Moe et al. 2008).

Recharge that is rejected from the deeper bedrock will either flow along the shallow fractured zone at the top of bedrock (transition zone) or as surface runoff when the recharge capacity of the transition zone is reached. The weathered nature of shallow bedrock in the transition zone would impart heterogeneity to shallow groundwater occurrence and flow.

Groundwater flows from upland areas towards the Avoca River, generally following topography. In the mines area, the underground shafts serve as hydraulic sinks, whereby natural groundwater flow is locally deflected and captured by the underground mine workings. The mine workings therefore act as preferential pathways for the captured water that emerges from the mine adits in the Avoca valley.

Given the generally low-permeability characteristics of bedrock at Avoca, regional groundwater flow systems have not developed. Flow systems are short and localised, generally less than 1 km in length between recharge (upland) and discharge areas (river/streams).

2.4.4 Groundwater/Surface Water Interaction

In the Avoca River valley, deep groundwater and flow along the transition zone discharges towards the Avoca River and its tributaries. At several locations along the valley sides, surface seeps and springs occur where groundwater tables intersect topography. Such seeps and springs have been sampled on both sides of the Avoca River (see *Investigative Reports, Data Report*, CDM 2008). The springs and seeps ultimately discharge to the Avoca River (as overland flow) or re-infiltrate into the ground along the way.

The mining spoil areas represent a particular hydrological setting. A significant proportion of rainfall will run off the spoil heaps to low-lying spots due in part to their low-permeability characteristics. Exposed cross-sections on Mount Platt show layering of waste materials. Water that infiltrates will accumulate above low permeability layers and seep laterally outwards, following paths of least resistance. Such seeps follow surface water drainage courses or infiltrate further into bedrock.

Deeper groundwater (including interflow) not captured by the underground workings discharges directly to alluvial sediments along the river valley. The Avoca River valley consists of alluvial sediments and glacial till overlying bedrock. The alluvium is up to 20 m thick in East Avoca near the Deep Adit spoils area and up to 30 m thick in West Avoca near the Emergency Tailings area and downstream from the Ballymurtagh Landfill. At the Shelton Abbey tailings facility, 12 m of alluvium was encountered during recent drilling, without reaching bedrock. Similar indications of alluvial sediment depth are reported from Ballymurtagh Landfill investigations (RPS 2006) and trial well drilling near Woodenbridge for water supply (White Young Green 2004 and 2005).

The alluvial sediments are of fluvial origin; i.e., they were deposited by the Avoca River and represent floodplain deposits. The width of the alluvial sediments is constrained by the U-shape form of the Avoca valley, ranging from approximately 100 m at the Deep Adit to several hundred metres at Woodenbridge.

The alluvial sediments are consistently coarse grained, consisting mainly of coarse, sub-angular sands and gravels with occasional bands or thin layers of fine silts and clays. Large, sub-angular cobbles are lodged throughout the alluvial deposits, at all depths. The alluvium partly represents reworked boulder clay (till). The cobbles comprise shale, slate, rhyolite, and granitic rocks (the latter transported from the Leinster granite that underlies of the Wicklow Mountains at higher elevation).

In addition to the existing wells drilled for Ballymurtagh Landfill monitoring purposes, six additional wells were installed in the alluvium for this study, as follows:

- Two nested wells in the Emergency Tailings area, downgradient of the West Avoca pit and slightly sidegradient of the Ballymurtagh Landfill
- Two nested wells in the Tigroney West spoil area near the Deep Adit
- One shallow well upgradient of the Deep Adit area, near the eastern margin of the alluvial sediments
- One shallow well immediately adjacent to, and downgradient of, the tailings dam at Shelton Abbey

The primary purposes of installing the six additional monitoring wells were to:

- Explore the hydraulic relationship between the alluvial aquifer and the river
- Determine the water quality immediately beneath potentially significant groundwater contaminant sources (Deep Adit spoils, Emergency Tailings, Shelton Abbey Tailings Facility)
- Explore the thickness and nature of the alluvial sediments beneath the mentioned potential source areas

Drilling that penetrated the alluvium encountered weathered schist/slate bedrock. Weathering was apparent from observations of drill cuttings and intervals of "softer rock" reported by the driller and recorded in the drill logs.

No pumping tests were carried out in the new wells installed as part of this study. The alluvial sediments were sufficiently permeable to render falling and rising head tests meaningless. Pumping testing of alluvial trial wells near Woodenbridge and Shelton Abbey (for the Arklow Water Supply Scheme) indicate reported individual "sustainable" well yields ranging from approximately 600 m^3/day to 2,000 m^3/day (White Young Green 2004).

The Avoca River has an immediate and measurable impact on groundwater levels in the alluvial sediments in the mines area. The degree of hydraulic communication between the river and groundwater is of primary importance in reviewing potential contaminant loads to the river from diffuse groundwater flow.

The water level data measured to date from the existing and new wells point to a complex relationship between bedrock, the alluvial aquifer, and the Avoca River (more detailed evaluations are provided in the *Investigative Reports, Conceptual Site Model*, CDM 2008). Where a positive hydraulic gradient from the alluvial aquifer to the river predominates (i.e., the head in the aquifer is higher than in the river), the Avoca River is a net gaining river. In this scenario, there is greater probability that diffuse groundwater pollutants will flow into the Avoca and contribute to the contaminant loading of the river.

Conversely, where a negative gradient from the river to the alluvial aquifer predominates (i.e., the head in the aquifer is lower than in the river), the Avoca River is a net losing river. In this scenario, better quality river water will flow into the alluvial sediments, and thereby influence (dilute) the higher groundwater contaminant concentrations.

Whether the river gains or loses water is a function of many factors, including:

- Rainfall and river stage (with time)

- Characteristics of river-bed and riverbank sediments (low/high permeability)
- River bank elevation (exposure of river bank along river's edge)
- Presence and/or exposure of (alluvial) floodplain deposits, facilitating groundwater recharge

Hydraulic gradient data between the well clusters and the river shows an estimated net positive gradient from the wells to the rivers in September and November 2007. Whether the river is gaining all throughout the year is not yet proven, without further groundwater and river level monitoring over one or more full hydrological year.

The apparent net gain in flow of the Avoca River in the area near the Deep Adit and Emergency Tailings is supported by direct flow measurements and tracer tests that were carried out at different river transects in late July/early August 2007. These flow measurements indicated a net increase in flows from upgradient of Whitesbridge to past the Deep Adit area. This was occurring during a time when the river was receding; i.e., flow was decreasing with falling river stage.

Conversely, the flow measurements and tracer tests indicated a net loss in river flow along the stretch of river that runs past the Road Adit and abandoned coal yard. The point where the river starts losing water is not precisely defined, but is inferred to start at a location just downstream of the Deep Adit. The Avoca River valley and associated alluvial aquifer narrows considerably below the Road Adit, and the river banks steepen. The precise cause for the loss of flow is not known without supporting groundwater elevation data to the south of the Road Adit, but the loss is inferred to be related to riverbed seepage and riverbank storage.

Overall, the current and past studies have shown that the Avoca River/groundwater interaction is dynamic. As a result, routine monitoring is recommended (see Section 6.3). However, the current evaluations are adequate to recommend and evaluate proposed remedial options with the understanding that final designs may require some information refinement.

2.4.5 Groundwater Zone of Contribution of the Underground Mine System

Surface and groundwater pathways in the Avoca mine area are complex and are controlled by topographic, geologic, and man-made features. The measured discharges from the East and West Avoca adits represent the bulk of the water that moves through the mine system. Several past studies have measured the discharge flows from the Deep and Road Adits. These are summarised in Table 2-6.

Table 2-6 Historic Flows, Deep and Road Adits (l/s)

	May '94 - April '95[1]		Oct '04 - Sept '05[2]	Sept '05 - June '06[2]
	Deep	**Road**	**Deep**	**Road**
Minimum	8.5	6.1	8	6
Maximum	37.3	35.2	38	33
Mean	17.7	17.1	15	19

[1] Newcastle University

[2] Eastern Regional Fisheries Board (Reported in Avoca Mines Pilot Phase Treatment Trials, Unipure 2007)

Measured flows during the 2007 field program (July 31, 2007) were 16.2 l/s (Deep Adit) and 19.2 l/s (Road Adit). GSI measured flows of 13.7 l/s (Deep Adit) and 13.4 l/s (Road Adit) on June 13, 2007 and 24.1 l/s (Deep Adit) and 26.3 l/s (Road Adit) in February 2, 2007.

The discharges at the Deep and Road Adits represent water that is collected and discharged by a tiered and complex network of underground mine workings that reflects a number of pathways and sources of water:

- Rainfall over the open pit areas that partly infiltrates into the underground drainage system
- Surface runoff from adjacent areas that flows into the open pits and infiltrates into the underground drainage system
- Groundwater that flows into the underground drainage system from adjacent areas (via shallow and deep groundwater pathways)

The first two sources can be estimated with reasonable certainty, but the latter can only be inferred using a water balance approach and estimating a zone of contribution for the mine system. An estimated water balance for long-term average conditions for the East and West Avoca is described below and summarised in Table 2-7.

The long-term (30-year) median precipitation (P) over the Avoca mine area is estimated to be 1,082 mm/yr. The estimated potential evapotranspiration (PET) rate is approximately 540 mm/yr (Met Eireann 2007). The actual evapotranspiration (AET) is assumed to be about 90 percent of PET, or 486 mm/yr. This leaves 596 mm/yr as potential recharge (PR = P-AET). Due to the steep slopes of the mines area, it is further assumed that about 50 percent of rainfall runs off as overland flow, which leaves approximately 298 mm/yr as available recharge (AR).

Using the derived available recharge rate of 298 mm/yr, the volume of water that accumulates and infiltrates through the open pit areas is estimated (see Table 2-7), on average, to be:

West Avoca:	3.5 l/s
East Avoca:	6.4 l/s

The difference between these volumes and the measured average discharges from the East (Deep) and West (Road) adits represent groundwater recharge and flow from a larger area adjacent to the mine shaft system, i.e., the zone of contribution (ZOC). These areas would cover approximately 1.23 km^2 and 1.50 km^2 for East and West Avoca, respectively (see Table 2-7). In the case of East Avoca, the ZOC is expected to be elongated along the axis of the mine workings, covering an area 3.5 km long (along axis of ore bodies) by 350 m wide (perpendicular to the axis). In the case of West Avoca, the ZOC would cover an area that is nearly rectangular, as a function of the layout of underground mine workings. The calculated ZOC areas are in addition to the areas of the open pits.

Table 2-7 Estimated Water Balance and Zone of Contribution of the Underground Mine System

		mm/yr	**Source**
Precipitation	P	1082	Met Eireann 1961-1990
Potential Evapotranspiration	PET	540	Met Eireann 1961-1990
Actual Evapotranspiration (90% of PE)	AET	486	
Potential Recharge (P-AE)	PR	596	
Runoff (50% of PR)	R	298	ERBD rainfall runoff modeling
Available Recharge (PR-R)	AR	298	
Deep Groundwater Recharge Cap	CAP	100	National Groundwater Working Group

WEST AVOCA		
Direct Rainfall Into Pits:		
P is used for direct rainfall over open pit areas	1082	mm/yr
West Pit Areas	33181	m^2
Volume in Pits from Rainfall	35901.84	m^3/yr
Surface Runoff Into Pits:		
Surface Area Draining to Pits	101819	m^2
R that drains to Pits	298	mm/yr
Volume in Pits from Surface Runoff	30342.06	m^3/yr
Total Volume Accumulating in Pits from P and R	66243.90 2.10	m^3/yr l/s
Recharge in Pits from P and R	2.10	l/s
Contribution from Spoil:		
Area	81690	m^2
50% of P on spoil runs off into pits	541	mm/yr
Volume in Pits from Spoil	44194.29	m^3/yr
	1.40	l/s
Total Recharge in Pits (Direct Rainfall, Surface Runoff, Spoil)	**3.50**	
Measured Average Flow in Road Adit	17.1	l/s
Difference (Measured - Contribution from Pits)	13.60	l/s
Recharge from Other Areas Needed to Make Up Difference	13.60	l/s
Available Recharge over Other Areas	298	mm/yr
Zone of Contribution needed to arrive at Measured Adit Flows	1500000	m^2 1000 m x 1500 m
Zone of Contribution needed to arrive at Measured Adit Flows if Recharge Cap Applies	4600000	m^2 2000 m x 2200 m
EAST AVOCA		
Direct Rainfall into Pits:		
P is used for direct rainfall over open pit areas	1082	mm/yr
East Pit Areas	20500.00 62000.00	m^2 Tigroney m^2 Cronebane
Volume in Pits from Rainfall	89265.00	m^2/yr

Table 2-7 Estimated Water Balance and Zone of Contribution of the Underground Mine System

Surface Runoff into Pits:		
Surface Area Draining to Pits	41500	m^2 Both pits
R that drains to Pits	298	mm/yr
Volume in Pits from Surface Runoff	12367.00	m^3/yr
Total Volume Accumulating in Pits from P and R	101632.00 3.22	m^3/yr l/s
Recharge in Pits from P and R	3.22	l/s
Contribution from Spoil:		
Area	183689.00	m^2
50% of P on spoil runs off into pits	541.00	mm/yr
Volume in Pits from Spoil	99375.75	m^3/yr
Total Volume Accumulating in Pits from Spoil	99375.75	m^3/yr
Total Recharge in Pits (Direct Rainfall, Surface Runoff, Spoil)		
Measured Average Flow in Deep Adit	17.70	l/s
Difference (Measured - Contribution from Pits)	11.33	l/s
Recharge from Other Areas Needed to Make Up Difference	11.33	l/s
Available Recharge over Other Areas	298	mm/yr
Zone of Contribution needed to arrive at Measured Adit Flows	1225000	m^2 350 m x 3500 m
Zone of Contribution needed to arrive at Measured Adit Flows if Recharge Cap Applies	3675000	m^2 1050 m x 3500 m

The available recharge defined above represents recharge to bedrock. The low-permeability rocks of Avoca have a finite ability to accept the AR, and it is suggested that recharge should be capped at approximately 100 mm/yr for rocks of the Pl (poor aquifer, generally unproductive except for local zones) and Pu (poor aquifer, generally unproductive) categories (National Working Group on Groundwater 2005). In this case, the ZOCs would be much larger; 3.68 km^2 and 4.5 km^2, respectively for East and West Avoca.

The actual shapes and sizes of the ZOCs can only be determined by installing monitoring wells and measuring groundwater levels over a period of time. The ZOC could be different in shallow and deep bedrock, and could be further influenced by geological structures, notably the N-S trending faults (which cut across the mine workings and probably deliver groundwater to the workings) and the southeasterly dip direction (i.e., the ZOC may extend further away from the mine system to the NW than SE). The ZOCs would also be influenced by heterogeneities in the underlying shallow and deep bedrock, as well as dynamic (transient) changes in hydrological conditions.

While it is not possible to predict the actual extent of the ZOC without bedrock monitoring wells, the above estimates of areal extents are considered reasonable. What is certain is that the ZOCs of the mine system on either side of the river are localised features, not regional.

Based on the above calculations, the majority of the adit discharges (Deep and Road Adits) result from infiltration and recharge from a limited area. Therefore, remediation techniques that decrease infiltration (caps, covers, liners, etc.) will be effective in reducing adit discharges.

2.4.6 Groundwater Quality

The bulk of contaminant loading to the Avoca River is AMD associated with the adit discharges on both sides of the river. This AMD originates either as surface water or as groundwater, which are hydraulically captured by the underground mine drainage system. Contaminant mass loading to the river may also be contributed by diffuse groundwater flow, most notably within the alluvial aquifer where groundwater is in direct contact with the mine spoil areas on both sides of the river. Infiltration and lateral groundwater flow through the spoil materials results in the chemical leaching of metals from the spoils. This is shown by the low pH and high metals content of alluvial groundwater samples within the Deep Adit spoils area of East Avoca (see *Investigative Reports, Site Conceptual Model*, CDM 2008).

A second, but very minor, source of diffuse loading is represented by groundwater that flows through the bedrock outside the capture zone of the underground mine drainage system. This groundwater flows towards the Avoca River valley under natural hydraulic conditions and gradients, and may be chemically affected by the host rock, resulting in slightly elevated metals and lower pH content of the groundwater. This natural flow may give rise to some of the seeps that can be observed on both sides of the river, or discharges into the alluvial aquifer where bedrock and alluvium are hydraulically connected. Overall, it is not believed to be a significant contributor to mass loading to the river (see discussion below).

Diffuse groundwater refers to any subsurface groundwater flow that does not discharge to the main adits, whether it flows along the transition zone, in deep bedrock (deep groundwater), or alluvium.

The first potential diffuse groundwater source is spoil directly overlying the alluvial aquifer. This is considered the most significant input to diffuse contamination of the Avoca River. Drilling of wells in East Avoca near Whitesbridge (Deep Adit Area) indicated that the spoil materials are up to 7-8 m thick, and therefore in direct contact with the alluvial aquifer. Moreover, measured groundwater levels in the Deep Adit wells are only 5-6 m below ground surface, thus within the spoil materials. As the river rises and falls with hydrological conditions, groundwater levels also in the alluvium rise and fall. Therefore there is a constant cycling/leaching effect of the contact area between the spoils and the underlying alluvial groundwater.

The second potential diffuse source, groundwater outside the ZOC of the underground drainage system, cannot be directly measured or evaluated due to a lack of bedrock monitoring wells downgradient of the mine workings. However, a qualitative assessment of potential total contribution (as a discharge rate) can be made by considering the estimated average hydraulic properties of the bedrock. Hydraulic characteristics of the bedrock have been partly quantified from past drilling and basic hydraulic testing in the east Wicklow and Avoca mines area (Flynn 1996; Woods 2003). These studies, as well as recent work by the GSI on poorly productive aquifers (GSI 2005), indicate that fracturing is more prevalent in the top 20-30 m of bedrock, with derived transmissivity values (away from fault zones) ranging from 0.04-11.5 m^2/day. Using reported ranges of transmissivity values and hydraulic gradients in poorly productive bedrock, and assuming most of the groundwater flows in the top 30 m of bedrock, diffuse discharges from groundwater in bedrock would be expected to range between 100-500 m^3/day per km of river length, or approximately 1-5 l/s per km of river length. These flows are almost negligible compared to flow rates (and volumes) in the alluvial aquifer, but could nonetheless add mass loading of contaminants (primarily metals) to the alluvial groundwater. Potentially polluted discharges from bedrock into alluvium would also be limited to short stretches of the Avoca River in the immediate vicinity of the open pit systems and spoil/tailing materials.

Compared to existing drinking water and indicator parameter thresholds, groundwater quality in the Deep Adit wells are significantly degraded, notably with very high concentrations of dissolved and total metals – aluminum, cadmium, copper, iron, manganese, nickel, and zinc. Of general water quality parameters, the wells show elevated concentrations of sulphate.

On the western side of the river, downgradient of the Ballymurtagh landfill and the West Avoca open pits, alluvial wells show similar high concentrations of metals and sulphate, notably in wells placed in the vicinity and upgradient of the Emergency Tailings. While most of the wells on the western side of the Avoca River are located downgradient of the Ballymurtagh landfill (itself a source of historic groundwater contamination), the elevated metal concentrations are most likely related to the mines, rather than the landfill. This conclusion is based on the observation that most municipal landfills do not contain large quantities of leachable metals and do not generate the observed low pH values. The observed metal and low pH values are consistent with oxidation of sulfide mineralisation.

The shallow (water table) well downgradient of the tailings impoundment near Shelton Abbey also shows some elevated metals, notably (dissolved) arsenic, antimony, iron, lead, manganese, nickel, and zinc. However, copper was not detected at levels of concern. Concentrations of zinc are lower at Shelton Abbey than near the Deep Adit and Emergency Tailings.

A total of six private homeowner's wells in the Avoca mines area were sampled once in August 2007. With the exception of iron and manganese (which are inferred to be naturally occurring in bedrock), groundwater quality is good, with low metal concentrations, below Environmental Protection Agency's (EPA's) drinking and indicator water quality thresholds.

The elevated metals concentrations in groundwater imply that groundwater contributes to the mass loading of metals to the Avoca River, along those stretches of the river where the river is gaining water from the underlying and adjacent alluvial aquifer. As previously discussed, the available field data indicate that the river was gaining in the stretch of river that flows past the Deep Adit and Emergency Tailings in late July and early August 2007, but that it was losing water in the stretch flowing past the Road Adit and coal yard. Mass loading estimates to the river from diffuse sources, including groundwater are discussed in Section 2.4.8.

2.4.7 Geochemical Summary

2.4.7.1 Acid Rock Drainage (ARD) Production

ARD is produced mainly by the oxidation of pyrite (FeS_2) within the ore and host rock materials. Pyrite oxidises from exposure to oxygen, producing dissolved sulphate (SO_4^{-2}), ferrous iron (Fe^{+2}), and hydrogen ions (H^+). The hydrogen ions result in low pH waters. The ferrous iron can be oxidised to ferric iron (Fe^{+3}) by additional oxygen, but the reaction is very slow at low pH. However, bacteria typically drastically increase the reaction rate. The ferric iron produced then aggressively reacts with more pyrite to produce more acidity, resulting in a vicious cycle. Propagation of the cycle can be stopped or dramatically decreased by removing one or more of the elements within the cycle, including oxygen (by flooding or encapsulation of the pyrite), water (by capping, covering, or water capture), the bacteria (using bactericides), or ferric iron (by increasing the pH or adding phosphate). Other sulphide minerals that are present in the deposit, such as chalcopyrite, sphalerite, galena, and arsenopyrite (FeAsS), oxidise to produce dissolved copper, zinc, lead, and arsenic, respectively.

The previously discussed sulphide minerals (e.g., pyrite) are primary minerals resulting from the original ore body formation. ARD can also result from the dissolution of secondary minerals (formed since the ore body was formed), such as jarosite [$K\ Fe_3(OH)_6(SO_4)_2$] and metal sulphates. Secondary minerals can store acidity and metals until conditions change, at which point the metals and acidity are released into solution. In the case of metal sulphate, which is an evaporative crust, release of metals and acidity can occur as the result of a rain event as the material is very soluble. Jarosite can be dissolved as a result of an increase in the pH of the water in which it is in contact. Dissolution of secondary phases often results in elevated levels of metals and acidity following rain or storm events.

The laboratory results of samples collected from the spoil piles indicate that the concentrations of lead and arsenic are elevated; however, the concentrations of these contaminants are low or even below detection limits in the adit discharges while the other metals (e.g., copper and zinc) are present at high concentrations. Electronmicroprobe (EMP) analyses were conducted on samples of the spoils and tailings to determine the various mineral forms (*Investigative Reports, Conceptual Site Model*, CDM 2008). Primary mineral phases observed included pyrite, arsenopyrite, anglesite ($PbSO_4$), chalcopyrite, and sphalerite. Secondary phases observed included plumbojarosite (lead jarosite), iron oxyhydroxides, and schwertmannite [$Fe_{16}O_{16}(OH)_{12}(SO_4)_2$]. The formation of arsenic-bearing plumbojarosite explains the low mobility of lead and arsenic within the mine wastes.

2.4.7.2 Attenuation Processes

Subsequent to acid production and metal mobilisation, processes may occur that decrease the metal concentration. These processes are generally called attenuation processes and include neutralisation, adsorption, coprecipitation, and dilution. All these processes occur at the Avoca Site; however, some are more important than others as discussed below.

Neutralisation

ARD is neutralised by the reaction with minerals present in downgradient bedrock or soil/sediments within the drainage basin. However, the ability of these materials to have an impact on the generation and persistence of ARD depends on the rate of reaction with the neutralising minerals compared to the rate of pyrite oxidation. The neutralising mineral reaction rate depends on the following factors:

- The grain size of the minerals (the smaller the grains the faster the reaction)
- The mineral type (carbonates react the quickest followed by ferromagnesium [iron and magnesium containing silicates] minerals and quartz/feldspar minerals)
- The pH of the ARD (the lower the pH the faster the reaction)

In general, unless the ore deposited is hosted by carbonate rocks, silicate minerals dissolve in the presence of ARD. However, because the rate of pyrite oxidation is faster than the rate of neutralisation reactions (silicate mineral dissolution), low pH water results. Once the ARD leaves the sulphide-bearing materials, the neutralisation reactions become more effective and the pH can increase. Acid base potential was measured on all spoils materials at the Site. All materials had a net acid generating potential and no neutralisation potential (*Investigative Reports, Conceptual Site Model*, CDM 2008). During infiltration or water interaction, all spoils will generate low pH leachate with elevated metal concentrations.

The effect of the pH buffering has several effects on the fate and transport of metals and the quality of the ARD, including:

- The concentrations of ferric iron in solution and the rate of pyrite oxidation (as discussed previously)
- The degree of adsorption
- Precipitation/coprecipitation reactions

The neutralisation of the ARD ultimately attenuates most of the metals, although zinc tends to persist at pH values up to 7 or 8.

At the Avoca site, neutralisation by chlorite (iron/aluminum/magnesium silicate/ hydroxide), plagioclase (calcium/sodium/aluminium silicate), and to a lesser extent sericite (fine-grained mica), appears to be occurring within the mine workings. This conclusion is based on the chemical composition of the mine drainage being consistent with dissolution of these minerals. The Avoca River also appears to have some capacity to neutralise ARD, because the pH of the water in the river recovered a short distance downstream from the adit discharges during August 2007 investigations. This neutralisation was enhanced during this time due to the high flow conditions resulting in more dilution. However, overall, the alkalinity of the Avoca River is relatively low with little neutralisation capacity.

Adsorption

The adsorption of metals is enhanced at high pH due to the positive charge of the metals in solution and the negative surface charge of clay minerals and manganese dioxide. However, if the pH becomes too high, then neutral or negative aqueous species begin to become more important and adsorption tends to start to decrease. The result is a "window" in which adsorption is maximised (usually between a pH of 6 and 8). The neutralisation of the ARD to within the optimum adsorption range results in adsorption of metals onto sediments and removal from solution.

Coprecipitation

Precipitation of an amorphous iron oxyhydroxide phase with coprecipitation of copper, lead, zinc, and other metals is likely an important control on metals concentrations in the Avoca River where the adit water mixes with the river water. Deposits of "yellow boy" iron oxyhydroxide and iron sulphate precipitates are present at the point where the adit discharges enter the Avoca River. The precipitates are also observed in the drainage ditches from the Deep Adit and Road Adit before the water enters the Avoca River.

Dilution

Dilution can result in dramatic decreases in aqueous metals concentrations when the volume of dilution water is large. Using an average combined flow for the two adits of 34.8 l/s (Newcastle University, Table 2-6), a copper concentration of 1 mg/l for the adits, and a flow of 1,087 l/s for the Avoca River, results in an "in river" copper concentration of 0.05 mg/l (assuming 0.018 mg/l copper and a flow of 1,052 l/s in the Avoca River upgradient of the adits). Dilution ranges from a low of about 80 in July (Avoca River low flow) to 800 in January (Avoca River high flow). More detailed mass balances are presented in the next section.

The effect of dilution on pH is complicated by the buffering that occurs due to the formation of weak acids, such as bicarbonate and by adsorption of protons (H^+) onto solid surfaces. In addition, pH is in log units, such that a dilution of 1,000 (using neutral water) will change the pH from 3 to 6 (neglecting buffering).

2.4.8 Loading Analysis

2.4.8.1 Methodology

Mass loads were calculated for the Avoca River, the adits, and tributaries using flow and concentration data, as follows:

$$\text{Load (kg/day)} = [C\ (\mu g/l) * F\ (L/day)]\ /\ 1{,}000{,}000{,}000\ \mu g/kg$$

Where:

C = the concentration of the parameter in the water
F = the flow rate of the input

Flow and concentrations were measured directly in the field or from laboratory analyses, and therefore represent known inputs. However, the loading to the Avoca River also includes several "unknown" inputs that cannot be measured directly or easily in the field:

- Overland flow in contact with spoils (only during rain events)
- Seepage from spoils and tailings adjacent to the river (which can occur for long periods following a rain event)
- Seepage from "losing" adit ditches near the river (which may partly soak into ground before reaching the river)
- Diffuse flow (groundwater inflow, see previous sections)
- Desorption from or dissolution of metal-bearing coatings on river sediment

These potential source terms (not including overland flow, as the analysis was done following a "dry" period) were therefore lumped together as a single, lumped loading term, and calculated by difference, as follows.

$$\text{Load}_{\text{Lumped}}\ \text{(kg/day)} = \text{Load}_{\text{Transect}} - (\Sigma\text{Load}_{\text{Adits}} - \Sigma\text{Load}_{\text{Tributaries}})$$

The lumped input represents the sum total of all of the unknown gains and losses. This "lumped load" is typically referred to as the "diffuse load" because it is not a direct and discrete discharge to the river. Distinguishing between the lumped inputs is difficult, requiring a large amount of field data, and is further complicated by the fact that losses of water and/or mass in the system may also be occurring as a result of:

- Loss of river water to groundwater in certain stretches of the river
- Indirect pathways
- Evaporation (minimal)
- Attenuation (adsorption/co-precipitation onto river sediments)

The overall effect (loss or gain) depends on the relative importance of each loss or gain component, recognising that for any given chemical parameter, multiple processes apply (e.g., groundwater attenuation, seepage/recharge, etc.).

Once the lumped loading term was determined for each chemical parameter under study, a theoretical input concentration for each parameter was back-calculated using the volume of water gained within a particular segment of river.

Therefore, in order to simplify the analysis, the mass and flow evaluations were divided into segments of river, as defined by the transect locations along the Avoca River where flow and concentrations were determined (*Investigative Reports, Conceptual Site Model*, CDM 2008).

The first segment evaluated is above Whitesbridge to below the location of the discharge from the Deep Adit into the Avoca River. This segment of the river is gaining water. In addition, this segment is also gaining metal load (in terms of kg/day). The Deep Adit contributes the most metals load to the Avoca in this segment (e.g., approximately 77 percent of the zinc in the Avoca River). Upgradient concentrations contributed 17 percent of the zinc load. However, the diffuse component (lumped load) contributes about 30 percent of the copper and 6 percent of the zinc loads.

The second segment evaluated is from below the Deep Adit discharge point to a point adjacent to the abandoned coal yard (see Figure 2-3). The Road Adit discharges in this segment. According to studies performed at the Site, this river segment loses water. Despite this observation, the overall segment gains metals. The Road Adit is the single largest contributor to the additional metal load in the Avoca River in the segment; however, the diffuse component (lumped load) contributes about 30 percent of the copper and 10 percent of zinc loads. Overall, the upgradient load (from the Deep Adit, etc.) is significantly larger than the additional load in this segment.

In segments further downgradient, typically a loss of metals is observed probably due to attenuation in the river sediments. Evaluations show that typically treatment of the Deep and Road Adits alone will not achieve water quality standards for copper in the Avoca River (see *Investigative Reports, Site Conceptual Model*, CDM 2008). In addition to the direct adit discharges and diffuse component, significant loads of metals occur in surface water runoff during and after rainfall events (see Table 2-5).

2.5 Human Health Risk Assessment

A Human Health Risk Assessment (HHRA) for the Avoca site was performed. The complete report is part of the *Investigative Reports* (CDM 2008). The following sections summarise the evaluations.

2.5.1 Purpose of the Human Health Risk Assessment

A HHRA was conducted:

- To identify and describe conditions stemming from releases of mining-related contaminants that may result in adverse effects to people who live, work, or recreate in or near the study area currently or in the future

- To evaluate potential cancer risks and non-cancer hazards associated with exposure to mine related contaminants

- To provide preliminary remediation goals to help address human health concerns and to provide HHRA information to the assessment of remedial and management alternatives

The HHRA addresses potential hazards to human health associated with current conditions at the Site in the absence of any remedial actions. The analysis, results, and conclusions presented in this assessment provide a basis for evaluating the nature and magnitude of human health risks potentially associated with exposure to mine related contamination at the Site. This information can, in turn, be used to identify areas or exposure pathways of potential concern and to determine the need for risk management measures. In general, this risk assessment is focused on providing a conservative estimate of risk for the Avoca Mining Site. A number of assumptions and uncertainties likely to overestimate rather than underestimate risks are made throughout the risk assessment process.

2.5.2 Potential Risk Issues

The mine site is surrounded mainly by pasture, forest, and heathland. Several residences are, however, located on the margins of the Site. The near-site residents and any onsite workers could potentially be exposed to mine related contaminants in soil and/or mine wastes.

Grasing of farm animals takes place along the fringes of the mine site, and even on some portions of the mine site, and these animals may take up mine related constituents in soil and those accumulated in plants. Subsequent consumption of meat from these animals by people is a possible risk issue.

People also visit areas near and on the Site for recreational purposes. People use the area for walking although warning signs are posted in a number of areas. People are also known to bicycle and ride quad bikes in the area. These visitors are exposed to mine contaminants in soil and mine wastes (spoils) or soil contaminants re-suspended in air while engaged in recreation. Further, people recreating in the Avoca River might also ingest site related contaminants in surface water and sediment. People may be exposed to mine related contamination through consumption of fish taken from the river. Some metals observed in mine wastes can bioaccumulate in fish tissue. Although some areas of the river are biologically impaired, recent electrofishing surveys carried out by the Fisheries Boards in the Avoca River catchment in 2002 indicate that salmon and trout fish stocks are present in the system and some fish (e.g., eel, lamprey, and minnow) are present in contaminated stretches of the river.

Finally, groundwater in the alluvial aquifer near the Avoca River is contaminated by metals. This water is not currently used for domestic sources, but attempts could be made to use it in the future.

2.5.3 Risk Assessment Approach

Risk assessment is a tool used to evaluate the likelihood and degree of contaminant exposure and the possible adverse health effects associated with such exposure. The overall approach for the HHRA follows guidance and recommendations provided in the *Final Report of Expert Group for Silvermines County Tipperary* (EPA 2004) and in *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part A)* (USEPA 1989), subsequent USEPA supplemental risk assessment guidance documents and other guidance, literature, or site-specific information as appropriate. Based on site-specific data, the HHRA:

- Identifies contaminants of concern (COCs) associated with historical releases at the Site
- Evaluates potential exposure pathways by which people may contact COCs at the Site
- Assesses toxicity of COCs
- Combines toxicity information with exposure assumptions to estimate potential carcinogenic and noncarcinogenic health risks
- Provides preliminary remediation goals (PRGs) to assist in the preliminary evaluation of remedial action alternatives at the Site

2.5.4 Summary of Data

Assessment of human health risk and hazards relies on analytical data from samples collected at the Site. These data are used to estimate the amounts of contaminants that could be taken into the body orally, dermally, or through inhalation. Samples were collected at the Site during the investigations conducted by the GSI in November 2006 and June 2007, and by CDM in July/August and November 2007, and in February 2008. The samples were typically analysed for an extensive suite of chemical parameters. The results of these analyses for surface water, groundwater, sediments, soils, and spoils have been used in the HHRA. The data used in the HHRA are provided in the *Investigative Reports, Human Health Risk Assessment* (CDM 2008) and are summarised in the following tables:

- Table 2-8 Summary of Spoil Samples
- Table 2-9 Summary of Surface Soil Samples
- Table 2-10 Summary of Groundwater Samples

Table 2-8 Summary of Spoils Samples Concentrations (mg/kg)

Area	Statistic	Ag	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Tl	Ti	U	V	Zn
Connary (n = 18)	Min	2.50	73.17	60.41	0.13	0.20	4.00	81.20	0.36	85.07	3.80	0.40	1,112	0.75	0.40	0.40	2.74	20.00	0.63	4.00	86.69
	Mean	29.23	1,076	346	0.66	0.62	4.00	2,016	5.90	259	47.67	2.44	23,812	13.28	1.25	1.58	12.99	45.51	3.05	6.59	485
	Max	**82.56**	**3,509**	**1,384**	**1.57**	**1.37**	**4.00**	**7,078**	**16.68**	**861**	**108**	**5.47**	**78,441**	**39.42**	**2.79**	**6.07**	**29.48**	**73.11**	**4.88**	**14.28**	**1,313**
	FD	1	1	1	1	0.72	0	1	1	1	1	0.89	1	1	0.61	0.44	1	0.72	1	0.39	1
Mt. Platt/ Cronebane (n = 24)	Min	1.35	263	24.76	0.13	0.20	4.00	150	0.57	20.00	2.14	0.40	1,506	1.29	0.40	0.40	8.85	20.00	1.35	4.00	47.29
	Mean	8.93	571	101	0.52	1.43	5.95	612	2.61	116	25.35	2.39	5,192	3.54	1.37	1.01	13.18	55.02	2.77	6.28	203
	Max	**19.05**	**1,046**	**343**	**1.21**	**3.68**	**37.58**	**1,337**	**17.48**	**417**	**53.82**	**11.52**	**24,266**	**7.45**	**3.94**	**5.25**	**26.24**	**209**	**12.82**	**15.54**	**376**
	FD	1	1	1	1	0.92	0.08	1	1	1	1	0.83	1	1	0.75	0.17	1	0.63	1	0.29	1
East Avoca/ Tigroney West (n = 10)	Min	1	8	5	0	0.58	4.00	73.95	0.17	44.67	1.31	0.40	111.81	0.89	0.40	0.40	0.40	20.00	0.40	4.00	49.01
	Mean	9.83	457	27.36	0.31	2.39	6.62	1,490	0.94	499	45.62	3.16	5,360	2.04	1.31	5.51	7.50	130	1.52	9.95	199
	Max	**31.38**	**942**	**93.23**	**0.53**	**5.92**	**13.33**	**2,912**	**3.76**	**1,043**	**88.34**	**8.16**	**21,753**	**4.62**	**3.06**	**24.59**	**9.46**	**259**	**2.36**	**22.96**	**415**
	FD	1	1	1	1	1	0.33	1	1	1	1	0.92	1	1	0.67	0.92	1	0.92	1	0.50	1
Ore Bin Area (n = 10)	Min	1.67	216	20.85	0.33	0.47	4.00	466	0.23	97.60	11.79	1.01	1,091	0.87	0.40	0.40	6.69	20.00	1.12	4.00	181
	Mean	20.18	1,084	31.23	1.94	3.37	4.88	2,895	5.73	365	88.34	4.28	21,932	11.42	1.82	6.58	9.81	185.80	2.63	11.02	1,037
	Max	**44.62**	**2,893**	**70.97**	**6.30**	**8.54**	**11.03**	**11,116**	**20.87**	**471**	**186**	**11.44**	**74,877**	**44.01**	**6.17**	**13.75**	**14.14**	**849**	**4.80**	**26.28**	**2,628**
	FD	1	1	1	1	1	0.13	1	1	1	1	1	1	1	0.75	0.88	1	0.88	1	0.63	1
Deep Adit Area (n = 16)	Min	35.00	371.91	10.00	50.00	30.00	75.00	410.12	15.00	35.00	NA	25.00	1,128	20.00	20.00	30.00	10.00	601	0.00	25.00	25.00
	Mean	35.00	982	421	50.00	411	75.00	1,210	15.00	669	NA	25.00	7,846	79.72	20.00	30.00	280	1,287	0.00	25.00	285
	Max	**35.00**	**2,940**	**1,549**	**50.00**	**1,774**	**75.00**	**3,404**	**15.00**	**957**	NA	**25.00**	**22,877**	**228.89**	**20.00**	**30.00**	**949**	**2,299**	**0.00**	**25.00**	**796**
	FD	0	1	0.38	0	0.31	0	1	0	0.94	NA	0	1	0.38	0	0	0.81	1	0	0	0.75
West Avoca (n = 26)	Min	0.02	67.46	13.27	0.02	0.20	4.00	57.11	0.16	89.33	1.20	1.24	106.77	0.10	0.40	0.40	5.59	72.77	1.18	4.00	65.96
	Mean	7.39	1,150	42.76	0.23	3.95	14.02	719	1.21	610	61.50	7.77	3,759	4.09	3.02	4.95	10.90	193	2.44	27.62	167
	Max	**55.35**	**3,903**	**92.40**	**1.32**	**17.64**	**90.21**	**2,822**	**8.20**	**1,777**	**188**	**31.33**	**28,363**	**19.93**	**9.76**	**26.67**	**16.55**	**779**	**5.32**	**180**	**733**
	FD	0.96	1	1	0.85	0.96	0.31	1	1	1	1	1	1	0.96	0.88	0.85	1	1	1	0.88	1
Shelton Abbey (n = 4)	Min	ND	24.0	0.24	ND	59.7	35.2	31.1	4.2	112	NA	24.3	29.4	ND	ND	ND	NA	NA	NA	NA	4.9
	Mean	ND	62.3	1.2	ND	59.7	118	44.0	4.4	297	NA	45.5	274	ND	ND	ND	NA	NA	NA	NA	22.2
	Max	**ND**	**184**	**2.2**	**ND**	**59.7**	**243**	**59.9**	**4.6**	**791**	**NA**	**79.9**	**960**	**ND**	**ND**	**ND**	**NA**	**NA**	**NA**	**NA**	**41.3**
	FD	ND	1	1	ND	1	1	1	1	1	NA	1	1	ND	ND	ND	NA	NA	NA	NA	1
	Spoils MAX	**82.56**	**3,903**	**1,549**	**6.30**	**1,774**	**243**	**11,116**	**20.87**	**1,777**	**188**	**79.9**	**78,441**	**229**	**9.76**	**26.67**	**949**	**2,299**	**12.82**	**180**	**2,628**

Notes:
Means based on half the detection limit for nondetect samples
Overall maximums do not include maximums where constituent was not detected (i.e., where maximums are based only on half the detection limit)
n = number of samples
FD = frequency of detection (fraction)
Data for the Deep Adit are from GSI (XRF) and values associated with non-detect data (where FD=0) are not valid for comparison or risk estimation
ND = constituent not detected above detection limit in any sample (FD=0)
NA = not analysed for this constituent

Table 2-9 Summary of Surface Soil Samples Concentrations (mg/kg)

Area	Statistic	Ag	As	Ba	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Th	Ti	U	V	Zn
Field 1	Min	1.02	53.8	23.7	0.35	1.30	9.52	192.2	0.09	185	5.05	3.19	346	0.41	0.40	1.43	4.12	100.6	1.56	15.7	89.5
	Mean	2.75	84.0	35.5	0.49	2.04	13.07	283.0	0.22	295	6.32	4.77	568	0.64	0.46	1.76	5.40	134.8	1.81	22.2	134.7
	Max	**6.01**	**106.1**	**49.4**	**0.68**	**2.86**	**17.56**	**359.9**	**0.35**	**469**	**7.09**	**7.42**	**818**	**0.96**	**0.81**	**2.02**	**6.30**	**178.9**	**2.00**	**32.9**	**168.6**
	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.14	1	1	1	1	1	1
Field 2	Min	0.16	15.7	12.1	0.15	0.20	4.00	26.7	0.01	23	1.04	0.40	39	0.10	0.40	0.40	2.62	20.0	0.81	4.00	17.3
	Mean	0.26	22.8	15.1	0.25	0.62	5.13	42.8	0.03	88	2.52	1.36	62	0.16	0.40	0.47	3.94	54.8	1.12	9.65	33.6
	Max	**0.48**	**28.3**	**24.9**	**0.44**	**1.31**	**11.90**	**73.9**	**0.07**	**215**	**4.65**	**3.11**	**117**	**0.39**	**0.40**	**0.87**	**6.28**	**112.1**	**1.54**	**26.9**	**56.5**
	FD	1	1	1	1	0.86	0.14	1	0.71	1	1	0.71	1	0.29	0.00	0.14	1	0.86	1	0.43	1
Field 3	Min	0.42	32.7	19.4	0.27	0.60	4.00	29.8	0.02	91	1.78	1.85	100	0.10	0.40	0.40	3.44	81.2	1.31	4.00	35.8
	Mean	1.15	59.8	24.4	0.44	0.93	8.37	50.5	0.11	146	4.02	2.89	142	0.25	0.53	0.89	4.77	100.8	1.35	17.9	48.0
	Max	**2.43**	**144.4**	**28.8**	**0.72**	**1.39**	**12.06**	**83.9**	**0.18**	**187**	**7.16**	**3.50**	**219**	**0.45**	**1.06**	**1.27**	**5.97**	**143.0**	**1.38**	**24.8**	**68.6**
	FD	1	1	1	1	1	0.60	1	1	1	1	1	1	0.60	0.20	0.80	1	1	1	0.80	1
Field 4	Min	0.38	40.6	36.5	0.22	1.41	10.68	81.0	0.11	180	3.21	3.37	143	0.10	0.40	0.40	4.12	78.1	1.73	19.6	59.5
	Mean	0.48	47.3	73.9	0.33	2.67	18.25	110.7	0.13	289	4.22	6.84	195	0.16	0.51	0.40	5.19	114.8	1.87	26.8	78.5
	Max	**0.71**	**60.7**	**166.7**	**0.48**	**3.81**	**23.72**	**177.3**	**0.17**	**412**	**5.83**	**10.06**	**346**	**0.30**	**0.94**	**0.40**	**6.13**	**132.8**	**2.16**	**34.3**	**114.9**
	FD	1	1	1	1	1	1	1	1	1	1	1	1	0.40	0.20	0.00	1	1	1	1	1
Field 5	Min	1.19	70.2	126.1	1.08	18.63	26.78	358.8	0.34	2,204	4.43	21.05	659	0.38	0.40	2.53	5.42	175.6	2.06	33.8	344.3
	Mean	1.41	73.1	135.3	1.67	19.42	29.05	428.9	0.46	2,296	4.60	21.81	728	0.47	0.40	2.90	5.90	196.0	2.29	35.9	541.6
	Max	**1.57**	**74.7**	**147.2**	**2.11**	**20.67**	**31.20**	**515.6**	**0.56**	**2,345**	**4.76**	**22.25**	**766**	**0.54**	**0.40**	**3.52**	**6.52**	**215.1**	**2.57**	**38.0**	**647.2**
	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	1.00	1	1	1	1	1	1
Field 6	Min	0.72	114.8	44.4	0.15	4.00	12.64	158.5	0.13	405	5.65	5.17	227	0.43	0.40	1.15	5.50	69.6	2.05	19.6	118.7
	Mean	1.83	184.3	65.6	0.34	5.84	16.43	313.0	0.25	565	8.18	9.40	379	0.85	0.78	1.69	6.57	97.8	2.62	26.9	162.0
	Max	**2.63**	**275.5**	**89.2**	**0.48**	**9.80**	**29.78**	**574.7**	**0.65**	**861**	**12.39**	**13.11**	**643**	**1.87**	**1.30**	**2.69**	**7.83**	**137.4**	**3.76**	**57.2**	**227.4**
	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.57	1	1	1	1	1	1
Field 7	Min	0.30	47.6	43.6	0.13	2.62	9.48	94.0	0.09	271	2.33	3.42	145	0.21	0.40	0.40	4.13	54.2	1.77	19.9	69.7
	Mean	1.30	106.1	77.4	0.35	8.98	27.10	124.4	0.17	715	7.66	11.34	190	0.40	0.80	1.04	5.40	132.6	2.25	49.0	146.4
	Max	**4.12**	**227.9**	**111.7**	**0.58**	**31.95**	**73.94**	**163.8**	**0.33**	**1,381**	**18.56**	**41.11**	**225**	**0.75**	**1.43**	**2.67**	**8.97**	**387.3**	**2.77**	**128.3**	**335.7**
	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	0.43	0.71	1	1	1	1	1
	SS MAX	**6.01**	**275.5**	**166.7**	**2.11**	**32.0**	**73.9**	**574.7**	**0.65**	**2,345**	**18.56**	**41.11**	**818**	**1.87**	**1.43**	**3.52**	**8.97**	**387.3**	**3.76**	**128.3**	**647.2**

Notes:
Means based on half the detection limit for nondetect samples
n = number of samples
FD = frequency of detection (fraction)
Field 1 = South of Cronebane (n = 7)
Field 2 = Northwest of Mt. Platt and Cronebane (n = 7)
Fields 3 and 4 = North of Mt. Platt and Cronebane (n = 5 and 5)
Field 5 = Near Avoca River West of the Deep Adit (n = 3)
Fields 6 and 7 = West Avoca, South of Mining Area (n = 7 and 7)

Table 2-10 Summary of Groundwater Samples Concentrations

Contaminant	Maximum Total Concentration in Homeowner Wells[1]	Maximum Total Concentration in Monitoring Well[2]	Maximum Dissolved Concentration in Monitoring Well[3]
Aluminum	1,186	62,440	1,300,000
Antimony	1	ND (<1)	ND (<1)
Arsenic	ND (<1)	ND (<1)	27
Barium	46	47	41
Cadmium	ND (<1)	30	294
Chromium	4	4	370
Cobalt	ND (<1)	116	1,087
Copper	81	8,028	85,460
Iron	502	1,058	136,000
Lead	3	10	231
Manganese	25	5,537	51,310
Mercury	0.0014	NA	NA
Nickel	8	58	575
Selenium	ND (<1)	ND (<1)	3
Silver	ND (<2)	ND (<2)	ND (<2)
Thallium	ND (<1)	ND (<1)	ND (<1)
Tin	2	4	ND (<1)
Titanium	5	21	9
Uranium	4	7	93
Vanadium	2	4	2
Zinc	234	9,855	137,700

Units are in micrograms per liter (µg/l)
ND = Nondetect
[1] Maximum reported total concentration for all residential wells sampled (µg/l), six wells
[2] Maximum reported total concentration (µg/l) for shallow monitoring wells sampled, 3 wells
[3] Maximum reported dissolved concentration (µg/l) for shallow monitoring wells sampled, 12 wells

The tables summarise the analyses of samples collected from spoil piles (Table 2-8), pastures (Table 2-9), and monitoring and homeowner wells (Table 2-10). Concentrations of metals in the Avoca River and the river sediments were typically at levels that would not be a human health concern. These data are presented in Section 2.6, Ecological Risk Assessment.

2.5.5 Selection of Contaminants of Concern (COCs)

COCs are mine-related constituents that could pose a threat to people that use the Site. COCs associated with releases of mining-related contaminants that may result in adverse effects to people who live, work, or recreate in or near the study area currently or in the future were identified for surface soil/spoils, surface water, groundwater, and sediment.

Identification of COCs is based on comparison of measured concentrations of all constituents in the various Site media (i.e., soil, water, spoils, etc.) to conservative Irish EPA or USEPA risk-based screening levels and/or commonly accepted benchmarks. Screening levels are conservative risk-based or other estimated concentrations that, if not exceeded, would be protective for human receptors under all possible chronic exposure conditions. Screening levels are generally based on potential cancer and non-cancer effects to humans and are chemical-specific and media-specific. COCs are retained for further risk evaluation when measured maximum concentrations exceed their respective screening level. Acute exposure conditions typically do not occur and are not important for risk evaluation at the Site.

COCs were identified for surface soil, spoils, groundwater, surface water, and sediment. Surface soil and spoils COCs are: antimony, arsenic, cadmium, cobalt, copper, iron, lead, manganese, thallium, and vanadium. Groundwater COCs for the deep bedrock aquifer (homeowner wells) are: aluminum and iron. COCs for shallow alluvial groundwater are: aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc. COCs identified for sediment are: arsenic, lead, and manganese. COCs for rivers and tributaries (first category of surface water) include: aluminum, iron, lead, and manganese. In the second category of surface water (i.e., adits, discharges, etc.) COCs include: aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc. Contaminants detected in surface water that are potential COCs due to bioconcentration potential in fish include: cadmium, copper, lead, manganese, nickel, and zinc. The detailed evaluations providing the screening levels are provided in Tables 2-8 to 2-11 in the *Investigative Reports, Human Health Risk Assessment*, CDM 2008.

The following COCs for each media are summarised in Table 2-11.

Table 2-11 Summary of COCs

Contaminant	Surface Soil/Spoils COC	Groundwater[1] COC	Surface Water[2] COC	Sediments COC	Bioconcentration Potential in Fish
Aluminum	No	Yes	Yes	No	No
Arsenic	Yes	Yes	Yes	Yes	No
Antimony	Yes	No	No	No	No
Cadmium	Yes	Yes	Yes	No	Yes
Cobalt	Yes	Yes	No	No	No
Chromium (total)	No	Yes	Yes	No	No
Copper	Yes	Yes	Yes	No	Yes
Iron	Yes	Yes	Yes	No	No
Lead	Yes	Yes	Yes	Yes	Yes
Manganese	Yes	Yes	Yes	Yes	Yes
Thallium	Yes	No	No	No	No
Vanadium	Yes	No	No	No	No
Nickel	No	Yes	Yes	No	Yes
Zinc	No	Yes	Yes	No	Yes

[1] Shallow alluvial wells
[2] Including adits, etc.

2.5.6 Exposure Assessment

Exposure assessment defines, in qualitative or quantitative fashion, the ways that people living, working, or recreating in the study area might be exposed to contaminants released as a result of historic mining operations.

An exposure pathway (the sequence of events leading to contact with a contaminant) generally consists of the following elements:

- A contaminant source and mechanism of release to the environment
- An environmental transport medium for the released contaminant to reach locations where human contact is possible
- A point of potential human exposure with the contaminated medium (i.e., the location of contact with the contaminated medium)
- A route of exposure (e.g., ingestion, dermal absorption, inhalation) into the receptor

An exposure pathway is considered complete only if all of these elements are present. Exposure pathways are evaluated for both current and potential future land uses (residential, occupational, and recreational). Some pathways, though not currently complete, can be assumed to be complete in the future. Such pathways are evaluated as potential future sources of exposure.

Figure 2-7 shows graphically the various sources, release mechanisms, pathways, exposure routes, and potential receptors. The following paragraph discusses the receptor and exposure pathways.

Populations (i.e., receptors) that could theoretically be exposed to contaminants from the mine site as a result of the exposure assessment evaluation may include:

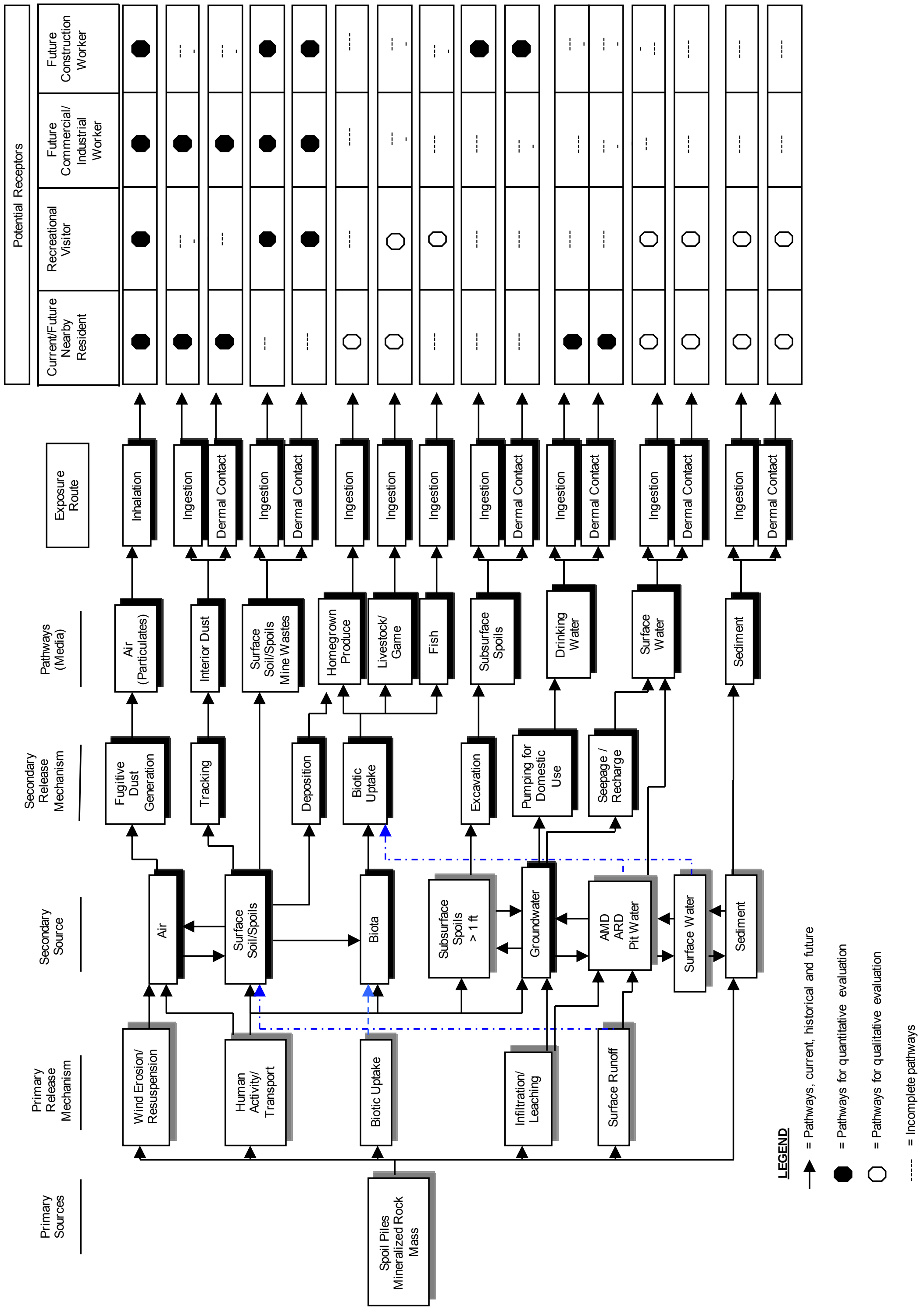
- Current and future recreational visitors (these receptors could also be residents and/or workers)
- Nearby residents (current and in the future)
- Onsite commercial/industrial workers (future)
- Future construction workers

An additional potential receptor population could be the consumer of livestock, fish, or produce (vegetables, etc.) affected by site contaminants. This concern is addressed by considering the exposures for the above list (see last three bullets below and Figure 2-7). Potential exposure pathways for these populations may include one to several of the following:

- Incidental ingestion of and dermal contact with soil and spoils material
- Inhalation of particulates in ambient air
- Incidental ingestion of surface water and sediment
- Dermal contact with surface water and sediment
- Ingestion of groundwater (incidental and/or voluntary [domestic groundwater use])
- Dermal contact with groundwater (showering and bathing)
- Ingestion of animal products from animals fed affected feed, or watered with affected surface water or groundwater
- Ingestion of produce from gardens with affected soil and/or watered with affected surface water or groundwater
- Ingestion of contaminated fish

2.5.6.1 Sensitive Receptors

To provide assessment of health risks and hazards and to address concerns about potential risk to children currently recreating on the mine site, a risk analysis was performed for a recreational scenario. The recreational scenario assumes that the recreational visitor lives nearby and visits the site frequently. Children are identified as a sensitive subpopulation due to their potential for greater sensitivity and/or exposure to heavy metals. Behaviors that may increase exposure in children include biking on mine wastes, digging and playing in soil or spoils, and frequent hand-to-mouth contact. Children and others may be exposed via several pathways including incidental ingestion, dermal contact, and inhalation of particulates.



Pathways (Media)	Exposure Route	Current/Future Nearby Resident	Recreational Visitor	Future Commercial/ Industrial Worker	Future Construction Worker
Air (Particulates)	Inhalation	●	●	●	●
Interior Dust	Ingestion	●	----	●	----
Interior Dust	Dermal Contact	●	----	●	----
Surface Soil/Spoils Mine Wastes	Ingestion	----	●	●	●
Surface Soil/Spoils Mine Wastes	Dermal Contact	----	●	●	●
Homegrown Produce	Ingestion	○	----	----	----
Livestock/ Game	Ingestion	○	○	----	----
Fish	Ingestion	----	○	----	----
Subsurface Spoils	Ingestion	----	----	----	●
Subsurface Spoils	Dermal Contact	----	----	----	●
Drinking Water	Ingestion	●	----	----	----
Drinking Water	Dermal Contact	●	----	----	----
Surface Water	Ingestion	○	○	----	----
Surface Water	Dermal Contact	○	○	----	----
Sediment	Ingestion	○	○	----	----
Sediment	Dermal Contact	○	○	----	----

Figure 2-7 Preliminary Site Conceptual Exposure Model - Human Health
Avoca Mine Site

2.5.6.2 Exposure Areas

Geographic areas where human exposure could occur were identified for the HHRA to estimate potential risks to receptors within specific areas based on concentrations of COCs in media of concern. The primary criteria for designation of specific exposure areas are the identification of distinct geographic areas, the magnitude and distribution of COCs, known or suspected contaminant source areas, and receptor behavior. Exposure areas were identified for soils, spoils, groundwater, surface water, and sediment.

Exposure areas identified for spoil piles include: Connary, Mount Platt/Cronebane, East Avoca/Tigroney West, Ore Bins areas at Tigroney West, Deep Adit Area, West Avoca, and Shelton Abbey. These areas and a summary of contaminant concentrations are provided in Table 2-8. All areas contain spoil piles with elevated concentrations of metals. Several fields and pastures in the vicinity of the site were designated as soil exposure areas. Some of these fields are downwind of spoil piles. These areas and the measured soil concentrations are provided in Table 2-9. All fields contain elevated concentrations of metals; however, the metal concentrations are much lower than the spoil piles and metal concentrations in Field 2 approach background levels (see Section 3.2 for background levels).

Groundwater is grouped into two exposure areas: deep bedrock wells (homeowner "wells") and shallow alluvial aquifer wells (monitoring wells). See Table 2-10 for a summary of concentrations.

As discussed in Sections 2.3.3.4 and 2.3.3.5, the adit discharges and Avoca River have elevated concentrations of metals. These data were not quantitatively evaluated because human exposures are expected to be infrequent and of short duration. However, qualitative evaluations were performed for those exposure areas.

2.5.6.3 Exposure Point Concentrations

One of the necessary components of a quantitative exposure assessment is an exposure point concentration (EPC). EPCs represent concentrations of contaminants at points of potential human contact with the environmental media of interest. Tables 2-8 to 2-10 provide summaries (minimum, maximum, mean values) of the site-specific data. The same data used to generate the summary tables were used to calculate EPCs. For each data set (representing a single chemical in each medium), a 95% UCL (Upper Confidence Level) on the arithmetic mean concentration was calculated and compared to the maximum detected concentration for that chemical. A 95% UCL was also calculated for site-specific bioavailability estimates for lead and arsenic. The lower value of the UCL and the maximum detected value is the EPC, as recommended by USEPA (USEPA 1992). The methods used to calculate the EPCs and the resulting values are provided in Section 3.9.1 and Appendix B of the *Investigative Reports, Human Health Risk Assessment*, CDM 2008. A summary of the EPCs are provided in Table 2-12. In this assessment, ingestion, dermal contact, and inhalation exposures are estimated using soil, spoils, and groundwater analytical data. EPCs for air are estimated from COC concentrations in soil.

Table 2-12 Summary of Exposure Point Concentrations for Spoils and Soils

COC	Exposure Area						
	Spoils						Soil (Fields and Pastures)
	Connary	Mt. Platt/ Cronebane	East Avoca/ Tigroney West	Ore Bin Area	Deep Adit Area	West Avoca	
Antimony	19.9	4.1	2.4	20.6	203	6.4	1.9
Arsenic	631	493	535	1,545	1,237	1,622	275.5
Cobalt	0.815	1.84	3.4	5	1,217	12	32.0
Copper	2,673	678	2,227	4,803	1,637	1,174	574.7
Iron (%)	8	7	14	14	22	19	11.1
Lead	34,525	13,768	5,221	70,792	10,834	3,808	818.0
Manganese	248	165	601	423	775	839	2,345.0
Thallium	NA	NA	NA	NA	404	NA	NA
Vanadium	10.5	5.5	19.7	15.5	NA	48.2	128.3

Units are mg/Kg, except iron (%)
NA= Not available, data are not available to estimate EPC

2.5.6.4 Exposure Assumptions

Section 3.10 in the *Investigative Reports, Human Health Risk Assessment*, CDM 2008 provides the assumptions that are used to quantify potential exposures in the HHRA. Exposure parameters are presented for recreational visitors, nearby residents, future onsite commercial/industrial workers, and future onsite construction workers. Exposure assumptions for current receptors also apply to future receptors under the same exposure scenario. Exposure assumptions were identified based on characteristics of specific receptor groups reasonably assumed to be affected by mine wastes. Exposure assumptions are presented for estimates of reasonable maximum exposure (RME). RME is designed to represent high-end exposure, well above the average, but still within the possible range of exposures (USEPA 1993), and is generally considered to be the highest exposure that is reasonably expected to occur at a site. The exposure values used for each receptor scenario are based on USEPA and other guidance and include the following:

- Exposure duration (both carcinogenic and noncarcinogenic)
- Body weight (both adult and children)
- Averaging time (period of days over which intake is averaged)
- Exposure frequency (number of days per year exposure occurs)
- Ingestion rates (both soil and water)
- Fraction ingested from contaminated media
- Bioavailability factor (see below)
- Skin surface area available for contact (soil and water)
- Adherence factor (amount of soil/spoils that adheres to the skin)
- Dermal absorption factors (for soil/spoils, contaminant specific)
- Dermal permeability constant (for water, contaminant specific)

- Event frequency (number of contact events per day)
- Inhalation rate (both adult and children air intake)
- Particulate emission factor (for dust)

2.5.6.5 Toxicity Assessment

The toxicity assessment provides qualitative and quantitative descriptions of potential health impacts of COCs. The toxicity assessment provides contaminant-specific information that can be used along with estimates of exposure to estimate possible cancer risks and non-cancer health hazards. Toxicity values are numerical expressions of the relationship between dose (exposure) and response (adverse health effects). Separate toxicity values are developed for carcinogenic and noncarcinogenic (i.e., systemic) health effects. Toxicity values for carcinogens are provided as cancer slope factors (CSF) in units of risk per milligram of chemical per kilogram of body weight per day. A CSF is developed based on the assumption that no threshold for carcinogenic effects exists, and that any exposure is associated with some finite risk of cancer. Toxicity values for noncarcinogen or for significant systemic effects caused by carcinogens are provided as reference doses (RfD) in units of mg/kg-day. RfDs are interpreted as thresholds below which adverse health effects are not expected to occur, even in the most sensitive individuals in a population. CSFs and RfDs are used in conjunction with estimates of exposure to quantify risks and health hazards to exposed individuals. The CSFs and RfDs are based on USEPA and other guidance and are provided in Section 4 of the *Investigative Reports, Human Health Risk Assessment*, CDM 2008. A summary of ESFs and RfDs for selected COCs is provided in Tables 2-13a (cancer CSF) and 2-13b (non-cancer RFD).

Table 2-13a Cancer Toxicity Data

COC	Oral Cancer Slope Factor $(mg/kg/day)^{-1}$	Absorbed Dermal Cancer Slope Factor $(mg/kg/day)^{-1}$	Inhalation Cancer Slope Factor $(mg/kg/day)^{-1}$
Arsenic	1.5	1.5	15
Cadmium	—	—	6.3
Chromium	—	—	42
Cobalt	—	—	9.8
Nickel	—	—	0.91

Table 2-13b Non-Cancer Toxicity Data

COC	Oral RfD (mg/kg/day)	Absorbed Dermal RfD (mg/kg/day)	Inhalation RfD (mg/kg/day)
Antimony	4×10^{-4}	6×10^{-5}	—
Arsenic	3×10^{-4}	3×10^{-4}	—
Cobalt	2×10^{-2}	2×10^{-2}	5.7×10^{-6}
Copper	4×10^{-2}	4×10^{-2}	—
Iron	7×10^{-1}	3×10^{-1}	—
Manganese	2×10^{-2}	8×10^{-4}	1.4×10^{-5}
Thallium	7×10^{-5}	7×10^{-5}	—
Vanadium	1×10^{-3}	2.6×10^{-5}	—

"–" = not applicable or not available

2.5.6.6 Bioaccessibility (Bioavailability) Estimates

In most sites associated with mining activities, the concentration of arsenic and lead in solid media present the major risk concerns. Therefore, more detailed evaluations for arsenic and lead were performed to more accurately evaluate risks. In particular, bioavailability analyses for arsenic and lead were performed on representative spoil samples using (1) in vitro analysis of bioavailability of lead and arsenic, and (2) electron microprobe analysis of lead and arsenic speciation. Bioavailability is an estimate of the amount of lead or arsenic that might be absorbed from the Gastro-intestinal (GI) tract after ingestion of soil. Bioavailability of arsenic and lead at the site was found to be relatively low and is not directly related to the soil concentration (i.e., a higher soil concentration does not equate with a higher bioavailability).

Bioavailability of lead as assessed in the *in vitro* assays for the Avoca Mining Site show relatively low bioavailability, significantly below the USEPA default value of 60 percent. Bioavailability estimates for lead ranged from 1 to 13 percent and averaged about 3 percent. Arsenic bioavailability for mine wastes at the Avoca Mining Site is significantly less than the USEPA default value of 80 percent. *In vitro* bioavailability results for arsenic ranged from 0 to 8 percent. Detailed results are provided in the *Investigative Reports, Human Health Risk Assessment*, CDM 2008. These results are consistent with the formation of arsenic bearing lead minerals with relatively low solubility (see Section 2.4.7.1).

2.5.7 Human Health Risk Summary

2.5.7.1 Cancer Risk (Arsenic Exposure)

Cancer risk is estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a known, probable, or possible carcinogen. Excess lifetime cancer risks are generally expressed in scientific notation as incremental probabilities. An excess lifetime cancer risk of 1×10^{-6} (one in one million or 0.0001 percent), for example, represents the incremental probability that an individual will develop cancer as a result of exposure to a carcinogenic chemical over a 70-year lifetime under specified exposure conditions (USEPA 1989). This increment is in addition to the risk of developing cancer from causes unrelated to the exposure. Cancer risks below $1x10^{-6}$ are typically assumed to be so low that they would require no remediation. Cancer risk is calculated by multiplying the lifetime average daily dose (mg/kg per day) by the cancer slope factor.

Cancer risk at Avoca is due to exposure to arsenic. Site-specific bioavailability analyses have shown that arsenic in soil at the Site is in a relatively inaccessible form. However, even with low bioavailability, arsenic concentrations are high enough in the spoils to present potential or slightly elevated carcinogenic risk (above the $1x10^{-6}$ level) for the following receptors and areas.

- *Recreational Scenario:* Connary (adults), Ore Bins areas (adults and teens), Deep Adit area (adults), West Avoca (adults)

- *Commercial/Industrial Worker:* Connary, Mt. Platt/Cronebane, East Avoca/Tigroney West, Ore Bins area, Deep Adit area, West Avoca
- *Construction Worker:* Ore Bins area, West Avoca

Carcinogens were not reported above detection limits in homeowner wells. If shallow alluvial groundwater near the Site was used as a potable water source in the future, cancer risk could significantly exceed acceptable thresholds (calculated risk is 1,000 times the $1x10^{-6}$ level).

The calculated risk for exposure to arsenic in soils (from pastures) is slightly above the $1x10^{-6}$ level. However, because the soils are covered by vegetation, exposure (e.g., ingestion) is not probable and no adverse health effects would be anticipated.

2.5.7.2 Non-cancer Health Hazards (Metal Exposure)

The potential for non-cancer health effects of COC metals (except lead) is evaluated by comparing average daily doses with reference doses (RfD) applicable for chronic (long-term) exposure. The ratio of exposure to toxicity is referred to as a hazard quotient (HQ). The HQ is calculated by dividing the average daily dose (mg/kg per day) by the reference dose (RfD). A hazard index (HI) is a summation of all HQs (all parameters) for a particular pathway or from several pathways. If the HI exceeds 1, further evaluation is required. Generally, the greater the HI above unity, the greater the level of concern. (For additional detail see the *Investigative Reports, Human Health Risk Assessment,* CDM 2008, Section 5.2.)

Total HIs for receptors exposed to contaminants in spoils were below the threshold of one for all receptors except the future commercial/industrial worker and construction worker at the Deep Adit area. The concentrations of metals in this area were based on XRF data that may be elevated compared to chemical digestion and analyses used for the project.

For soils from pastures, the HI was only slightly above one for the nearby child resident. As previously discussed, this exposure will probably not occur due to vegetation cover. In addition, the elevated HI was due mainly to exposure to metals at concentrations similar to background levels (see Section 3.2 for background levels); therefore, no additional adverse effects are anticipated.

HIs for residents using groundwater from deep aquifers (homeowner wells) near the Site as a potable water source also were below the threshold of one for non-cancer effects at all locations sampled. If shallow alluvial groundwater near the Site was used as a potable water source in the future, non-cancer health hazards could significantly exceed acceptable thresholds (HIs for children were over 100 times the value of 1).

Possible air concentrations were calculated for the risk assessment based on spoils concentrations and using a generic particle emission factor. Risk estimates based on these calculated air concentrations were low and below levels of regulatory concern.

2.5.7.3 Lead Exposures

Risks from exposure to lead cannot be assessed using standard methods (HI values) because toxicological criteria for lead are not available. The primary threat to human health from exposure to lead is neurological effects in young children including decrease in IQ (Intelligent Quotient).

The Integrated Exposure Uptake Biokinetic (IEUBK) model (Version 1.0) is used to evaluate potential risks for nearby residents from exposure to lead associated with the Avoca Mining Site. Exposure to lead is evaluated for surface soils and spoils. The Adult Lead Model was used to assess non-residential (i.e., recreational, commercial/industrial workers and construction workers) exposures to lead. Site–specific bioavailability estimates for lead are relatively low for all exposure areas.

Lead levels are of concern for the following:

- Potential exposure to lead in spoils by recreational visitors is a concern in two areas: Connary and the Ore bins at Tigroney West.
- Future commercial/industrial workers may be exposed to lead in spoils at Connary, Ore bins at Tigroney West, and West Avoca at levels associated with adverse health effects.
- Future construction workers exposed to spoils exist at Connary, East Avoca/Tigroney West, Ore bins at Tigroney West, and West Avoca.

Evaluations using bioavailability estimates indicate that lead levels in soils in pastures and fields are below levels of concern for a young child based on the available data.

2.5.7.4 Uncertainties

Uncertainties are inherent in the risk assessment process because of the numerous assumptions that are made in estimating exposure, toxicity, and potential risk. Conservative assumptions are made at every step of the process in the HHRA so as not to underestimate potential risk. As a result of the uncertainties, the risk assessment should not be construed as presenting absolute risks or hazards. Rather, it is a conservative analysis intended to indicate the potential for adverse impacts to occur based on reasonable maximum and typical (central tendency) exposures.

2.6 Ecological Risk Assessment

A Baseline Ecological Risk Assessment (BERA) was performed for the Avoca Site. The complete Baseline *Ecological Risk Assessment* is part of the *Investigative Reports* (CDM 2008). The following sections summarise the evaluations.

2.6.1 Purpose and Risk Assessment Approach

The primary purpose of the BERA is to identify and describe conditions resulting from releases of mining-related contaminants that can result in adverse effects to present or future ecological receptors associated with the Avoca River and adjacent riparian and terrestrial habitats.

Ecological risk assessments evaluate the likelihood that adverse ecological effects may occur or are occurring at a site as a result of exposure to single or multiple contaminant stressors. Effects result from contacts between ecological receptors (i.e., plants and animals) and stressors (i.e., contaminants) that are of sufficiently long duration and of sufficient intensity to produce adverse effects. Following USEPA Superfund Guidance (USEPA 1997) and similar guidance from other agencies, ecological risk assessments can be performed at either a screening level or at a baseline level. This BERA generally relies on site-specific data and analyses, and is a more detailed effort than a screening level assessment. The BERA:

- Refines the list of potential contaminants to identify COCs
- Identifies ecological receptors and selects a subset of representative receptors for full assessment
- Estimates risks to representative ecological receptors using a less conservative approach (than a screening level assessment) based on multiple lines of evidence

The components of this BERA are Data Compilation, Problem Formulation, Analysis, and Risk Characterisation. Problem Formulation serves as the descriptive and planning stage of the BERA, where the site-associated habitats and ecological receptors or receptor groups are generally described, COCs are identified, and major exposure pathways are characterised and revealed using a site conceptual exposure model (SCEM).

The Analysis phase is divided into Exposure Assessment and Effects Assessment, which presents the nature and extent of chemical contamination (Exposure Assessment) and the ecotoxicity of COCs (Effects Assessment). Risk Characterisation integrates the exposure and effects information to estimate risks to ecological receptors.

2.6.2 Potential Risk Issues

As previously described, the Avoca River has been impacted by mining-related metals. The Water Framework Directive requires Ireland to achieve good ecological and chemical water status for its national waters unless less stringent objectives are set and justified. No decision has been reached for the Avoca River. Salmonids are indicators of good water status; therefore, efforts are focused on reestablishment of this river as one that supports salmonid survival, growth, and reproduction. The effects of mining-related metals and other related stressors on salmonid fish is a major concern. Also of concern are the effects of mining-related contaminants on terrestrial receptors (e.g., peregrine falcons, several species of bats, livestock, and vegetation) and on other ecologically important aquatic biota. For example, benthic macroinvertebrates (BMI) are important for nutrient recycling and serve as prey for fish and other aquatic biota. BMI are also commonly used as indicators of water quality, and are used in this BERA to help characterise the overall conditions of aquatic habitats at various locations within the study area.

2.6.3 Summary of Data

As previously discussed, samples of surface water, river sediments, soil in agricultural fields (pastures), and spoils were collected at the Site during the investigations conducted by the GSI in November 2006 and June 2007 and the investigations conducted by CDM in April 2007, July/August 2007, November 2007, and February 2008. The samples were analysed for an extensive suite of chemical parameters. In addition, some biological measurements were performed. The results of these analyses for surface waters, sediments, soils, and spoils have been used in this Baseline Ecological Risk Assessment. The data are summarised in the *Investigative Reports, Ecological Risk Assessment* (CDM 2008) and provided in the following tables:

- Table 2-8 Summary of Spoils Concentrations (already provided in Section 2.5)
- Table 2-9 Summary of Soil Concentrations (already provided in Section 2.5)
- Table 2-14 Summary of River and Tributaries Concentrations
- Table 2-15 Summary of Sediment Concentrations

Table 2-14 Summary of Rivers and Tributaries Concentrations
Part 1 - CDM Data (July/August 2007)

		Ammonia	Ag	Al	As	Ba	Cd	Cr	Co	Cu	Hg	Pb	Mn	Ni	Sb	Se	Sn	Tl	Ti	U	V	Zn
EA	**Statistic**	mg/l as N	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	min	0.02	1.0	13	0.5	7	0.2	0.5	0.5	0.5	0.025	0.5	8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3
1	mean	0.1175	1.0	60.75	0.5	8.75	0.2	0.5	0.5	3.625	0.025	2.125	9.75	1.125	0.5	0.625	0.5	0.5	0.625	0.5	1.375	17.75
1	max	**0.15**	**1.0**	**100**	**0.5**	**12**	**0.2**	**0.5**	**0.5**	**8**	**0.025**	**3**	**14**	**2**	**0.5**	**1**	**0.5**	**0.5**	**1**	**0.5**	**2**	**29**
1	frequency	25	0	100	0	100	0	0	0	75	0	75	100	75	0	25	0	0	25	0	75	100
2	min	0.03	1.0	164	0.5	6	0.2	0.5	0.5	12	0.025	4	35	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	143
2	mean	0.047	1.0	190	0.500	22.3	1.100	0.50	1.50	19.00	0.025	5.33	78.33	2.00	0.500	0.67	0.50	0.50	0.67	0.50	0.67	393
2	max	**0.06**	**1.0**	**208**	**0.5**	**54**	**2.5**	**0.5**	**2**	**24**	**0.025**	**7**	**103**	**3**	**0.5**	**1**	**0.5**	**0.5**	**1**	**0.5**	**1**	**770**
2	frequency	100	0	100	0	100	66.67	0	66.67	100	0	100	100	100	0	33.33	0	0	33.33	0	33.33	100
3	min	0.01	1.0	1	0.5	0.5	0.2	0.5	0.5	0.5	0.025	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	mean	0.032	1.0	108.2	0.7	9.4	0.42	0.7	0.7	6.6	0.025	2.5	33.6	1	0.5	1.3	0.5	0.5	0.6	0.5	0.5	171.9
3	max	**0.05**	**1.0**	**313**	**1**	**31**	**0.8**	**1**	**1**	**16**	**0.025**	**6**	**76**	**2**	**0.5**	**3**	**0.5**	**0.5**	**1**	**0.5**	**0.5**	**239**
3	frequency	100	0	80	40	60	40	40	40	60	0	40	60	60	0	40	0	0	20	0	0	80
4	min	0.15	1.0	69	0.5	7	0.6	0.5	1	10	0.025	1	78	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	219
4	mean	0.15	1.0	69	0.5	7	0.6	0.5	1	10	0.025	1	78	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	219
4	max	**0.15**	**1.0**	**69**	**0.5**	**7**	**0.6**	**0.5**	**1**	**10**	**0.025**	**1**	**78**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**219**
4	frequency	0	0	100	0	100	100	0	100	100	0	100	100	100	0	0	0	0	0	0	0	100
5	min	0.15	1.0	110	0.5	7	0.2	0.5	0.5	8	0.025	2	50	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	131
5	mean	0.15	1.0	114.5	0.5	22.5	0.4	0.5	0.75	8.5	0.025	2	52	1.5	0.5	0.75	0.5	0.5	0.5	0.5	0.5	133.5
5	max	**0.15**	**1.0**	**119**	**0.5**	**38**	**0.6**	**0.5**	**1**	**9**	**0.025**	**2**	**54**	**2**	**0.5**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**136**
5	frequency	0	0	100	0	100	50	0	50	100	0	100	100	100	0	50	0	0	0	0	0	100
6	min	1.3	1.0	133	0.5	37	0.5	0.5	1	10	0.025	2	82	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	146
6	mean	1.3	1.0	133	0.5	37	0.5	0.5	1	10	0.025	2	82	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	146
6	max	**1.3**	**1.0**	**133**	**0.5**	**37**	**0.5**	**0.5**	**1**	**10**	**0.025**	**2**	**82**	**2**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**146**
6	frequency	100	0	100	0	100	100	0	100	100	0	100	100	100	0	0	0	0	0	0	0	100
7	min	0.15	1.0	91	0.5	10	0.5	0.5	0.5	11	0.025	1	156	1	0.5	0.5	0.5	0.5	0.5	0.5	1	148
7	mean	0.15	1.0	91	0.5	10	0.5	0.5	0.5	11	0.025	1	156	1	0.5	0.5	0.5	0.5	0.5	0.5	1	148
7	max	**0.15**	**1.0**	**91**	**0.5**	**10**	**0.5**	**0.5**	**0.5**	**11**	**0.025**	**1**	**156**	**1**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**148**
7	frequency	0	0	100	0	100	100	0	0	100	0	100	100	100	0	0	0	0	0	0	100	100
8	min	0.15	1.0	59	0.5	7	0.2	0.5	0.5	2	0.025	0.5	93	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	103
8	mean	0.15	1.0	86.5	2.875	15.5	0.275	0.5	0.75	4.5	0.025	1.125	95	2	0.5	7.25	0.5	0.5	0.5	0.5	1.125	123.5
8	max	**0.15**	**1.0**	**124**	**6**	**41**	**0.5**	**0.5**	**1**	**7**	**0.025**	**2**	**101**	**2**	**0.5**	**17**	**0.5**	**0.5**	**0.5**	**0.5**	**3**	**152**
8	frequency	0	0	100	75	100	25	0	50	100	0	75	100	100	0	50	0	0	0	0	25	100
	SW MAX	**1.30**	**1.0**	**313**	**6.00**	**54.0**	**2.5**	**1.00**	**2.0**	**24.0**	**0.025**	**7.0**	**156**	**3.0**	**0.50**	**17.0**	**0.50**	**0.50**	**1.0**	**0.50**	**3.0**	**770**

Notes:
Means based on half the detection limit for nondetect samples
FD = frequency of detection (percent)
All concentrations are dissolved
See Section 2.6.3.1 for description of the sample locations

Table 2-14 Summary of Rivers and Tributaries Concentrations
Part 2 - GSI Data

Nov 06

EA	Statistic	Hg	Al	Sb	As	Ba	Cd	Cr	Cu	Fe	Pb	Mn	Mo	Ni	Se	Sn	U	V	Zn
2	Min	0.03	268	0.50	0.50	9.00	0.50	2.00	34.00	76.00	5.00	54.00	0.50	3.00	0.50	0.50	0.50	0.50	102
2	Mean	0.04	3,407	0.67	0.50	10.33	2.83	2.67	86.00	9,094	57.67	2,032	0.50	14.67	0.50	0.50	1.00	0.50	2,305
2	Max	0.08	8,982	1.00	0.50	12.00	5.00	3.00	184	27,060	143.00	5,925	0.50	37.00	0.50	0.50	2.00	0.50	5,904
2	Frequency	33	100	67	0	100	67	100	100	100	100	100	0	100	0	0	67	0	100
3	Min	0.03	205	0.50	0.50	6.00	0.50	0.50	6.00	221	3.00	57.00	0.50	0.50	0.50	0.50	0.50	0.50	145
3	Mean	0.04	206	0.50	0.50	7.00	0.50	1.75	11.50	234	4.00	60.00	0.50	1.75	0.50	5.25	0.50	0.75	164
3	Max	0.05	207	0.50	0.50	8.00	0.50	3.00	17.00	246	5.00	63.00	0.50	3.00	0.50	10.00	0.50	1.00	182
3	Frequency	50	100	0	0	100	0	50	100	100	100	100	0	50	0	50	0	50	100
6	Min	0.03	130	0.50	0.50	6.00	0.50	0.50	0.50	80.00	2.00	2.00	0.50	1.00	0.50	0.50	0.50	0.50	49.00
6	Mean	0.03	152	0.50	0.50	6.00	0.50	0.50	3.25	103	2.00	25.00	0.50	1.50	1.25	4.75	0.50	0.50	85.00
6	Max	0.03	173	0.50	0.50	6.00	0.50	0.50	6.00	126	2.00	48.00	0.50	2.00	2.00	9.00	0.50	0.50	121
6	Frequency	0	100	0	0	100	0	0	50	100	100	100	0	100	50	50	0	0	100
June 07	**Statistic**	**Hg**	**Al**	**Sb**	**As**	**Ba**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Mo**	**Ni**	**Se**	**Sn**	**U**	**V**	**Zn**
2	Min	0.03	4,705	0.50	0.50	5.00	2.30	0.50	69.00	75.00	15.00	787	0.50	5.00	0.50	0.50	0.50	0.50	1,159
2	Mean	0.03	11,043	0.50	0.50	6.00	13.15	0.50	184	198	127.00	793	0.50	7.00	0.75	0.50	1.25	0.50	5,163
2	Max	0.03	17,380	0.50	0.50	7.00	24.00	0.50	298	321	239.00	798	0.50	9.00	1.00	0.50	2.00	0.50	9,167
2	Frequency	0	100	0	0	100	100	0	100	100	100	100	0	100	50	0	50	0	100
3	Min	0.03	129	0.50	0.50	6.00	0.90	0.50	11.00	127	0.50	130	0.50	3.00	0.50	0.50	0.50	0.50	378
3	Mean	0.03	4,332	0.50	0.50	10.50	1.30	0.50	13.50	142	1.25	137	0.50	4.00	1.25	0.50	0.50	0.50	389
3	Max	0.03	8,535	0.50	0.50	15.00	1.70	0.50	16.00	156	2.00	143	0.50	5.00	2.00	0.50	0.50	0.50	399
3	Frequency	0	100	0	0	100	100	0	100	100	50	100	0	100	50	0	0	0	100

Notes:
Means based on half the detection limit for nondetect samples
FD = frequency of detection (percent)
All values = µg/l (dissolved)
See Section 2.6.3.1 for description of the sample locations

Table 2-15 Summary of Sediment Concentrations
Part 1 - CDM Phase 2 Sediment Data

EA	Statistic	Ag	As	Ba	Bi	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	Sn	Th	Ti	U	V	Zn
1	Min	1.05	27.79	59.85	0.30	1.84	20.20	29.02	34.91	0.08	5,016	0.99	23.84	259.31	0.10	1.28	0.87	8.02	262.85	1.78	26.27	267.95
1	Mean	1.05	27.79	59.85	0.30	1.84	20.20	29.02	34.91	0.08	5,016	0.99	23.84	259.31	0.10	1.28	0.87	8.02	262.85	1.78	26.27	267.95
1	Max	**1.05**	**27.79**	**59.85**	**0.30**	**1.84**	**20.20**	**29.02**	**34.91**	**0.08**	**5,016**	**0.99**	**23.84**	**259.31**	**0.10**	**1.28**	**0.87**	**8.02**	**262.85**	**1.78**	**26.27**	**267.95**
1	FD	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Min	0.02	30.25	4.57	0.04	0.17	1.77	4.00	133.60	0.01	77.53	0.94	3.62	229.33	0.10	0.40	0.40	2.00	45.05	0.49	4.00	141.63
2	Mean	0.19	202.86	19.98	0.75	0.48	7.79	14.76	265.92	0.10	2,852	1.40	10.76	400.25	0.95	0.40	0.76	4.21	129.48	1.65	14.03	193.83
2	Max	**0.35**	**481.25**	**40.34**	**1.84**	**0.98**	**17.92**	**30.59**	**503.46**	**0.16**	**8,070**	**2.00**	**20.79**	**704.21**	**1.68**	**0.40**	**1.49**	**6.66**	**263.75**	**3.84**	**24.63**	**238.17**
2	FD	33.33	1	1	33.33	1	1	33.33	1	33.33	1	1	1	1	33.33	0	66.67	1	1	1	66.67	1
3	Min	0.10	27.53	49.85	0.35	0.52	15.70	30.68	85.61	0.01	2,286	0.86	23.12	144.06	0.10	0.40	0.40	5.65	207.97	1.32	24.98	192.98
3	Mean	0.13	32.87	51.90	0.66	0.71	16.76	32.28	155.79	0.01	2,397	1.00	23.56	148.34	0.10	0.40	0.40	5.84	222.29	1.36	25.38	218.51
3	Max	**0.17**	**38.21**	**53.96**	**0.97**	**0.90**	**17.82**	**33.87**	**225.97**	**0.01**	**2,507**	**1.14**	**24.00**	**152.62**	**0.10**	**0.40**	**0.40**	**6.02**	**236.62**	**1.41**	**25.79**	**244.03**
3	FD	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1
6	Min	0.04	27.73	53.67	0.64	0.20	15.42	29.13	68.88	0.01	1,717	0.94	24.49	69.06	0.10	0.40	0.40	6.65	216.70	1.51	27.50	138.30
6	Mean	0.07	29.77	57.87	0.90	0.40	17.53	29.78	72.64	0.01	1,925	1.02	25.48	80.40	0.10	0.40	0.40	6.86	236.91	1.64	29.06	163.54
6	Max	**0.11**	**31.66**	**60.45**	**1.20**	**0.70**	**18.70**	**30.71**	**78.13**	**0.01**	**2,055**	**1.14**	**25.83**	**93.50**	**0.10**	**0.40**	**0.40**	**7.41**	**249.28**	**1.85**	**30.21**	**200.91**
6	FD	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1
unique	Min	0.02	21.58	70.55	0.29	0.26	18.23	24.43	21.83	0.01	2,066	0.57	21.95	21.36	0.10	0.40	0.40	6.21	291.46	1.89	28.81	102.86
unique	Mean	0.02	21.58	70.55	0.29	0.26	18.23	24.43	21.83	0.01	2,066	0.57	21.95	21.36	0.10	0.40	0.40	6.21	291.46	1.89	28.81	102.86
unique	Max	**0.02**	**21.58**	**70.55**	**0.29**	**0.26**	**18.23**	**24.43**	**21.83**	**0.01**	**2,066**	**0.57**	**21.95**	**21.36**	**0.10**	**0.40**	**0.40**	**6.21**	**291.46**	**1.89**	**28.81**	**102.86**
unique	FD	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1
	SED MAX	**1.05**	**481.25**	**70.55**	**1.84**	**1.84**	**20.20**	**33.87**	**503.46**	**0.16**	**8,070**	**2.00**	**25.83**	**704.21**	**1.68**	**1.28**	**1.49**	**8.02**	**291.46**	**3.84**	**30.21**	**267.95**

Notes:
Means based on half the detection limit for nondetect samples
FD = frequency of detection (fraction)
units = mg/kg
EA 1 = upstream reference
EA Unique = Aughrim River (secondary reference)
See Section 2.6.3.1 for description of the sample locations

COC - COCs with substantially different concentrations at one or more reference locations relative to mining-impacted areas of the Avoca River

Table 2-15 Summary of Sediment Concentrations
Part 2 - GSI Sediment Data (2007)

EA	Site	Cd	Pb	As	Zn	Cu	Ni	Mn
1	Meetings Avonmore river	NA	594	33.8	433	34.5	NA	5,397
1	Avonmore, up/s of mettings	NA	640	34.6	755	60.8	NA	6,959
2	Whitesbridge d/s	NA	181	47.7	267	443	NA	1,717
2	Deep adit	NA	314	53.0	151	280	NA	2,283
3	Avoca village	NA	546	73.1	587	381	NA	4,933
3	up/s sulphur brook	NA	134	33.0	193	57.3	NA	1,969
4	Woodenbridge	NA	412	60.2	573	257	NA	3,665
6	Shelton Abbey	NA	257	47.3	784	224	57.9	3,861

NA indicates chemical not analysed in these samples
units = mg/kg

Table 2-14 provides a summary of contaminant concentrations in specific locations (exposure areas or EAs) along the Avoca River. These EAs are described below:

2.6.3.1 SW Exposure Areas (EAs) - Rivers and Tributaries

- EA-1 – Avoca River from above Meeting of the Waters (Ballinacleish Bridge and Lions Bridge) downstream to above White's Bridge. Vale View stream also enters in this reach.

- EA-2 – Avoca River above Whitesbridge to the abandoned coal yard. This includes all the mining area discharges (Deep and Road Adits and Ballygahan discharge) and the landfill.

- EA-3 – Below the abandoned coal yard to below Avoca Bridge. This reach is below the mining and landfill areas and includes the following tributaries: Red Road, Sulphur Brook, and an unnamed tributary.

- EA-4 – Avoca River downstream of Avoca Bridge to just upgradient of confluence with Aughrim River.

- EA-5 – Confluence of Aughrim and Avoca Rivers downstream to just above Shelton Abbey Tailings.

- EA-6 – Avoca River at upper boundary of Shelton Abbey tailings downstream to just above the former Fertiliser Plant.

- EA-7 – Avoca River at upper boundary of the former Fertiliser Plant to the downstream boundary of the former Fertiliser Plant.

- EA-8 – Avoca River at the downstream boundary of the former Fertiliser Plant to Arklow. Some samples were collected near the outlet of the Avoca River to the Irish Sea. As a result, the samples contained high total dissolved solids (TDS), chloride, and hardness due to tidal influence and do not reflect conditions in the Avoca River.

Table 2-15 provides a summary of sediment concentrations. The EAs are the same as previously discussed for rivers and tributaries. Tables for spoils (Table 2-8) and soils (Table 2-9) are the same as used in the previous section for the Human Health Risk Assessment evaluation.

2.6.4 Problem Formulation

The Problem Formulation phase of the BERA establishes the goals and describes the scope and focus of the assessment. This phase of the BERA also considers site-specific regulatory and policy issues and requirements, and identifies potential stressors (e.g., COCs) and ecological resources potentially at risk. An important outcome of Problem Formulation is the SCEM, which describes potential exposure scenarios, including contaminant sources, transport mechanisms, exposure media, exposure routes, and receptors. The SCEM is depicted on Figures 2-8. This figure illustrates the connections between mining-related contaminant sources and the ecological receptors, via the various components of exposure pathways (e.g., sources, release mechanisms, exposure routes, etc.).

Figure 2-8 presents all the components of the SCEM for the mining related source areas and related areas of contamination. Included on this figure are symbols representing various assumptions about exposure pathways. Solid black dots represent complete and significant exposure pathways that are evaluated quantitatively. Dashed lines represent incomplete exposure pathways that are not evaluated. Open circles represent exposure pathways that are complete but not significant. Figure 2-9 illustrates a general ecological food web for the Avoca River site. This figure shows the relationships between contaminated media and ecological receptors.

2.6.5 Ecological Resources at Risk

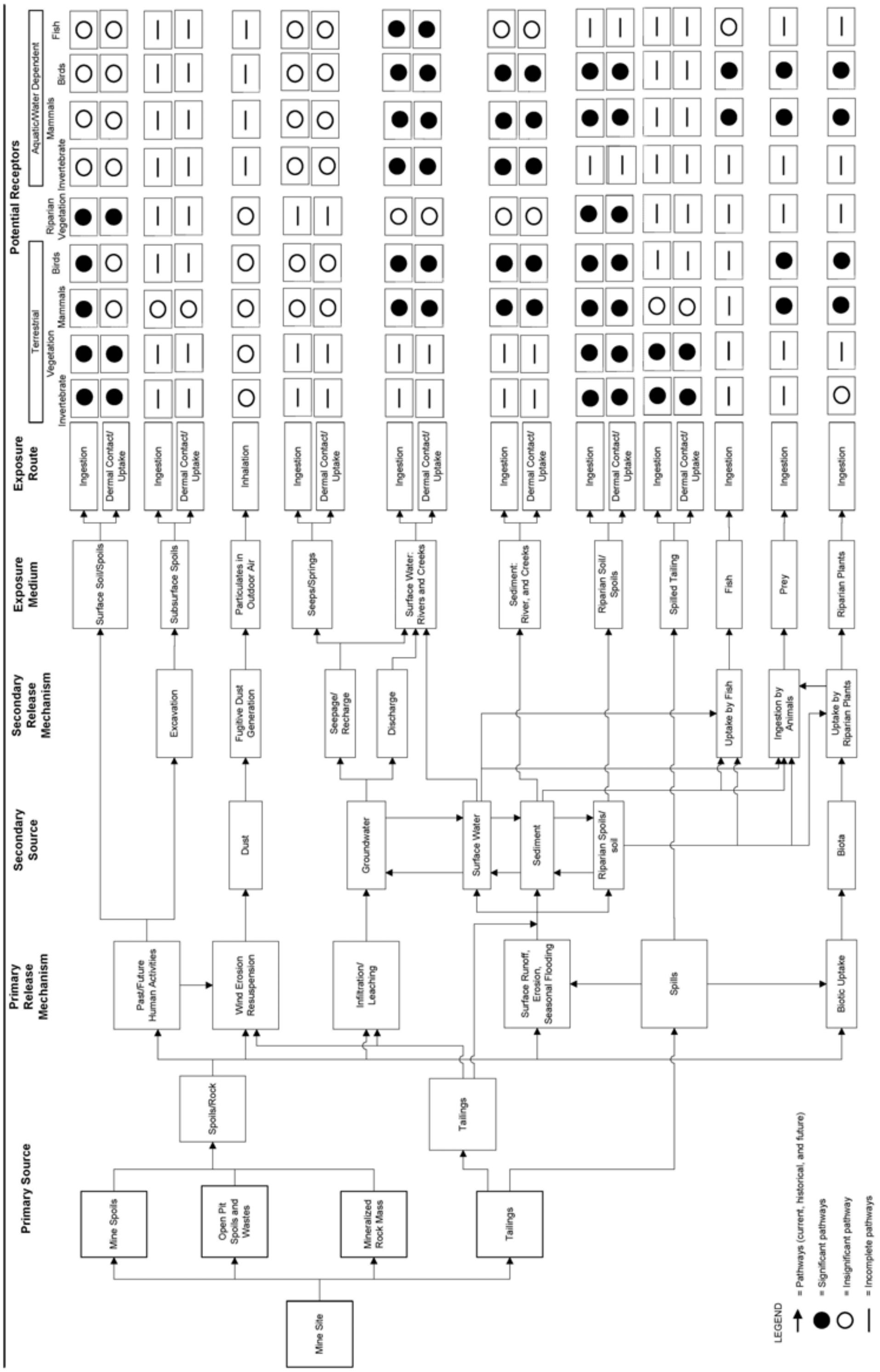
Ecological resources evaluated in this BERA include the aquatic and terrestrial habitats and ecological receptors that have potential to be affected by mining-related contaminants. These resources are described below.

2.6.5.1 Habitats

Of concern to this BERA are aquatic and terrestrial habitats that support or have potential to support important ecological receptors. These habitats include aquatic habitats within the mining-affected watershed, riparian habitats along water courses, and terrestrial habitats associated with past mining activities or affected by mine wastes.

Aquatic and Riparian Habitats – Aquatic habitats most relevant to this study are those associated with the Avoca River, primarily those areas near and downgradient of contaminant source areas related to past mining activities. Also important are upgradient and tributary (e.g., Aughrim River) waters that provide insight into reference conditions with little or no mining-related impacts.

Most of the Avoca River is characterised as a medium sized stream with cobble and gravel substrates, little silt or fine grained sediment, iron staining of the substrates in areas most affected by low pH and elevated metals concentrations, little channelisation and, in spring 2007, mostly runs with riffles in the more shallow areas and infrequent pools. Average depth in mid channel in spring 2007 was about 0.7 m, often with one bank having a deeper channel (>1.5 m) and the opposite bank being shallow (<0.5 m). River widths varied from about 5 m to over 15 m. Braiding within the channel was uncommon in spring 2007, mostly limited to the area adjacent to the Shelton Abbey tailings where several side channels and backwater areas were observed.



Exposure Medium	Exposure Route	Terrestrial				Riparian Vegetation	Aquatic/Water Dependent			
		Invertebrate	Vegetation	Mammals	Birds		Invertebrate	Mammals	Birds	Fish
Surface Soil/Spoils	Ingestion	●	●	●	●	●	○	○	○	○
	Dermal Contact/ Uptake	●	●	○	○	●	○	○	○	○
Subsurface Spoils	Ingestion	|	|	○	|	|	|	|	|	|
	Dermal Contact/ Uptake	|	|	○	|	|	|	|	|	|
Particulates in Outdoor Air	Inhalation	○	○	○	○	○	|	|	|	|
Seeps/Springs	Ingestion	|	|	○	○	|	○	○	○	○
	Dermal Contact/ Uptake	|	|	○	○	|	○	○	○	○
Surface Water: Rivers and Creeks	Ingestion	|	|	●	●	○	●	●	●	●
	Dermal Contact/ Uptake	|	|	●	●	○	●	●	●	●
Sediment: River, and Creeks	Ingestion	|	|	●	●	○	●	●	●	○
	Dermal Contact/ Uptake	|	|	●	●	○	●	●	●	○
Riparian Soil/ Spoils	Ingestion	●	●	●	●	●	|	●	●	|
	Dermal Contact/ Uptake	●	●	●	●	●	|	●	●	|
Spilled Tailing	Ingestion	●	●	○	|	|	|	|	|	|
	Dermal Contact/ Uptake	●	●	○	|	|	|	|	|	|
Fish	Ingestion	|	|	|	|	|	|	●	●	○
Prey	Ingestion	|	|	●	●	|	|	●	●	|
Riparian Plants	Ingestion	○	|	●	●	|	|	●	●	|

Figure 2-8 Ecological Site Conceptual Exposure Model
Avoca River, Ireland

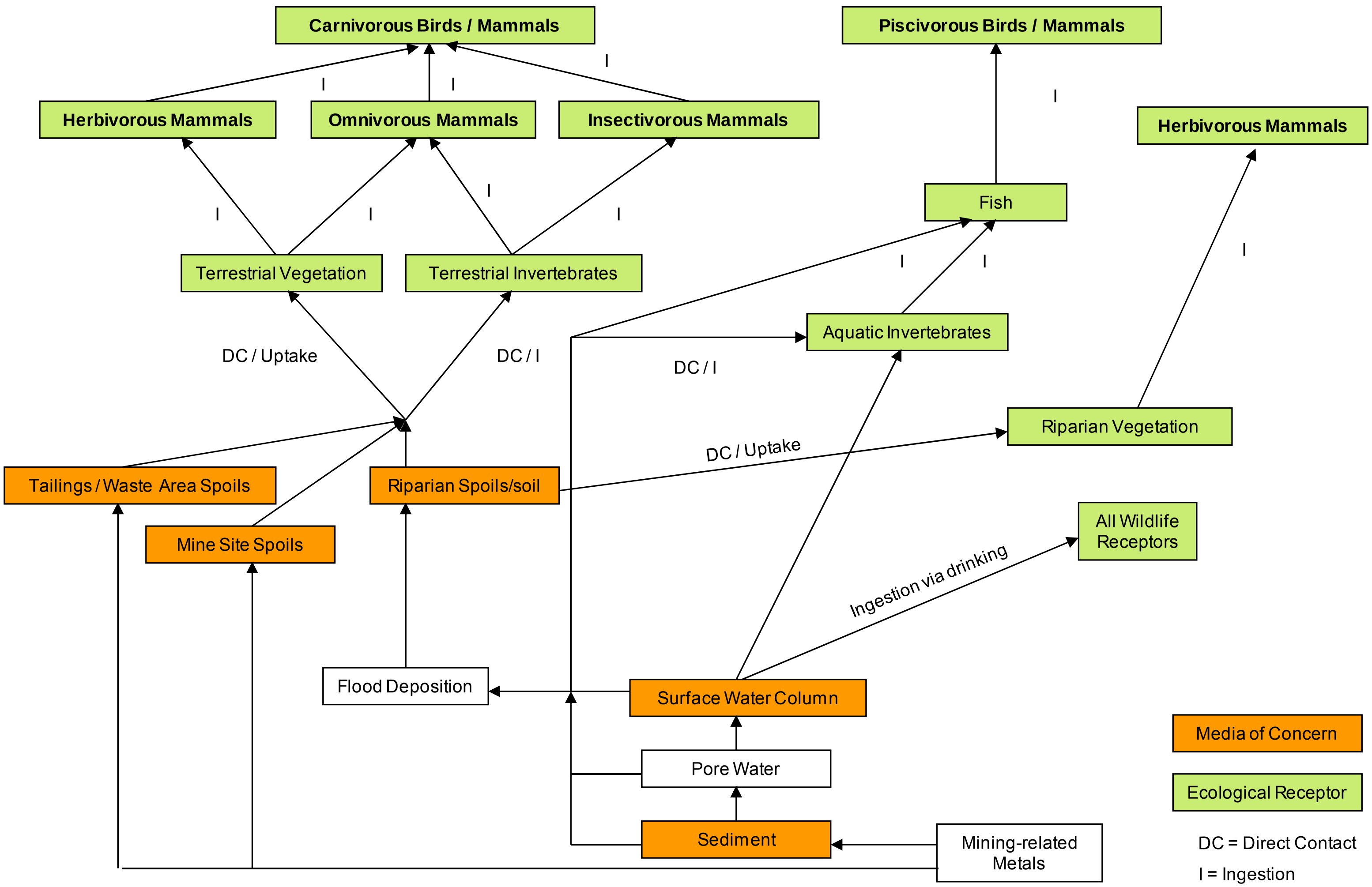


Figure 2-9 Ecological Site Conceptual Exposure Model Food Web

The land uses in the Avoca River valley adjacent to the river are diverse, and include historic mining areas where mine wastes/spoils and/or mine tailings have been deposited, agricultural uses, residential areas, and small communities such as Avoca Village, past industrial uses such as the former Fertiliser Plant Site, current light industrial uses such as the new automobile storage facilities at the site of the former Fertiliser Plant Site, institutional use (e.g., the prison at Shelton Abbey), landfills or capped waste areas with known and unknown (e.g., on the property of the former Fertiliser Plant Site) types of contaminants, and recreational areas (e.g., golf course at Woodenbridge and public riparian walking trails along the south bank of the river west of Arklow).

Much of the riparian corridor is well vegetated with a variety of grasses, forbs, shrubs, and mostly small trees. The upper reaches of the study area are especially well vegetated, with considerable shading of stream banks by mostly deciduous and fewer coniferous trees. The lower reaches of the riparian corridor are, in general, more open and developed, with fewer and small areas of natural vegetation.

Terrestrial/Upland Habitats – Little natural vegetation is observed in the upland areas (i.e., areas outside the riparian zones). Much of the upland terrestrial environment of concern to this study is highly disturbed by past mining activities. These areas include open pits, waste/spoils piles, highly eroded surface areas, covered and uncovered tailings, and roads. Beyond the highly disturbed areas are mostly residential properties with grass, planted shrubs and trees as well as agricultural areas subject to small scale farming and grasing. In some cases, agricultural land uses extend into the riparian corridor, and in fact grasing or farming up to the river edge is observed in a few locations.

Plant communities in the undeveloped portions of the upland areas that are not within the most severely mining-degraded areas are dominated by pasture grasses, blackberry vines or bramble (Rubus sp.) and gorse (Ulex europaeus). Gorse is a nitrogen-fixing legume that is considered by many to be a noxious weed. Gorse is difficult to control but grasing by goats appears to be a commonly applied approach in the Avoca River watershed. A more detailed description of the land uses and habitats is provided in Section 2.6.11.

2.6.5.2 Ecological Receptors

Ecological receptors are defined for this BERA as the plants and animals that have potential to be adversely affected by mining-related contaminants and other contaminants that may affect the goals and objectives of mining related remediation. Clearly not all receptors can be fully evaluated in the BERA and, therefore, specific representative receptors or receptor groups are selected for evaluation (see below).

Aquatic Receptors – Aquatic or water-dependent receptors for this study include benthic invertebrates, water column aquatic invertebrates, amphibians, fish, fish-eating birds, fish-eating mammals, aquatic insect-eating birds, and aquatic insect-eating mammals.

The fish community in the Avoca River is currently neither abundant nor diverse, primarily as a result of mine-related contamination. The types of fish that currently occur in nearby waters or those that have potential to occur most abundantly in the Avoca River are salmonid fish. These include brown and sea trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*).

BMI are important aquatic organisms from the standpoint of serving as prey for fish and other water-dependent wildlife (e.g., insectivorous birds) and as useful indicators of water quality. BMI are often used as water quality indicators because they integrate water quality over time; their life history requires months to a year or more as aquatic forms. Therefore, the abundance and diversity of BMI indicate long term water quality conditions. Also, they are not very mobile in most cases, and can therefore be used to indicate local conditions (water, sediment, habitat, etc.). BMI were also collected in spring 2007 specifically to provide current data for use in this BERA (see next section).

The only amphibians and reptiles expected to occur within the study area, based on geographic range and habitat availability, are common frog (*Rana temporia*) and common lizard (*Lacerta vivipara*). Larvae (tadpoles) of common frog (presumptive identification) were observed in a pool adjacent to the Shelton tailings in April 2007. Common lizards were observed at two locations (at East Avoca and near Woodenbridge golf course) within the study area in April 2007.

Piscivorous birds and mammals (e.g., introduced mink and native otter) are unlikely to find much suitable habitat along the Avoca River. Even if suitable habitat was present, the low numbers of fish that can serve as prey would likely limit the numbers of piscivorous birds and mammals. For these reasons, these types of receptors are probably not significantly exposed to mining-related contaminants in river water, sediments, or prey.

Terrestrial Receptors – Mammals associated with the upland terrestrial ecosystems within the study area are likely to include rabbits, foxes, hares, mice, rats, voles, and squirrels. Rabbits and pheasants were abundant during the site survey of the Shelton Tailings area in April 2007. Pheasants were also commonly seen throughout the study area in April 2007. Many of these are introduced forms that have adapted well to human-influenced environments.

Domesticated mammals dominate the terrestrial lands near the mining sites and other upland areas within the study area. These include sheep, goats, and cattle. Most of the mammals with potential to be exposed to mining-related contaminants are herbivores, and metals uptake by plants is therefore an important exposure pathway that warrants evaluation.

Species of Special Concern – Protected Irish fauna include a variety of invertebrates, amphibians, reptiles, birds, and mammals. Some of these are known to occur or have potential to occur within the area of interest to this study. Others are not known to occur or are unlikely to occur within the study area because, for example, of limited geographic range or lack of suitable habitat.

Those with low potential to occur near the Avoca mine sites and related areas of contamination include the otter (*Lutra lutra*, protected by Wildlife Acts of 1976 and 2000 and the European Communities Regulations 1997); natterjack toad (*Bufo calamita*) and common newt (*Triturus vulgaris*, both protected by Wildlife Acts of 1976 and 2000); and white-clawed crayfish (*Austropotamobius pallipes*, protected by the European Communities Regulations 1997). These protected taxa, and several of the bird species known to occur in Ireland are either not reported from County Wicklow or are unlikely to find suitable habitat or prey (e.g., piscivorous birds and mammals) in the study area.

In contrast to the above, several species protected in Ireland have been observed or reported from the study area. Others have significant potential to be found within the study area based on geographic range and habitat requirements, but occurrence has not be documented.

These include 10 species of bats within the families *Vespertilionidae* and *Rhinolophidae*, all protected by the Wildlife Act (1976), the Convention on the Conservation of Migratory Species of Wild Animals (1979), the Convention on the Conservation of European Wildlife and Natural Habitats (1982), and the European Communities Regulations (1997). Bats of unknown taxa have been reported from the adits and open pits associated with past mining activities in the study area. See Section 2.6.11 for more details concerning bats.

Also, peregrine falcon (*Falco peregrinus*) have been reported (but were not observed in April 2007) to utilise the walls of the open mine pits within the study area. The common lizard (*Lacerta vivipara*, protected by the Wildlife Acts of 1976 and 2000) was observed at the golf course in Woodenbridge and at the East Avoca Pit in April 2007 (one individual at each location). Badger (*Meles meles*, protected by Wildlife Acts of 1976 and 2000) have been previously recorded at the Site. Finally, most wild bird species in Ireland are protected under the Wildlife Acts of 1976 and 2000, with the exception of pest species and some classified as game species, the hunting of which is subject to various regulations.

No special or protected Irish flora have been identified in the study area. Some of the mining areas have a higher abundance of more metal tolerant species (e.g., gorse), but those species are already present in the area. No special species of other flora (e.g., algae) have been observed.

2.6.5.3 Benthic Macroinvertebrate Survey Data

During April 3-5, 2007, a screening level benthic macroinvertebrate survey was conducted within the Avoca River watershed. The method employed for this survey was timed (30 second) kick net sampling using a 500 µm D-frame kick net. The preferred habitat for this sampling was riffle, followed by shallow run where riffles were not present. Three replicates (center channel, near left bank, near right bank) were collected, and data were evaluated both independently and pooled. Metrics included the following:

- Total number of organisms
- Total number of mayflies (*Ephemeroptera*)
- Total number of caddisflies (*Trichoptera*)
- Total number of worms (*oligochaetes*)
- Total number of beetles (*Coleoptera*)
- Total number of dipterans (flies and midges)
- Total number of leeches
- Total number of ostracods
- Total number of snails (gastropods)

Most useful among these metrics are the first four, based on the assumption that greater numbers of organisms, mayflies, and caddisflies are generally a positive finding and greater numbers of worms (as well as dipterans, snails, etc.) signify a negative finding (indicative of some form of stress). These assumptions are not without uncertainty, given the fact that some mayfly and caddisfly taxa are known to be tolerant of various forms of pollution, including metals contamination and nutrient enrichment. However, the underlying general assumptions are sufficiently valid for a screening level assessment based on rapid field identification to the order level (e.g., *Ephemeroptera, Trichoptera, Diptera*, etc.).

Total Organisms – Both stations upgradient of the mining area are associated with a similar total number of organisms (140, 142). These substantially exceed the totals for all stations downstream of Whitesbridge and upstream of the confluence with the Aughrim River (maximum 35 organisms downstream of the Deep Adit).

Total Mayflies – The distribution of mayfly abundance is similar to that of total number of organisms, with both reference stations having high values (87 for both) compared to stations downstream of Whitesbridge and upstream of the Aughrim River.

Total Caddisflies – The relative abundance of caddisflies is also similar to that of total number of organisms. The most upstream Avoca River reference station had 39 organisms. None of the Avoca stations downgradient of the mining area exceeded nine caddisflies.

Total Worms – Excessive numbers of worms often indicate nutrient enrichment. Surface waters without metals contamination are unlikely to support high numbers of worms unless the nutrient levels are sufficiently high. This assumption seems to be confirmed by the findings. Worm numbers are low at the upstream reference station (below Meeting of the Waters) as well as most Avoca stations with mining related contamination.

Overall, the macroinvertebrate survey supports other findings that the Avoca River is impaired and not good status in the vicinity of and downgradient of the Mine area.

2.6.6 Contaminants of Concern (COCs)

To select COCs for the BERA, the maximum concentrations measured in the various media were compared to Environmental Screening Levels. The environmental screening levels are selected from various references, benchmark studies, or regulations. The screening levels represent conservative concentrations that are protective of the ecological receptors or in some cases are actual regulatory standards (e.g., Ireland EPA Water Quality Regulation, Dangerous Substances). When the measured concentration is greater than the screening levels, the contaminant is retained as a COC. This process of COC selection is the same as the COC selection for human health risk. The measured concentrations, screening levels, and calculated values are provided in Section 7.4 of the *Investigative Reports, Ecological Risk Assessment*, CDM 2008. The ecological COCs include:

- *Surface Water:* Ammonia, Aluminum, Barium, Cadmium, Cobalt, Copper, Lead, Manganese, Mercury, Nickel, Selenium, Silver, Uranium, and Zinc

- *River Sediment:* Arsenic, Cadmium, Copper, Lead, Manganese, Nickel, and Zinc

- *Surface Soil:* Arsenic, Chromium, Copper, Lead, Manganese, Mercury, Molybdenum, Nickel, Silver, Thallium, Vanadium, and Zinc

- *Spoils:* Antimony, Arsenic, Barium, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, Thallium, Titanium, Vanadium, and Zinc

2.6.7 Effects Assessment and Selection of Toxicity Reference Values

The Effects Assessment step of the BERA uses receptor-specific toxicity data. This results in risk estimates that are more realistic and more applicable to specific receptors or receptor groups. For all media, toxicity reference values (TRVs) are selected based on the receptors or receptor groups of most interest. The specific TRVs selected are provided in Section 8 of the *Investigative Reports, Ecological Risk Assessment*, CDM 2008.

2.6.7.1 Surface Water TRVs

TRVs for rivers and tributaries are based on toxicity data for salmonid fish where such data are available. For hardness-dependent metal COCs, the hardness-adjusted equations are based on studies in which salmonid fish were exposed to dissolved metal COCs at varying hardness. From these studies, a relationship was established between hardness and toxicity. Hardness values used to modify the salmonid-based TRVs were calculated using the average dissolved calcium and magnesium concentrations based on CDM 2007 data. The average hardness was calculated as approximately 31 mg/L $CaCO_3$. Salmonid-specific TRVs for hardness-dependent metals were adjusted for the hardness value. This value was based on measurements during elevated flow conditions. During lower flow, the hardness value will be lower resulting in lower TRVs. In a few cases, TRVs for rivers and tributaries are not salmonid specific because data were lacking. TRVs for rivers and tributaries, in order of preference, are based on the following test organisms: salmonid fish>freshwater non-salmonid fish>freshwater invertebrates.

2.6.7.2 Sediment TRVs

TRVs for stream or river sediment are based primarily on potential toxicity to freshwater benthic invertebrates. For most sediment COCs, these are Consensus Based Threshold Effects Concentrations (MacDonald et al. 2000). Maintaining sediment concentrations below the selected TRV levels is assumed to prevent adverse effects in the benthic community based on survival, growth, and reproduction.

2.6.7.3 Soil and Spoils TRVs

Ecotoxicity data for terrestrial media (defined here as soils and spoils) are sparse compared to data for water and sediment. For some of the less-studied soil and spoils COCs, there is greater uncertainty in selected TRVs. Where data allow, TRVs for both soils and spoils are based on toxicity to terrestrial plants (phytotoxicity) or terrestrial invertebrates (represented by earthworms). Because of special concerns with molybdenosis in livestock (which manifests as a copper deficiency), the TRV for molybdenum in soils and spoils is based on the threshold for molybdenosis in cattle. Cattle have been shown to be among the most sensitive domestic animals to molybdenum exposures.

2.6.8 Risk Characterisation

The Risk Characterisation approach used in this BERA is the Hazard Quotient or HQ approach. HQs are derived by dividing exposure point concentrations by effects data concentrations. Exposure concentrations for this BERA are based on average (arithmetic mean) values, which are assumed to best represent the COC concentration to which ecological receptors could be exposed. The human health risk assessment typically uses 95% UCL values. Enough samples were not available to use the same approach for the BERA. Typically for a given set of data, the 95% UCL will be greater than the mean. This will potentially result in a slightly more conservative evaluation of human health risks.

2.6.8.1 Hazard Quotients

Hazard quotients or HQs are used to quantify risks to ecological receptors, based on comparisons of exposure concentrations (e.g., mean measured concentrations) to effects concentrations (i.e., TRVs).

$$\mathbf{HQ} = \frac{\textbf{Exposure Concentration of COC}}{\textbf{Effects Concentration of COC}} = \frac{\textbf{Mean Measured Concentration}}{\textbf{TRV Concentration}}$$

HQs greater than 1.0 suggest potential for adverse effects (risk), while HQs below 1.0 suggest little or no significant risk. Higher HQs don't necessarily indicate more severe effects, but can be related to greater likelihood that adverse effects will occur or be observed.

Surface Water HQs – All River and Tributary HQs are based on salmonid fish TRVs. For River and Tributary data based on CDM high flow sampling, HQs generally remain below 1.0 for most dissolved inorganic COCs except for Cu and Zn. Based on GSI lower flow data, HQs are elevated for aluminum, barium, cadmium, copper, lead, manganese, and zinc. HQs were significantly higher (HQs = 16.7 to 47.4) using the GSI data at lower flows (especially for Cu, Zn, and Al). HQs for Cu, Zn, and Al upstream of the mining area (EA1) ranged from 0.07 to 0.33.

Many of the miscellaneous surface waters (adits, pit lakes, etc.) sampled by both CDM and the GSI are associated with elevated HQs based on the selected TRVs for aquatic invertebrates. These include aluminum, barium, cadmium, cobalt, copper, lead, manganese, nickel, uranium, and zinc.

Sediment HQs – Sediment HQs based on average concentrations within the CDM data set are most elevated for arsenic, copper, and lead downgradient of the mining areas (HQs = 8.4 to 20.7). Compared to the upstream reference location, the HQs for these COCs are substantially higher.

For the 2007 GSI data set, elevated HQs are shown for arsenic, copper, lead, manganese, nickel, and zinc. Data from the reference area probably have elevated metal concentrations due to upgradient metal sources.

Spoils HQs – Due to the high concentrations, HQs are quite elevated for arsenic, chromium, copper, lead, mercury, silver, thallium, vanadium, and zinc. The HQs for lead range from 95 to 476 for spoil areas in East and West Avoca. The HQs for arsenic ranged from 57 to 115. HQs are moderately elevated for molybdenum, and these HQs are based on potential for molybdenosis in livestock.

Soils HQs –HQs for metals in agricultural fields are generally below 1.0 (no unacceptable risk) for molybdenum, nickel, and silver. HQs are highest for chromium, but these risk estimates are likely not indicative of a strong likelihood of adverse effects because of the very conservative TRVs based on protection of sensitive plants or soil-dwelling organisms. HQs are also elevated for arsenic, copper, lead, manganese, thallium, vanadium, zinc, and, in a few cases, mercury. Many of these HQs are only slightly above the 1.0 threshold, based on very conservative TRvs or near background concentrations (see Section 3.2), and therefore adverse effects are not expected.

2.6.9 Risk Conclusions

This section summarises the BERA risk estimates. The risk hypotheses are stated below, with responses based on the BERA used to summarise risks.

Are the average levels of contaminants in whole sediments from the river and tributary exposure areas greater than the sediment TRVs for the survival, growth, or reproduction of benthic invertebrates?

> **YES** – Average concentrations of one or more COCs in sediments, based on CDM 2007 sampling, exceed threshold TRVs for adverse effects in benthic invertebrates at all sediment sample locations. Exceedances were observed for As, Mn, Cu, Pb, and Zn.

Is the structure of benthic macroinvertebrate communities in Avoca River sediments significantly different than that from reference locations?

> **YES** – Screening level benthic invertebrate community surveys (April 2007) indicate that the communities in the Avoca River below the mining-impacted areas are impaired relative to the reference stations.

Are the average concentrations of contaminants in water from the rivers and tributaries greater than the surface water TRVs for the survival, growth, and reproduction of fish?

> **YES** – Based on exceedance of hardness-adjusted salmonid-specific chronic TRVs and other chronic TRVs intended to protect the survival, growth, and reproduction of salmonid fish. Exceedances were observed for Cu and Zn at both high and low flow conditions and Al, Cd, and Pb at low flow conditions. Conclusions are based on both CDM and GSI data. HQs were significantly higher for the GSI data at lower flows.

Are the concentrations of contaminants in water from the adits, springs, and miscellaneous surface waters greater than the surface water TRVs for the survival, growth, and reproduction of aquatic invertebrates?

> **YES** – Based on multiple combinations of COCs (dissolved metals) and sampling locations. Exceedances were observed for Al, Ba, Cd, Co, Cu, Pb, Mn, Ni, U, and Zn. The highest HQs were for dissolved Cu, Cd, and Zn.

Are the concentrations of contaminants in water from the rivers, tributaries, adits, springs, and miscellaneous surface waters sufficiently elevated to contribute to adverse effects in upper trophic level (ecological) consumers of fish and adult life stages of aquatic invertebrates?

> **VARIABLE – Rivers and Tributaries** – This exposure route is most applicable (and most likely) for the rivers and tributaries. However, the concentrations of COCs for these media suggest that such exposures would be of minimal concern. None of the most bioaccumulative and toxic COCs (e.g., Cd and Hg) exceed conservative thresholds for the protection of salmonid fish. Salmonid-based TRVs do not, however, address potential effects due to bioaccumulation and effects related to ingestion of COC-contaminated fish by upper trophic level consumers (e.g., piscivorous birds and mammals).
>
> **CONDITIONAL – Adits, Springs, and Miscellaneous Surface Waters** – Although the concentrations of COCs in these waters are highly elevated in many cases, this exposure pathway is of less concern for the following reasons. First is the expectation that most of these waters do not support sufficient numbers of aquatic invertebrates (and probably no fish) to provide successful foraging by insectivorous (or piscivorous) predators. Second, most of these waters are not associated with habitat suitable for most ecological receptors.

Are the average levels of contaminants in spoils from the spoils exposure areas greater than the TRVs for the survival and growth of terrestrial plants?

> **YES** – Phytotoxicity TRVs for spoils COCs (Sb, As, Cd, Co, Pb, Mn, Ni, Se, Ag, Tl, V, and Zn) are exceeded by (or equal to) the average COC concentrations.

Are the average levels of contaminants in spoils from the spoil exposure areas greater than the spoil TRVs for protection of other soil-based receptors or receptor groups?

> **YES** – Toxicity based on exceedance of TRVs for spoil EAs: Cr, Cu, and Hg (invertebrates); Mo (cattle); and Ti (soil microbes and microbial processes).

Are the levels of contaminants in soils and/or spoils from the terrestrial exposure areas sufficiently elevated to contribute to adverse effects in consumers of terrestrial plants, invertebrates, birds, and/or small mammals?

> **Spoils - VARIABLE** – Mo concentrations in spoils exceed thresholds for molybdenosis in cattle, and therefore adverse effects in cattle may be experienced if cattle have access to and consume sufficient amounts of plants growing in Mo-contaminated spoils. This exposure is expected to be unlikely or limited in most cases. In general, spoils areas provide mostly unsuitable conditions for vegetative cover and also provide little suitable habitat for most terrestrial invertebrates (based in part on expectations of low moisture and nutrient content and in part on particle size). The conditions limiting survival, growth, and reproduction of soil dwelling invertebrates and terrestrial plants

also precludes significant exposure by upper trophic level vertebrates. Birds and mammals are unlikely to find sufficient cover or food (plants or prey) in most of the spoils areas. Based on measured concentrations of highly toxic and bioaccumulative cadmium and mercury in spoils, potential exposure to these areas may be a concern for upper trophic level receptors. However, the lack of suitable habitat, limited cover, and likely scenario of limited foraging in spoils areas suggests that such exposures would be minimal at best. Because mercury does not accumulate in the aboveground portion of plants, even risk to sheep grazing on spoils (Connary) would be minimal.

Soils - VARIABLE – Some metals in farmer's fields exceed conservative thresholds for direct toxicity to plants and soil invertebrates. However, the most bioaccumulative COCs (e.g., Hg) that would be of most concern for upper trophic level consumers (e.g., birds and mammals) are only slightly elevated above very conservative thresholds. The expectation of infrequent and short duration foraging on these fields, along with the minimally elevated concentrations of bioaccumulative COCs, suggests that risks to birds and mammals would be insignificant. This conclusion also applies to grazing cattle and sheep.

2.6.10 Risk Summary

Overall the average concentrations of copper and zinc in the Avoca River waters near the mine area exceed salmonid-specific regulatory standards. In addition, during low flow conditions, concentrations of aluminum, cadmium, and lead exceed aquatic criteria. The BMI communities in the Avoca River sediments are impaired near and downgradient of the mine area compared to reference areas. Benthic macroinvertebrates are used as an indicator of water quality. Sediment concentration for copper, lead, and zinc exceed TRVs. Concentrations of many metals in spoils exceed TRVs for protection of flora and fauna. Concentrations of metals in soil (farmer's fields) are much lower than spoils and are only slightly higher than conservative thresholds. As a result of these concentrations and limited exposure to the soils, risks to fauna would be insignificant. Avoca River water quality data in the vicinity of Shelton Abbey have elevated concentration of metals compared to areas upgradient of the Meeting of the Waters. However, the HQs do not exceed the value of 1 (the copper HQ is equal to 1.0). In addition, no increases in metal concentrations were observed between the Shelton Abbey upgradient and downgradient locations during the July/August 2007 sampling.

2.6.11 Supporting Studies

Several supporting studies were undertaken to provide additional lines of evidence regarding protection of ecological resources. These include a survey and summary of land uses/habitats along the Avoca River; a survey to identify potential physical barriers to fish migration within the Avoca River; a compilation of information regarding use of the mining-impacted portions of the Avoca River corridor by bats; and uptake of metals by terrestrial plants in mining-impacted areas. Each of these studies is discussed below.

2.6.11.1 Habitat Descriptions / Land Use

The habitat assessment study area includes the West and East Avoca mining areas, as well as Shelton Abbey tailings. It also includes the Avoca River from Meeting of the Waters to Shelton Abbey. The study area is shown in Figure 2-10.

The Avoca River Valley is a proposed National Heritage Area (site code 001748). The proposed area includes Shelton Abbey but does not include the East and West Avoca Mine Areas. The proposed area is a large area of mixed woodland located in the valleys of the Avoca and Aughrim rivers. The best examples of relatively pure deciduous woods are found around Shelton Abbey. Oak is the dominant tree species with ash, beech, and birch locally abundant.

Methodology – The habitat assessment was carried out on March 19 and 20 and April 9, 2008. It was conducted in accordance with The Heritage Council's Draft methodology, *A Standard Methodology for Habitat Survey and Mapping in Ireland* (Natura 2005) and habitats were classified according to The Heritage Council's *A Guide to Habitats in Ireland* (Fossitt 2000). The classification of habitats according to this Guide is primarily based on the combination of plant species that occur in a particular area. The Lidar survey (2007) was employed to aid delineation of habitat types for the mine sites and Shelton Abbey and aerial photography (2000) was used for the riparian corridor. Plant identification principally follows Webb et al. (1996). The results of the assessment are summarised in Table 2-16 and shown on maps for the East and West Avoca areas of Figures 2-11 and 2-12, respectively. The maps for the additional areas are contained in the *Investigative Reports, Ecological Risk Assessment*, CDM 2008.

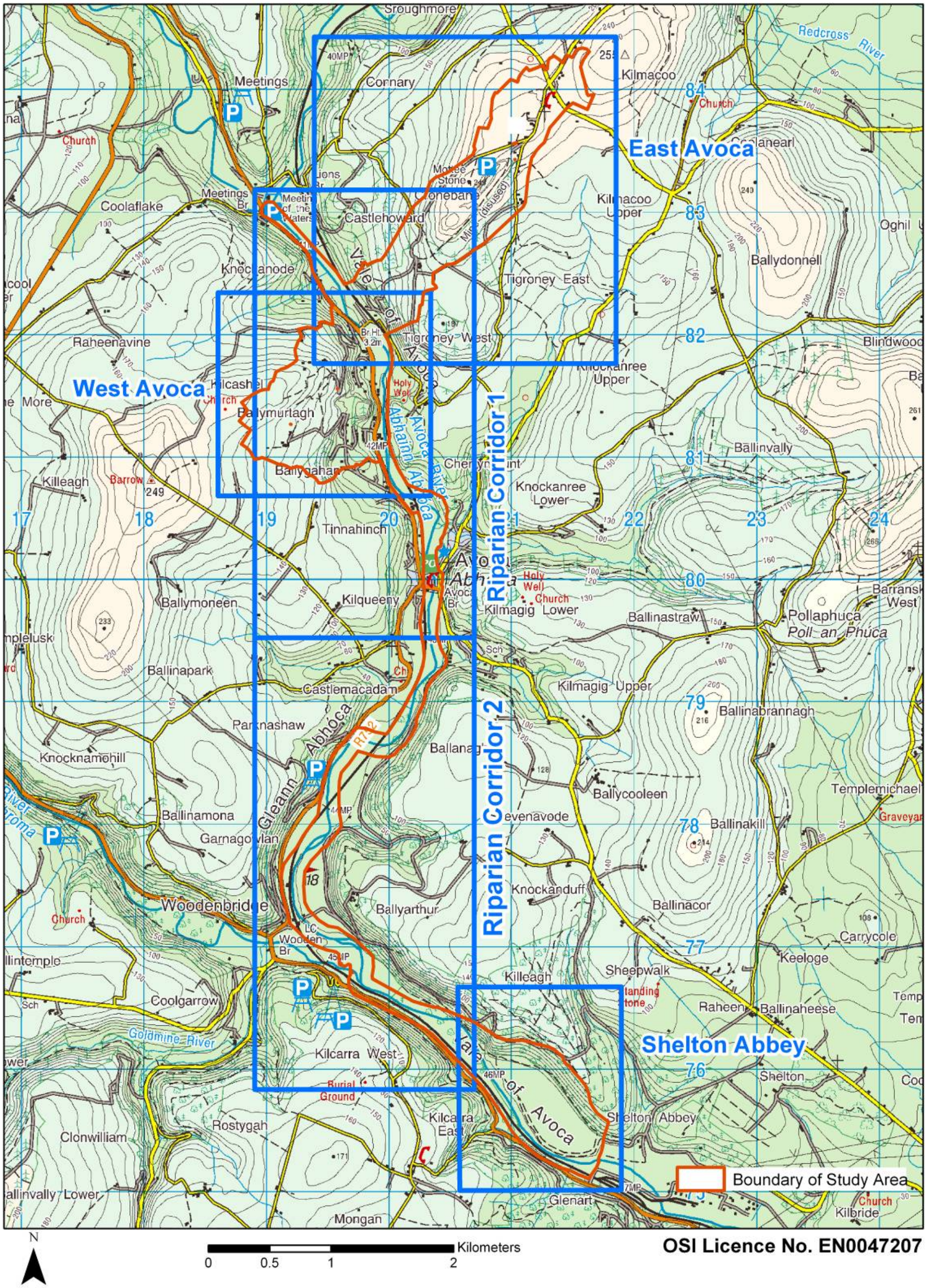


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Figure 2-10 Habitat Survey - Study Area

Table 2-16 List of Habitat Categories

	Area (ha)			
Habitat Categories	**East Avoca**	**West Avoca**	**Shelton Abbey**	**Riparian Corridor**
Spoil and bare ground (ED2)	27.37	6.29	0	0
Recolonising bare ground (ED3)	4.87	0	0	0
Refuse and other waste (ED5)	0	8.10	0	0
Dry siliceous heath (HH1)	10.05	7.37	0	0
Oak-birch-holly woodland (WN1)	0	0	15.22	6.52
Riparian woodland (WN2)	0	0	0	2.86
Broadleaf woodland (WD1)	0	0	16.93	0
Mixed broadleaf/ conifer woodland (WD2)	10.80	15.98	7.64	12.87
Conifer woodland (WD3)	26.43	18.59	0	0
Conifer plantation (WD4)	12.07	0	0	1.92
Scattered trees and parkland (WD5)	0	0	0	0.38
Scrub (WS1)	5.58	8.32	24.96	1.48
Recently-felled woodland (WS5)	0	0.30	0	0
Hedgerows (WL1)	n/a			
Treelines (WL2)				
Improved agricultural grassland (GA1)	42.58	32.78	1.46	25.84
Amenity grassland (GA2)	4.52	4.93	0	23.70
Wet grassland (GS4)	0	0	16.33	0
Depositing/lowland rivers (FW2)	n/a			
Other artificial lakes and ponds (FL8)	0	0	0	0.49
Arable crops (BC1)	0	3.00	0	0
Tilled land (BC3)	0	0	0	9.64
Buildings and artificial surfaces (BL3)	3.14	4.28	0	4.29

N/A = Not applicable = line category (rows or lines) or a river

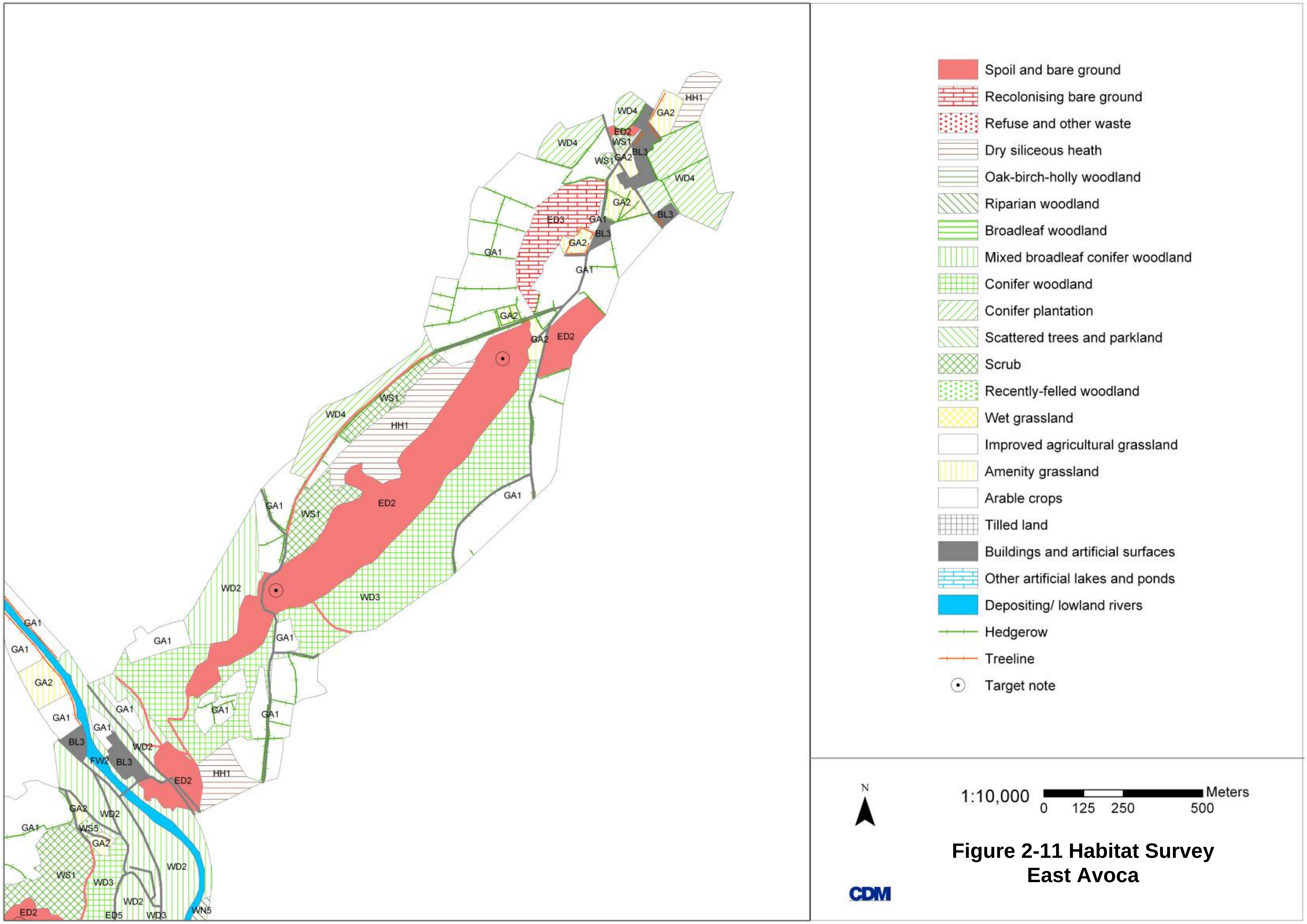


Figure 2-11 Habitat Survey East Avoca

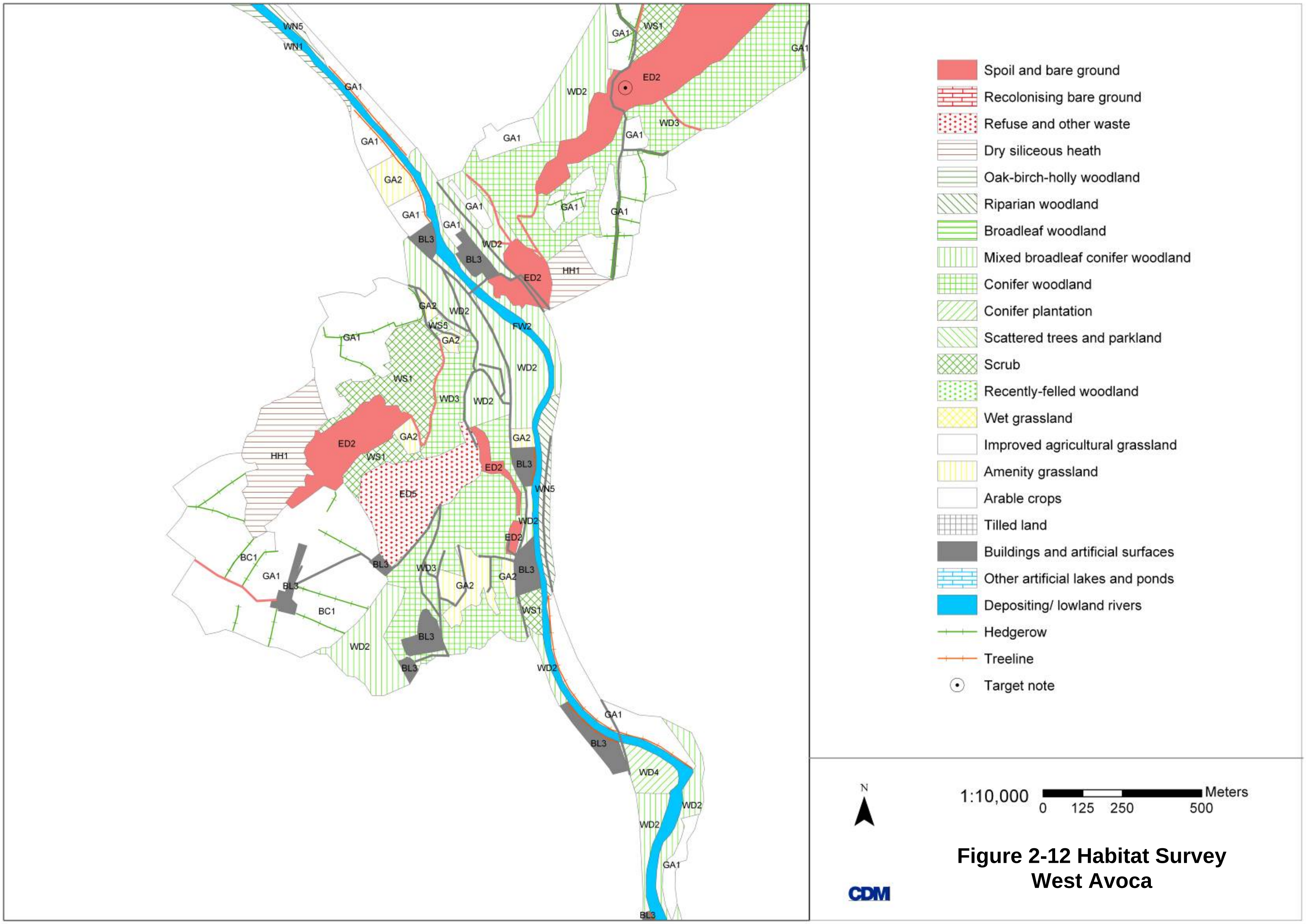


Figure 2-12 Habitat Survey West Avoca

CDM

Habitats – The main habitats of the Avoca mines, Shelton Abbey tailings, and the Avoca riparian corridor are summarised in Table 2-16. Habitat codes given in parentheses are those given by Fossitt (2000). Table 2-16 lists the 23 habitats categories encountered and the associated size of the areas.

Conclusion – The study area includes a large area of mixed woodland along the river valley. Around the mine area are pine and pine/birch woodland. There are also pine and larch woodland on both sides of the river. The steep slopes of the Tigroney hill and the Mottee Stone and a large area in West Avoca are covered in heather/ gorse heathland. Agricultural land is mainly for grazing. Spoil heaps are covered scarcely or not at all by vegetation.

Many of the vascular plant species occurred in more than one habitat. This is an illustration of how the process of colonization of disturbed land relies on the surrounding flora to provide "volunteer" plants. *Erica* and *Ulex*, species belonging to the heathland vegetation, successfully establish themselves in the pine woods of the mine sites and in scrub vegetation. *Pinus* can invade the oak wood, and likewise *Quercus* is a common component of the pine woods (Fay 1996).

2.6.11.2 Fauna

Section 2.6.5.2 discusses species of special concern and other protected organisms. The common lizard (*Lacerta vivipara*, protected by the Wildlife Acts of 1976 and 2000) was observed at the golf course in Woodenbridge and at the East Avoca Pit in April 2007. Table 2-17 shows the fauna of the Avoca mine site. The observed column shows the fauna seen during the habitat survey, the recorded column shows the fauna that have been noted in the literature (based on survey in the Shelton Abbey area, Wann 2000) and the expected column are based on the habitats present or the geographic range. See the sections below for summary of the different groups of fauna.

Table 2-17 Summary of Fauna

	Observed	**Recorded**	**Expected**
Mammals	Rabbit (*Oryctolagus cuniculus*)	Badger (*Meles meles*) Fox (*Vulpes vulpes*) Hare (*Lepus timidus hibernicus*) Brown rat (*Rattus norvegicus*) Stoat (*Mustela erminea hibernica*) Mink (*Mustela vison*)	Red squirrels (*Sciurus vulgaris*)
Bats		Pipistrelles (*Pipistrellus* spp.) Leisler's bat (*Nyctalus leisleri*) Daubenton's bat (*Myotis Daubentonii*) Natterer's bat (*Myotis nattereri*)	Brown long-eared bat (*Plecotus auritus*)
Birds	Pheasant (*Phasianus colchicus*)	Wren (*Troglodytes troglodytes*) Robin (*Erithacus rubecula*) Blackbird (*Turdus merula*) Rook (*Corvus frugilegus*) Jackdaw (*Corvus monedula*) Woodpigeon (*Columba palumbus*) Red kite (*Milvus milvus*) Falcon (*Falco peregrinus*)	Jay (*Garrulus glandarius*) Long-eared owl (*Asio otus*) Treecreeper (*Certhia familiaris*) Woodcock (*Scolopax rusticola*) Blackcap (*Sylvia atricapilla*) Buzzard (*Buteo buteo*)

Table 2-17 Summary of Fauna

	Observed	Recorded	Expected
Fish		Salmon (*Salmo salar*) Sea trout (*Salmo trutta*) Eel (*Anguilla anguilla*) Brook lamprey (*Lampetra planeri*) River lamprey (*Lampetra fluviatilis*) Sea lamprey (*Petromyzon marinus*)	

Mammals – Mammals such as badger (*Meles meles*), fox (*Vulpes vulpes*), hare (*Lepus timidus hibernicus*), brown rat (*Rattus norvegicus*), stoat (*Mustela erminea hibernica*) and mink (*Mustela vison*) have been recorded in the study area (Wann 2000). Rabbits (*Oryctolagus cuniculus*) have been observed on the mine area of West Avoca, and Shelton Abbey during the habitat assessment, as well as, burrows and faecal pellets. Red squirrels (*Sciurus vulgaris*) are expected in the Scots pine forests as it is an important habitat for them as they feed on its cones and live high up in the trees.

Birds – The principal bird habitats within the study area are upland heath and the woodlands. The unvegetated parts of the mines are poor in bird life. Wren (*Troglodytes troglodytes*), robin (*Erithacus rubecula*), blackbird (*Turdus merula*), rook (*Corvus frugilegus*), jackdaw (*Corvus monedula*) and woodpigeon (*Columba palumbus*) are the most common bird species in Ireland and were recorded in the study area.

The woodlands contain a typical breeding bird community of old woodlands. This includes a number of less common species such as jay (*Garrulus glandarius*), treecreeper (*Certhia familiaris*), woodcock (*Scolopax rusticola*) and blackcap (*Sylvia atricapilla*). Ireland's most common owl, the long-eared owl (*Asio otus*) has taken very well to coniferous forests and is more prevalent in the east of the country.

The buzzard (*Buteo buteo*) is a bird of prey which has recently re-established breeding territories in County Wicklow. It is very likely to breed in some of the older, less disturbed woodlands. Thirty red kites (*Milvus milvus*) have been reintroduced to County Wicklow. The majority of the kites can still be located in and around one large farm. Kites that frequent the main roost have been seen up to 9 km away during the day. Steep cliffs offer suitable nesting sites for falcons. A pair of peregrine falcons (*Falco peregrinus*) have been reported (but were not observed during the studies) to utilise the walls of the open mine pits within the study area.

Fish – Species of fish in the Avoca River include salmon (*Salmo salar*), sea trout (*Salmo trutta*), eel (*Anguilla anguilla*) and three species of lamprey: brook (*Lampetra planeri*), river (*Lampetra fluviatilis*) and sea lamprey (*Petromyzon marinus*). Both salmon and all three species of lamprey are listed Annex II species under the EU Habitats Directive. Fish kills occur regularly during low flow periods and thirteen fish kills have been recorded on the Avoca River between approximately 2000 and 2003. Species killed included adult salmon, sea trout, and juvenile lamprey (Doyle et al. 2003). Most salmon (*Salmo salar*) and sea trout (*Salmo trutta*) were attempting to swim upstream to spawning grounds, while all lampreys found were metamorphosed juveniles. Even though migratory salmonids successfully spawn in the headwaters of the Avoca catchment there is a potentially significant mortality risk to salmon and sea trout smolts as they migrate downstream to the sea. Although the polluted section supports little by way of resident salmonids, other species including lamprey and eel were present. This suggests that these species may have some tolerance to this form of toxic pollution (Doyle et al. 2003).

During the habitat survey in April 2008 there were no obvious physical barriers observed in the Avoca River that would hinder the migration of fish. Adult salmon have penetrated up into the upper reaches of the Avonmore, the middle reaches of the Avonbeg and the upper reaches of the Aughrim. Salmon continue to enter the Avoca to spawn despite the toxic nature of the water through which they must ascend to reach these spawning areas (Doyle et al., 2003). If water and sediment quality were improved, fish should be able to complete their migration with no physical or chemical barriers.

2.6.11.3 Bat Survey Information

This section provides a summary of the information on the species of bat found around mines, Avoca area and nearby parts of Wicklow. Data were compiled from the Avoca Bat Watch (Fay 1996) and records of detections of bats from Bat Conservation Ireland.

Bats are widespread in Ireland and can generally be found in areas where suitable roost sites (trees, disused buildings, old stone walls and bridges, or caves) occur in close proximity to areas of suitable foraging habitat (woodland, scrub, hedgerows, wetland areas and open water). Bats commonly feed and commute along linear habitats; such as hedgerows, treelines and watercourses, for cover and because of the high densities of insects that are usually present. Two species of bat would benefit greatly from underground sites associated with mines, the Daubenton's and Natterer's.

Bats in Ireland are protected under Irish and EU legislation (see Section 2.6.5.2). Under the Wildlife Act (1976) and Wildlife (Amendment) Act 2000, it is an offence to intentionally harm a bat or disturb its resting place. Bats constitute a large proportion of the mammalian biodiversity in Ireland. Ten species of bat are known to occur in Ireland and form almost one third of Ireland's land mammal fauna (Aughney et al., 2006).

In September to November of 1995, six evenings were spent monitoring bat activity at the Avoca mines. Three sites were monitored: East Avoca open pit, West Avoca shaft and West Avoca closed adit. Four species of bat were identified. Pipistrelle (*Pipistrellus spp.*) and Leisler's bat (*Nyctalus leisleri*) were identified by using a bat detector, emerging from East Avoca open pit. Daubenton's bat (*Myotis Daubentonii*) and Natterer's bat (*Myotis nattereri*) were on or by the river at Whitesbridge (Fay 1996).

A search of the Bat Conservation of Ireland database was undertaken on February 9, 2008 by Dr. Tina Aughney. The grid reference (E319700 N182090) acts as the centre point of a square. The centre was a location between the East and West Avoca Mine Sites. For the 10 km search, the database search was undertaken 10 km north, south, east and west of the grid reference. An important point to note is that bat species, where records are not currently available, does not mean that this species is not present within the study area. Records are in the form of the following: roosts, transect records, and ad hoc observations.

There were a large number of records for the 10 km search for the years 1997 to 2007. Six species of bat have been recorded in the area: the common pipistrelle (*Pipistrellus pipistrellus*), soprano pipistrelle (*Pipistrellus pygmaeus*), brown long-eared bat (*Plecotus auritus*), Leisler's bat (*Nyctalus leisleri*), Myotis species, and Daubenton's bat (*Myotis Daubentonii*). Pipistrelle's are noted as being the most abundant type of bat in the area.

The Daubenton's Bat Waterway Survey focuses on Daubenton's (*Myotis Daubentonii*) bat activity along waterways such as rivers and streams (but excludes ponds and lakes) as this species is known to have a high dependency on such waterbodies for foraging. Two All Ireland Daubenton's Bat Waterway Sites are located within 10 km of the Grid Reference. Daubenton's bats were recorded at each of the sites:

- Roddenagh Bridge, River Ow, E311700 N179200 (2006 and 2007)
- Clara Vale, Avonmore River, E318455 N191104 (2007)

The Car-Based Bat Monitoring Scheme is a method of monitoring bats while driving. Monitoring is carried out using a bat detector that picks up the ultrasonic (high pitched) echolocation calls made by bats and converts them to a frequency audible to the human ear. The monitoring is carried out along known routes, at a specific time of year, while driving at a prescribed speed (Roche et al. 2006).

A 30 km^2 area where the car-based monitoring was carried out in County Wicklow was referenced as T05. The route for this car survey starts close to Hacketstown and zig-zags in a roughly south-easterly direction to Courtown. The closest the route comes to the Avoca Valley is at Ballinglen, approximately 13-15 km west of Woodenbridge. A number of transects within the T05 recorded the following species:

- Common pipistrelle (*Pipistrellus pipistrellus*)
- Soprano pipistrelle (*Pipistrellus pygmaeus*)
- Pipistrelle unidentified
- Brown long-eared bat (*Plecotus auritus*)
- Leisler's bat (*Nyctalus leisleri*)
- Myotis species

In conclusion, these data indicate that six species of bats have been observed or recorded in or near the Avoca River mining area. Data are lacking to identify the relationship between mining-related caves, adits, and other potential habitats and bat abundance or diversity. It is expected that bats consume large numbers of flying insects, including adult life stages of species with aquatic early life stages. However, the screening level benthic macroinvertebrate survey results previously discussed suggest that insect taxa with flying adult life stages (e.g., mayflies, caddisflies, and midges) are currently not abundant in the mining-affected portions of the Avoca River. Where such taxa are abundant for prey (e.g., the lower Avoca below the confluence with the Aughrim River), the bats should not contain elevated levels of potentially toxic mining-related metals. This expectation is based on the substantially lower levels of metals in riverine sediments outside the mining impacted areas.

2.6.11.4 Metals Uptake in Terrestrial Plants

Many metals occur naturally in soil, and concentrations vary substantially from one area to another. Metals-related adverse effects on terrestrial plants can be influenced by the metal form as well as concentration in soil. Site-specific soil characteristics such as pH, cation exchange capacity (CEC), and clay content affect metals bioavailability. For most metals except mercury, root uptake is probably the most important exposure route for terrestrial plants. Most mercury is acquired by terrestrial plants via foliar uptake. Another issue to be considered when evaluating metals concentrations in soils and plant tissues is essentiality. The following trace elements are essential for normal development of plants: cobalt, copper, iron, manganese, selenium, molybdenum, and zinc. In contrast, arsenic, cadmium, lead, and mercury have no known functions in plants (or animals).

Metals-related impacts on terrestrial plants can be evaluated with varying degrees of success using metals concentrations in soil, metals concentrations in plant tissues, or both using either soil-to-biota uptake factors or bioaccumulation factors (BAFs). The rate of uptake is often more important than tissue concentrations because adverse effects will not occur as long as the uptake rate does not exceed the rate at which plants can bind the metal. BAFs for terrestrial plants most often remain below 1.0, but where BAFs exceed 1.0, risks to upper trophic level consumers of plants should be considered. Where BAFs remain much lower than 1.0, the role of soil ingestion by herbivores becomes more important than ingestion of plants.

Site-specific BAFs were determined for ten metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn) and locations in support of this BERA. Mercury was analyzed in soil and plants as well, but all plant concentrations were below the detection limit of 0.02 mg/kg. BAFs are therefore not determined for mercury. These BAFs are based mostly on co-located soil and plant tissue samples (above ground unwashed plants). In a few cases, the soil sample is near but not co-located with the associated plant sample.

Nearly all BAFs are below 1.0. (For detailed information see the *Investigative Reports, Ecological Risk Assessment*, CDM 2008, Section 9.4.4). Average BAFs by metal (average of all locations) range from 0.0095 (Fe) to 0.34 (Mn). These findings suggest that risks to local herbivores from consuming plants which have accumulated metals are low.

2.7 Summary of Investigations

The investigations and evaluations conducted at the Avoca Site have identified many concerns. These concerns can be categorised into the following:

- Physical Hazard Concerns
  - Stability
  - Safety

- Human Health
  - Residents
  - Recreational Users
  - Commercial and Industrial Workers
  - Construction Workers

- Ecological Concerns
  - Acid/Metal Generation
  - Aquatic life
  - Benthic Macroinvertebrates
  - Flora
  - Terrestrial Animals
  - Protected Species (Fauna)

- Industrial Archaeology Concerns
  - Heritage Structures
  - Mining Landscape Features

Table 2-18 lists these concerns and indicates which of the various site features (spoil piles, adit discharges, etc.) present or contribute to the concerns. The following paragraphs discuss major site features and the above issues and concerns they present.

2.7.1 Spoil Piles

The spoil piles present physical hazards and ecological and human health concerns. Many spoil areas (Connary, East Avoca, West Avoca) are unsafe due to subsidence features and voids. Major piles including Mt. Platt have unstable slopes. Major slope failure has occurred in the past on Mt. Platt and current conditions are also not safe. In addition, erosion, runoff, infiltration, and seeps from Mt. Platt have low pH values and very high metal concentrations that impact groundwater and surface water. Average metal concentrations in the surface spoils of Mt. Platt affect human health (residents and workers) and ecological health of fauna and flora.

Table 2-18 Identified Areas of Concern

	ISSUES/CONCERNS													
	Physical Hazards		Industrial Archaeology		Ecology						Human Health			
Site Features	Stability	Safety	Heritage Structures	Mining Landscape Features	Acid/Metal Generation	Aquatic Life	Benthic Macro-invertebrates	Terrestrial Animals	Flora	Protected Species	Residents	Recreational Users	Commercial and Industrial Workers	Construction Workers
Solids														
Spoil Piles	●	●	○	●	●	-	-	●	●	●	●	●	●	●
Tailings	○	○	○	●	●	-	-	●	○	○	○	○	○	○
River Sediments	○	○	-	-	●	●	●	○	○	○	○	●	○	○
Field Soils	○	○	-	-	○	-	-	○	○	○	○	-	-	-
Water														
Adit Discharges	-	-	-	●	●	●	●	●	○	●	●	●	-	○
Seeps	-	-	-	-	●	-	-	-	○	-	○	-	-	-
Springs	-	-	-	-	○	-	-	○	○	○	○	○	○	○
Groundwater-deep (homeowner)	-	-	-	-	○	-	-	-	-	-	○	○	○	○
Groundwater-shallow	-	-	-	-	●	-	-	-	-	-	●	-	-	-
Diffuse Flow	-	-	-	-	●	●	●	-	-	-	-	-	-	-
Surface Water Runoff	-	-	-	-	●	●	●	-	○	-	-	-	-	-
Pit Lakes	-	●	-	●	●	-	-	●	-	●	-	●	-	-
Structures														
Engine houses, etc.	●	●	●	●	-	-	-	-	-	-	-	-	-	-
Ore bins	●	●	●	●	-	-	-	-	-	-	-	-	-	-
Shafts	●	●	●	●	-	-	-	○	-	●	-	-	-	-
Adits	●	●	●	●	-	-	-	○	-	●	-	-	-	-
Open Pits	●	●	○	●	●	-	-	○	-	-	-	-	-	-
Pit Rock Faces/ Highwalls	●	●	○	●	●	-	-	○	-	●	-	-	-	-
Underground Workings	●	●	○	○	●	-	-	-	-	-	-	-	-	-

- = not Applicable

● = Feature contributes to concern

○ = Feature does not contribute to concern

When exposed to precipitation (rainfall), all spoil piles generate acid conditions and release metals impacting groundwater and surface water. The average metal concentrations of spoil piles in all areas affect human health and ecological health. The lead concentrations at Connary and the Ore Bins areas are very high and could affect the health of a recreational visitor. Arsenic concentrations at the Connary, the Ore Bins, Deep Adit, and West Avoca could also affect human health including the recreational visitor.

2.7.2 Adit Discharges and Diffuse Flow

Adit discharges and diffuse groundwater flow affect aquatic life including fish and macroinvertebrates in the Avoca River. In particular, the metal loads of the discharges from the Deep Adit, Road Adit, and Intermediate Adit are very large. Although the metal load from diffuse groundwater contamination is much smaller than the direct adit loads, the diffuse loads alone affect aquatic life and result in river quality exceeding regulatory standards.

2.7.3 Structures

Open shafts and adits exist resulting in physical hazards and unsafe conditions. Rock faces and pit highwalls (Cronebane Pit, East Avoca Pit, Weaver's Pit, and Pond Lode Pit) are not stable and present unsafe conditions. Some historic structures (e.g., Tigroney Ore Bins) are not stable and present unsafe conditions in accessible areas.

2.7.4 Sediment

Sediment quality (metal concentrations and physical habitat) in the Avoca River severely limit macroinvertebrate population. This also affects other aquatic life (fish) due to limited food sources.

2.7.5 Constraints

All of the above concerns should be addressed to mitigate safety, human health concerns, and ecological concerns. However, any actions should also preserve structures of industrial archeological importance. To the extent possible, actions compatible with the mining landscape and other site features should be evaluated. The local ecology should be preserved or enhanced by any actions (e.g., construction of plugs and seals that allow access to bats). These constraints are evaluated in Section 4.4.5 under the Site Compatibility evaluation criterion.

2.7.6 Specific Investigative Results Affecting Remedial Actions

The above sections summarise overall issues and concerns related to site features. Many specific conclusions related to evaluation and selection of remedial alternatives resulted from the investigations. Some specific examples are summarised below (some repeat observations made in the above sections):

- Capture and treatment of adit discharges will substantially reduce concentrations of metals in the Avoca River. However, because of the contribution of metals in the diffuse flow (groundwater) component entering the Avoca River, the applicable Water Quality (Dangerous Substances) Regulations for copper and zinc concentrations would not be achieved.

- Additional capture and treatment of the diffuse flow (groundwater) component will result in copper and zinc concentrations in the Avoca River that are nearer the applicable Water Quality Regulations. Water quality in the Avoca River may approach standards for most of the year. However, detailed mass balance calculations were only conducted for one set of flow and quality conditions; therefore, definitive conclusions cannot be made for all flow conditions. Overall, treatment of both the adit discharges and diffuse component metal loads would be necessary in order to achieve water quality standards.

- During the data collection period, no adverse impact on the Avoca River was observed downgradient of the Shelton Abbey Tailings facility. However, high concentrations of metals were observed in the alluvial groundwater and the small pond at the base of the facility

- The discharge from the Intermediate Cronebane Adit contributes a significant metal load to the Deep Adit discharge.

- Because the emergency tailings are dry and relatively impermeable, the tailings in the emergency tailings pond do not directly contribute additional metals to the Avoca River. The contamination observed along the river bank in the vicinity of the emergency tailings results from upgradient contaminated groundwater.

- The alluvial groundwater level is above the base of the spoils in the Deep Adit area, resulting in high concentrations of metals that enter the Avoca River as diffuse flow. The spoils in the Deep Adit area contribute metals to the Avoca River.

- The sediments in the Avoca River in the vicinity of the discharges from the Deep and Road adits contain high levels of metals that contribute to the elevated concentrations of metals in the Avoca River by dissolution processes.

- In addition to the direct discharge to the Avoca River, the ditches flowing from the Deep Adit and Road Adit contribute metal loads to the Avoca River via diffuse flow.

- All spoil piles have a high acid generating potential when contacted with water. As a result, infiltrating water will have low pH values and elevated metal concentrations. The contaminated water will contribute to the high concentrations of metals observed in seeps, groundwater, and adit discharges.

- Lead concentrations in the spoil piles near the Ore Bins and in the Connary area present unacceptable risks to recreational users. Arsenic and lead in all other spoil pile areas also present unacceptable risk to residents and commercial and construction workers.

- The Avoca River does not currently pose any adverse risk from the point of view of recreational use (e.g., kayaking and angling).

- There is no anticipated adverse ecological risk from the fields surrounding the Site as a result of the historic mining.

- Many physical hazards exist at the Site. The major physical hazards are pit highwall and spoil pile stability. Other physical hazards include open adits and shafts, subsidence, voids, and unsafe structures.

2.8 Public Participation

2.8.1 Introduction

The views and concerns of people from the local communities around Avoca and local interest groups are considered to be important inputs to the project. Many residents and their families have worked in or for the mines in the past. Some have become involved in efforts to preserve the mines for heritage purposes or restore the river for angling purposes. Others have no connection with the mines but are concerned with quality of life issues in the area. In general, there was a high level of interest in the project from local people. Groups who use the Avoca valley for fishing and boating were also very interested in the outcomes of the project.

Stakeholder engagement took the form of two major public meetings, one before the major fieldwork investigations in July 2007, and another before the completion of the draft Feasibility Study in April 2008. Both meetings were held in the function room of the Woodenbridge Hotel. In addition to these meetings, a webpage with information on the project was maintained on the GSI's website for the duration of the project, while a dedicated phone line was established to allow local people to make enquiries about the project.

Both public meetings were extensively publicized in the local press, on local radio, on the GSI's website and by posters in shops and public buildings around the Avoca area. Additionally, for the second meeting, invitations were issued to those attendees of the first meeting who provided their contact details in an attendance book. Sean O'Riordain of Heneghan PR was retained by CDM to assist with publicity and organisation of the first meeting.

Attendance at both meetings was very good, with approximately 80 present at the first meeting and approximately 100 present at the second. Many attendees came to both meetings, and those present comprised a good cross section of local people, elected representatives and members of environmental, community, recreation and heritage groups. Many young people with an interest in the project were present and participated.

2.8.2 First Public Meeting – July 2007

The purpose of the first meeting was to explain the objectives of the project, and to elaborate in particular on the extensive fieldwork planned for the weeks following the meeting. The potential remediation options available for the Avoca Mining Area were discussed in a presentation to the attendees, using examples from other mine remediation projects undertaken around the world to demonstrate the various options available.

Feedback and input was invited from the attendees by dividing the attendance into smaller groups of around 10 people, each facilitated by representatives from the GSI, the Department of Communications, Energy & Natural Resources, Wicklow County Council or CDM. Each group was asked the same questions about what they value about the Avoca valley and in particular the Avoca Mining Area, and what changes are required to ensure that these values are preserved and enhanced. The answers and discussions from the groups were compiled and summarised at the end of the meeting. This formed part of the record of the first public meeting.

Overall, the key issues and questions raised at this first meeting concerned site safety, the environment, heritage and cost. These issues were confirmed by the project team as being integral to the development of options for the Avoca Mining Area. There were a range of views expressed some of which were conflicting. All views were recorded and have been posted on the website. The views are also summarised in Table 2-19.

Contact details were provided to the attendance to ensure an open line of communication between the project team and the local community over the remainder of the project, particularly when the project team would be present around various parts of Avoca undertaking fieldwork in the month subsequent to the meeting. The presentations were made available on the GSI website.

A separate meeting was also held between the GSI Project Manager and Eastern Regional Fisheries Board (ERFB) representatives, who have been involved in various initiatives over the years to restore the Avoca River for fishing purposes, and have collected much data on the river. During the course of the project, the EPA was updated by GSI and Eastern River Basin District consultants were kept informed of progress by CDM.

2.8.3 Second Public Meeting – April 2008

The second public meeting was held at a point when CDM had almost completed in draft their Feasibility Study of the Avoca Mining Area. Before final decisions were made on the remediation options, feedback from the local communities around Avoca was sought. The format of the meeting was similar to the first meeting, without the break-out groups. The attendees were shown a presentation concerning the findings of the study, and in particular, the results of the extensive fieldwork, and the remediation options being recommended for the Avoca Mining Area were discussed.

Questions from the attendees were answered by representatives from the GSI, the Department of Communications, Energy & Natural Resources, Wicklow County Council or CDM. Generally the response to the presentation was positive, although some attendees felt that individual issues such as heritage were not being given adequate attention in the remediation options. The overall core objectives of the feasibility study, i.e., public safety, protection of human health and the environment, were reiterated as being the drivers behind the various options proposed for remediation. Written comment on the proposals was encouraged.

Separate meetings were also held between the GSI Project Manager and representatives of the Mining Heritage Trust of Ireland (MHTI) and the ERFB while submissions were received from:

- Celtic copper Heritage
- ERFB
- Mining Heritage Trust of Ireland
- Nick Coy
- SPC Developments
- Vale of Avoca Development Association Ltd

Information, views, and concerns of the local community and interest groups were used and considered throughout the Feasibility Study.

Table 2-19 Responses from Participants at the First Public Meeting

What do you like about Avoca mine site and what are the main uses?	***What is your vision for the area in 20 years?***
• Fishing and tourism potential (water pollution) • Canoeing / sea scouts • Tourism potential –international genealogy dimension • Wildlife / nature corridor, wildness of the site / flora & fauna • Beauty / tranquillity / scenery / view • Quality of life / environment –mining is a bad thing • Location • History (oral) Heritage / Buildings • Educational value • No traffic • Amenity / recreation • Cross on hill • Distinctive colour – ochre • Wildness of site • Don't like site / dislike mines / Mine office is ugly • Eyesore • Dangerous • Open to abuse – dumping • Illegal encampments • Site not managed • Want public to have greater access to the site • Joyriding • Quad bikes • Going underground	• Better recreational use • Tourism • Fishing –clean river / River quality restored / Angling tourism • Sports, adventure sports • Museum / Interactive interpretative centre / Mine office should be a centre / Themed heritage park or centre • Preserve the buildings and heritage • Landscape pits and piles • Preserve the ecological diversity • Develop as a nature attraction • Amenity • Rock climbing • Employment • Re-open railway station • Need more access • Make site safe without loss of buildings / heritage

Table 2-19 Responses from Participants at the First Public Meeting

What do you like about Avoca mine site and what are the main uses?	***What is your vision for the area in 20 years?***
• Hill walking / lots of places • Equestrian	

Section 3
Remedial Action Objectives

The site investigations for this project (see *Investigation Reports*, CDM 2008, and summaries in Section 2) and extant information from many sources have identified various metals in both solid and water media at levels exceeding the human health and ecological health risk criteria and available standards. In addition, physical hazards exist due to unsafe and unstable mining features (e.g., shafts, pit highwalls, historic structures). The Avoca Project remedial action objectives (RAOs) for the solid and water media are goals for protecting the human health and environment based on the identified contaminants of concern (COCs), exposure routes, and the probable human, animal and aquatic receptors. The RAO for physical hazards address the unsafe and unstable conditions. As shown in Figure 1-1, development of RAOs is one of the first steps in the feasibility study process. RAOs developed to protect human health and the environment and contain the following items:

- Media of concern (e.g., soil, surface water, spoils, groundwater, etc.)
- Contaminant of concern (e.g., copper, lead, zinc, etc.)
- Exposure route/pathway (e.g., ingestion, direct contact, etc.)
- Receptor (e.g., humans, aquatic life, etc.)
- Preliminary remediation goal (e.g., standards or risk-based values)

Preliminary remediation goals (PRGs) are typically concentrations of the COC in the specific media (e.g., copper in surface water) that have been shown to prevent adverse effects on human or ecological receptors. If available, PRGs are based on standards developed by regulatory agencies. If standards are not available for a specific contaminant, generally accepted criteria values or site-specific risk based values are used. Section 3.1 provides the RAOs for the Avoca site and Section 3.2 provides the PRGs for the Avoca site.

3.1 Site-Specific RAOs

The potential exposure pathways provide the basis on which the site-specific RAOs are established. The RAOs are designed to address potential impacts on human and ecological health by mitigation of significant exposure pathway elements (i.e., elimination of contamination source, contaminated media, transport pathway, exposure route, or exposed population). These RAOs are medium-specific because they seek to preserve or restore an environmental resource. They address the two media of concern: solids (spoils, tailings, soils, sediments, etc.) and water (surface water, groundwater, etc.). Each RAO has an associated PRG. The PRGs are specifically discussed in Section 3.2 and provided in Tables 3-1 to 3-7, located at the end of this section.

In addition to human and ecological concerns with solid and water media, the Site has numerous safety issues due to physical hazards associated with existing spoils piles, shafts, adits, mine workings, pit highwalls, and historic structures as summarised in Section 2.1.6. Site-wide RAOs are also developed to address these issues.

The following RAOs are proposed for the Avoca Project:

Physical Hazards (Pit Highwalls, Pit Ponds, Spoil Piles, Adits, Shafts, and Structures)

- RAO PH1 (Physical Hazard): For human safety, stabilise or prevent access to rock faces or pit walls, stabilise spoil piles and stabilise or prevent access to structures (e.g., ore bins); prevent access to adits, shafts, and other mine openings; reduce subsidence risk; and eliminate or prevent access to pit ponds.

Solid Sources (Spoil Piles, Pit Backfills, Tailings, Sediments, Soils, and Pit Highwalls) and Resultant Contaminated Media

- RAO HHS1 (Human Health Solids): For human health, prevent the long-term ingestion of or direct contact with solid sources (e.g., tailings and spoils) having total concentrations of contaminants of concern that exceed PRGs provided in Tables 3-5 and 3-6 (see Section 3.2).

- RAO HHS2: For human health, prevent the migration via leaching of contaminants of concern from solid sources which would result in groundwater concentrations at residential wells in current use that exceed PRGs provided in Table 3-7 for drinking water.

- RAO ES1 (Ecological Solids): For ecological health, prevent the migration via leaching of contaminants of concern from solid sources which would result in contaminated groundwater and subsequent surface water concentrations that exceed PRGs provided in Tables 3-1 and 3-2 for aquatic life (fish and invertebrates).

- RAO ES2: For ecological health, prevent the direct contact of aquatic life with sediments having concentrations that exceed PRGs provided in Table 3-3 for aquatic life (macroinvertebrates).

- RAO ES3: For ecological health, prevent the direct contact of flora and fauna with spoils and soils having concentrations that exceed PRGs provided in Table 3-4 (plants and invertebrates).

Water Media [Surface Water (Avoca River, Tributaries, Groundwater, Acid Mine Discharges, Acid Rock Drainage, Pit Water, Pond Water, Seeps, Springs]

- RAO HHW1 (Human Health Water): For human health, prevent the ingestion of water media (e.g., groundwater) having concentrations of contaminants of concern that exceed PRGs provided in Table 3-7 for drinking water.

- RAO EW1 (Ecological Water): For ecological health, prevent the seepage of groundwater and discharge from adits having concentrations of contaminants of concern that result in surface water concentrations exceeding PRGs for aquatic life (fish and invertebrates) in surface water provided in Tables 3-1 and 3-2.

- RAO EW2: For ecological health, prevent the direct contact of aquatic life (fish and invertebrates) with surface water media (e.g., Avoca River) having concentrations of the contaminants of concern that exceed PRGs provided in Tables 3-1 and 3-2.

Besides RAOs that address human and ecological health and physical hazards, the cultural and heritage features at the Site must be considered during a remedial action. The objective will be to preserve to the extent possible sites of archaeological importance and cultural and heritage features and improve access to such sites. However, safety, human health, and ecological concerns must be addressed first. Section 4 provides evaluation criteria to address all of the identified human health, ecological health, safety, and cultural concerns at the Avoca site.

3.2 Preliminary Remediation Goals

The *Human Health Risk Assessment* (CDM 2008) and the *Ecological Risk Assessment* (CDM 2008) plus typical risk-based values developed by regulatory agencies in Ireland, the European Union, and the United States are the basis for the preliminary remediation goals (PRGs). Tables 3-1 to 3-7 summarise the PRGs identified in the Ecological and Human Health Risk Assessments. The PRGs are given for the contaminants of concern.

As explained in the Ecological and Human Health Risk Assessments (CDM 2008), the values given in Tables 3-1 to 3-7 are conservative. The values given in the tables are preliminary goals and may change based on, at least, the following items:

- Alternatives selected for final evaluations
- New regulations
- Refined remedial action objectives
- Additional site specific information
- Assumptions of exposure scenarios

The values provided in Tables 3-1 to 3-7 are conservative and, therefore, appropriate for development and screening of alternatives.

Tables 3-1 to 3-4 provide PRGs for the following ecological receptors:

- Salmonid Fish (Table 3-1)
- Aquatic Invertebrates in Water (Table 3-2)
- Macroinvertebrates in Sediments (Table 3-3)
- Plants and Invertebrates in Soils and Spoils (Table 3-4)

Tables 3-5 to 3-7 provide PRGs for human health:

- Recreational Visitors and Workers for Soils and Spoils (Table 3-5)
- Residential for Soils and Spoils (Table 3-6)
- Drinking Water (Table 3-7)

3.2.1 Comparison of PRGs to Site-Specific Data

To determine if remedial actions should be evaluated for complete or potentially complete exposure pathways, the PRGs in Tables 3-1 to Tables 3-7 were compared to the site-specific data obtained during the Site investigations and data from literature and known sources. These comparisons are provided in the *Human Health Risk Assessment* (CDM 2008) and *Ecological Risk Assessment* (CDM 2008). General observations concerning these comparisons follow.

Surface Water (Avoca River) and Groundwater
The ecological PRGs for copper, lead, and zinc were routinely exceeded by average and maximum concentrations in the Avoca River. The human health PRGs (drinking water) were typically not exceeded in the Avoca River or homeowner wells for those parameters measured.

Mine Spoils
The ecological PRGs for many parameters were typically exceeded at most locations. The human health PRGs for arsenic and lead for recreational visitors, future construction workers, and future commercial/industrial workers exposure were typically exceeded.

Tailings
The ecological PRGs for most parameters were typically exceeded at Shelton Abbey. The human health PRGs for arsenic and lead for recreational exposure were not exceeded at Shelton Abbey.

Sediments
Ecological PRGs for most parameters were exceeded at most locations. Fewer parameters exceeded the PRGs at locations downgradient from the mining areas. Some concentrations in the sediments may exceed very conservative human health PRGs.

Soils
The ecological PRGs (based on background levels) for selected metals were exceeded in some fields. Overall, exposure is limited and adverse affects are not anticipated.

Overall evaluations indicate the following:

- Concentrations of metals in the Avoca River impact aquatic life including fish and macroinvertebrates.

- Concentrations of metals in groundwater in the alluvium near the Avoca River impact aquatic life (via seeps).
- Concentrations of metals in homeowners wells do not impact humans (via drinking)
- Concentrations of metals in spoils and tailings could impact humans (via recreational exposure and future construction/commercial/industrial worker exposure).
- Concentrations of metals in spoils and tailings could impact animals, plants, and invertebrates.
- Concentrations of metals in tailings do not impact aquatic life (via seepage into the Avoca River).
- Concentrations of metals in sediments impact macroinvertebrates.
- Concentrations of contaminants in soils do not impact agricultural activities.

Table 3-1 Surface Water Ecological PRGs (Salmonids)

COC	PRG	Description / Comment
Surface Water PRGs (µg/L, salmonids present)		
Barium (D)	4	survival, growth, reproduction (salmon fish), Oak Ridge National Laboratory (ORNL) Tier 2
Copper (D)	5	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness <100 mg/L
	5	SI No. 293 (1988), European Communities (Quality of Salmon Waters) Regulation, hardness <10 mg/L
	11	survival, growth, reproduction (salmon fish) - calculated based on average hardness of 31 mg/L in Avoca River
	22	SI No. 293 (1988), European Communities (Quality of Salmon Waters) Regulation, hardness 10-50 mg/L
Lead (D)	5	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness <100 mg/L
	13	Survival, growth, reproduction (salmonid fish) - calculated based on average hardness of 31 mg/L in Avoca River
Silver (D)	0.12	survival, growth, reproduction (salmonid fish), ORNL Lowest Chronic Value for Fish
Zinc (D) (total for EU standards)	8	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness <10 mg/L
	30	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness <10 mg/L
	50	SI No. 12 (2001), Water Quality Regulations (Dangerous Substances), hardness 10 - 100 mg/L
	268	Survival, growth, reproduction (salmonid fish) - calculated based on average hardness of 31 mg/L in Avoca River
	200	SI No. 293 (1988), European Communities (Quality of Salmonid Waters) Regulation, hardness 10-50 mg/L

Table 3-2 Surface Water Ecological PRGs (Invertebrates) (ORNL Lowest Chronic Value for Daphnids)

COC	PRG	Description / Comment
Surface Water PRGs (µg/L, aquatic invertebrates (fish absent), variable hardness but not <25 or >200 mg/L)		
Ammonia (mg/L)	3.5	Lowest EC_{20} for aquatic invertebrates or surrogate
Aluminum (D)	1900	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Barium (D)	4	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Cadmium (D)	0.15	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Cobalt (D)	5.1	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Copper (D)	0.23	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Lead (D)	12.3	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Manganese (D)	1,100	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Nickel (D)	5	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Uranium (D)	2.6	Lowest chronic value for daphnid or secondary chronic value for aquatic life
Zinc (D)	46.7	Lowest chronic value for daphnid or secondary chronic value for aquatic life

Table 3-3 Sediment Ecological PRGs (Macroinvertebrates)

COC	PRG	Description / Comment
Sediment PRGs (mg/kg, benthic macroinvertebrates)		
Arsenic	35	Background sediment concentrations (EA1)
Copper	61	Background sediment concentrations (EA1)
Lead	640	Background sediment concentrations (EA1)
Manganese	5,000	Background sediment concentrations (EA1)
Nickel	24	Background sediment concentrations (EA1)
Zinc	750	Background sediment concentrations (EA1)

Table 3-4 Soil and Spoils Ecological PRGs (Plants and Invertebrates)

COC	PRG	Description / Comment
Surface Soil - Spoils PRGs (mg/kg, plants and soil invertebrates)		
Arsenic	23	Background soil concentrations(1)
Chromium	61	Background soil concentrations(1)
Copper	50	Earthworm (Oak Ridge National Laboratory benchmark) (2)
Lead	62	Background soil concentrations(1)
Manganese	1,180	Background soil concentrations(1)
Mercury	0.14	Background soil concentrations(1)
Molybdenum	10	Cattle (lowest observed effect concentration)(2)
Nickel	30	Plant (Oak Ridge National Laboratory benchmark)(2)
Silver	2	Plant (Oak Ridge National Laboratory benchmark)(2)
Thallium	3.9	Background soil concentrations(1)
Vanadium	84	Background soil concentrations(1)
Zinc	83	Background soil concentrations(1)

(1) Based on highest concentrations of the median levels of soils in Counties Wicklow and North Wexford or lowest mean field levels (Field 2).

(2) Values based on toxicity reference values (TRVs) that were higher values than background levels. Background levels = 43 mg/kg for copper, 2.5 mg/kg for molybdenum, 19 mg/kg for nickel, and 0.26 mg/kg for silver.

Table 3-5 Human Health PRGs for Soil and Spoils (Recreational Visitors and Workers)

Chemical of Concern	Target Risk or HI	Preliminary Remediation Goal (mg/kg)		
		Recreational Visitor(1)	Commercial/Industrial Worker	Construction Worker
Lead (2)	See note 2 below	10,012	4,165	2,427
Arsenic (1)	1 x 10^{-6}	571	221	3,925
Antimony	1	772	409	235
Cobalt	1	37,348	13,345	10,103
Copper	1	77,212	40,880	23,462
Iron (3)	1	100,000(3)	715,400	410,583
Manganese	1	38,604	20,429	11,729
Thallium	1	147	78	45
Vanadium	1	1,930	1,022	587

(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children

(2) PRGs for lead for receptors were calculated using the USEPA Adult Lead Model, and are based on 95% UCL of absolute bioavailability estimate for lead for all exposure areas (3.95% = average bioavailability, see *Investigative Reports, Human Health Risk Assessment*, CDM 2008, Section 2.1.2)

(3) PRG is a ceiling limit equivalent to a chemical representing 10% by weight of the soil sample. The risk based PRG exceeds unity (>1,000,000 mg/kg), which is not possible.

Table 3-6 Human Health PRGs for Soil and Spoils (Residential Exposure)

Chemical of Concern	Target Risk or HI	Preliminary Remediation Goal (mg/kg) Offsite Resident(1)
Lead (2)	See note 2 below	2,671
Arsenic (1)	1 x 10^{-6}	134
Antimony	1	31
Cobalt	1	1,381
Copper	1	3,129
Iron	1	54,750
Manganese	1	1,564
Thallium	1	6
Vanadium	1	78

(1) Carcinogenic exposure are estimated for adults, non-cancer exposures for children

(2) The PRG for lead for the Offsite Resident was calculated using IEUBK Model for young children and is based on 95% UCL of absolute bioavailability estimate for lead for all exposure areas (3.95% = average bioavailability)

Table 3-7 Human Health PRGs for Drinking Water

Chemical of Concern	Preliminary Remediation Goal (mg/l) for Drinking Water (1)
Arsenic	0.01
Antimony	0.005
Cadmium	0.005
Copper	2.0
Iron	0.2
Lead	0.01
Manganese	0.05
Nickel	0.02
Selenium	0.01
Chromium	0.05
Aluminum	0.2
Sulphate	250

(1) S.I. No. 106 of 2007, European Communities (Drinking Water) Regulations

Section 4
General Response Actions, Remedial Technologies, and Process Options

4.1 Introduction

In Section 2, the concerns at the Site related to human health, ecology, physical hazards, and industrial archaeology were identified and discussed. In Section 3, remedial action objectives were formulated to address these concerns. This section consists of identifying and evaluating remedial techniques that will address the concerns and satisfy the remedial action objectives. The identification of remedial techniques consists of three levels:

- Identifying general response actions. These are general categories or types of actions such as treatment or containment. General response actions are discussed in Section 4.2.

- Identifying remedial technologies associated with each general response action. For example, the general response action category of treatment will include several remedial technologies such as biological, physical, and chemical. Remedial technologies are discussed in Section 4.3.

- Identifying process options for each remedial technology. For example the remedial technology for chemical treatment of contaminated water will include many process options such as lime precipitation, ion exchange, etc. Process options are described in Section 4.3.

After each of the process options has been identified, they are evaluated based on technical feasibility, effectiveness, implementability, cost, and site compatibility (Section 4.4). In Sections 5 and 6, the retained process options are then combined into remedial action alternatives that address all the identified human health, ecological, and physical hazards concerns. Different individual process options may be applicable to various areas of the Site. In addition, the no action (with monitoring) option may also be appropriate for some areas. The evaluation process discussed above is shown in the middle boxes in Figure 1-1.

4.2 General Response Actions

The first step in developing remedial action alternatives consists of identifying general response actions (GRAs) that will satisfy the remedial action objectives formulated in Section 2. The selected GRAs for the Avoca Site are as follows:

- *No Action or No Action with Monitoring* – This GRA is included for purposes of establishing a baseline to compare with other GRAs. No preventative or corrective actions are taken. However, no action with monitoring of the contamination sources, contaminated media, or physical hazards may be a valid solution in some cases.

- *Institutional Controls* – This GRA controls contact of the potentially exposed population (human or biota) with the contaminated media or physical hazards through access controls, use restrictions, or protective covenants.
- *Containment* – This GRA restricts contact with contaminated media or physical hazards, transport via various pathways, or exposure via various exposure routes. For example, contact is prevented by isolating the source or hazard using various process options, such as covering with inert materials.
- *Collection/Removal* – This GRA involves physically collecting and removing the hazard, the contamination source, or contaminated media from the Site. Other GRAs may be necessary to achieve remedial action objectives for the removed media.
- *Relocation/Disposal/Discharge* – This GRA involves the transfer of contaminated media or treated/removed materials to an area reserved for long-term storage for solid media or discharge of treated water. This GRA for solid media may have the complementary effect of reducing or eliminating a number of physical hazards.
- *Treatment* – This GRA involves removal of the contaminant from the contaminated media or alteration of the contaminant, resulting in reduction of mobility, volume, or toxicity.

These GRAs may incorporate several different remedial technologies, each of which may incorporate several different process options. Technologies and process options for each GRA are developed in the following section of this report.

4.3 Identification of Remedial Technologies and Process Options

Each GRA may contain one or more different remedial technologies. Similarly, each technology may contain one or more different process options. Technologies and process options are identified based on their capability to address the physical hazards and one or more of the potential exposure elements described in Sections 2.2, 2.5, and 2.6. By addressing exposure elements and hazards, the remedial action objectives described in Section 3 are also addressed. The screening process in Section 4.4 evaluates how well the process options address the site-specific remedial action objectives.

In addition to the process options applicable to the protection of human health and the environment, it is necessary to define process options that apply to the many physical hazards associated with inactive mine sites. Such physical hazards may include mine openings (shafts, adits, and cave-ins), steep and unstable rock highwalls, rockfalls, pits, ponds and tailings impoundments, unstable spoil piles, and abandoned structures.

A number of the GRAs for physical hazards and their associated technologies and process options also apply to solid sources and media or water sources and media. For example, the Containment GRA containing the mass movement of rock, rock faces or spoils, or preventing access to mine openings also relates to limiting contaminant mobility. Removal/Relocation GRAs may relate to physically removing a hazard and relocating it to a more stable environment. The remedial technologies and process options that relate to the remediation of these physical hazards are identified and evaluated in Section 4.3.1.

The following sections provide descriptions of the various remedial technologies and process options evaluated for the Avoca Site. Section 4.3.1 describes technologies and process options that address the physical hazards, Section 4.3.2 describes technologies and process options that address solid sources and media, and Section 4.3.3 describes technologies and process options that address water sources and media.

4.3.1 Physical Hazards Technologies and Process Options

The GRAs for physical hazards are no action (with monitoring), institutional controls, containment, removal, and relocation/disposal.

4.3.1.1 No Action or No Action with Monitoring

No action means that no remedial activities will be conducted to reduce the risk of physical hazards at the sites associated with the mine openings, unstable rock highwalls, unstable spoil piles, abandoned structures, etc. While the no action (with monitoring) GRA serves as a baseline for comparison with other GRAs, in some cases it may be the appropriate solution where there is no immediate risk but one may develop in the future. No specific technology or process option is associated with this GRA. Usually, however, additional monitoring of the physical features is prescribed in the form of periodic inspections, monitoring (e.g., slope stability), and/or characterisation.

4.3.1.2 Institutional Controls

Institutional controls are a means to limit or prevent risks to human safety exerted through governing agencies in the form of planning restrictions, covenants, and/or physical restrictions on access to physical hazards. Fences or other barriers and signage may be installed to discourage, limit, or prevent access. Use restrictions may also be implemented through public education, whereby residents are educated concerning the physical hazards. Restrictive covenants may be used to restrict development. Such institutional controls address physical dangers by attempting to prevent the population (receptors) from entering potentially dangerous areas or conducting inappropriate activities.

4.3.1.3 Containment

Containment GRAs for physical hazards involve the use of two remedial technologies: stabilisation techniques or barriers. These technologies reduce safety concerns of unstable features or prevent access to unsafe features. Brief descriptions of the various process options for each technology follow:

Stabilisation

Stabilisation technologies eliminate or reduce the risk of physical hazards by reshaping or strengthening hazardous or unstable land forms and restoring structural integrity to historic structures. A number of process options follow:

- *Regrading* – Regrading is accomplished with use of conventional earth moving equipment. The option applies to spoil piles and spoil areas. Its purpose is to reshape the pile/area to a stable or more stable configuration. The word "stable" relates to both the structural or strength condition so materials are much less likely to fail and move, and the surficial condition that limits erosion and encourages vegetative stabilisation.

- *Backfilling* – Backfilling is also accomplished with conventional earthmoving equipment. Backfilling, or buttressing, applies to stabilising both earth embankment slopes and rock faces (highwalls). The addition of mass to the base of an embankment or rock face is a means of increasing the stability. Also, backfilling against highwalls to reduce or eliminate the exposed rock faces is a substantial method for highwall stabilisation. Additionally, backfilling is a simple and effective process for eliminating pit ponds.

- *Rock Bolts* – Rock bolts are a common option in mining and highway construction for stabilising weak rock faces or rock faces that are structurally prone to shift or slide. Rock bolts are installed in closely spaced patterns and directions to accomplish resistance against movements.

- *Tunnel Rehabilitation* – Tunnel rehabilitation is a common option, especially in mining and mine reclamation, for re-establishing a safe, stable environment to work underground. The rehabilitation typically begins at the face-up or portal of an existing adit or other entry to the underground. The work proceeds by clearing debris, scaling loose rock from the tunnel walls, and installing structural supports, rock bolts and heavy screen, and ventilation as need, so work can proceed in a stabilised environment.

- *Structure Repair/Rehabilitation* – As discussed in Section 2.1.6, historic engine houses, chimneys and other structures, such as the Tramway Arch and the Tigroney Ore Bins, are present at the Avoca mine sites. A number of these structures have been stabilised or repaired to some extent over the years in order to maintain their physical character and make them safer to observe or access. Some chimneys have been restored, and some structure walls have been strengthened with steel members and cables. The Avoca mine structures naturally deteriorate with time, so the process option of periodic inspection, structure rehabilitation, design, and construction is a necessary continuous task so long as public access is available and encouraged.

- *Scaling/Rock Breaking* – Scaling is the process of peeling or wedging loose rock from a rock face. Its purpose is to remove an imminent physical hazard. It is commonly utilised in underground mine workings in advance of working or passing through a section of a tunnel. It also has application on the surface; scaling or rock breaking can be utilised on rock faces/highwalls in advance of personnel and equipment working in the vicinity.

- *Shotcreting* – Shotcrete and gunite are two commonly used terms for substances applied via pressure hoses. Shotcrete is mortar or (usually) concrete conveyed through a hose and pneumatically projected at high velocity onto a surface. Shotcrete undergoes placement and compaction at the same time due to the force with which it is projected from the nozzle. It can be placed onto any type or shape of surface, including vertical or overhead areas. It can be used to temporarily stabilise unsafe and unstable spoil piles.

Barriers

Barrier technologies either prevent access to hazardous environments, such as underground mine workings, or stop or retard the motion of rock falls or land slides. Process options follow:

- *Reinforced Concrete Bulkheads* – Reinforced concrete bulkheads can be constructed in rehabilitated adits/tunnels where competent rock exists. The bulkheads would be designed to withstand the geostatic and hydrostatic forces that may develop after installation. The bulkheads become a barrier to further access to the mine workings. They can also be constructed with piping and valving that provide for controlled or uncontrolled discharge of the mine water that may accumulate behind the bulkheads.

- *Shaft Sealing/Shaft Plugging* – Mine shafts and other mine openings that occur on the surface, such as open stopes, can be made safe by plugging and/or sealing. Plugging of well defined openings may be accomplished by the methodic injection, placement or dumping of select materials in the opening. Sealing may be accomplished by first preparing the surface around the opening, typically by excavating to a competent, stable work platform, then constructing/installing a suitable fabricated reinforced concrete or steel cap or plug designed to resist future subsidence in and around the shaft/opening.

- *Rock Screens* – Heavy duty rock screens/cables are typically applied in conjunction with rock bolts. Rock bolts in this case are fasteners for the rock screen as well as stabilisers for the rock mass. The rock screens function as a barrier against rock segments that weaken or slide and break away from the rock faces.

- *Rock Trap Ditches and Bunds* – The size and shape of earthen structures for stopping the motion of rock falls can be determined through measurement and inspection of highwall rock face geology, dimensions, fractures and breaking planes and observations of the debris field below the highwall. The earthen structures consist of a bench, including a ditch constructed adjacent to a highwall or debris slope and an embankment elevated above and on the far side of the ditch. The outside toe of the embankment would be the boundary of a zone protected from falling rock.

4.3.1.4 Removal

The removal GRA for physical hazards consists of physically removing materials from their present location using stabilising technologies. Removal is an effective response action that eliminates the physical hazard. It is used in conjunction with relocation and disposal; i.e., the removed material must be properly relocated or disposed to achieve the remedial action objectives. Stabilisation technologies eliminate or reduce the risk of physical hazards by removing unstable land forms and removing dangerous structures (and if warranted restoring them elsewhere onsite). A number of process options follow:

- *Excavation* – Source material or contaminated media are excavated using conventional heavy earth moving equipment, such as scrapers, articulated dump trucks (ADTs), dozers, loaders, backhoes (JCBs), and excavators. The earth work option is viable for ground (e.g., spoils) excavation.

- *Regrading* – Regrading is accomplished with use of conventional earth moving equipment. The option applies to spoil piles and spoil areas. Its purpose is to reshape the pile/area to a stable or more stable configuration. The word "stable" relates to both the structural or strength condition so materials are much less likely to fail and move, and the surficial condition that limits erosion and encourages vegetative stabilisation. Regrading is a process option for both containment and removal response actions.

- *Blasting* – Blasting is an effective process option for reshaping land forms when use of heavy equipment is limited. A particular application for blasting would be to lay back or degrade sheer rock highwalls remaining from pit mining. Rock faces may be stabilised by reshaping them to reduced slopes.

- *Scaling/Rock Breaking* – Scaling is the process of peeling or wedging loose rock from a rock face. Its purpose is to remove an imminent physical hazard. It is commonly utilised in underground mine workings in advance of working or passing through a section of a tunnel. It also has application on the surface; scaling can be utilised on rock faces/highwalls in advance of personnel and equipment working in the vicinity. Scaling/rock breaking is a process option for both containment and removal response actions.

- *Structure Repair/Rehabilitation* – Historic engine houses, chimneys and other structures, such as the Tramway Arch and the Tigroney Ore Bins, are present at the Avoca mine sites. A number of these structures have been stabilised or repaired to some extent over the years in order to maintain their physical character and make them safer to observe or access. Some chimneys have been restored, and some structure walls have been strengthened with steel members and cables. The Avoca mine structures naturally deteriorate with time, so the process option of periodic inspection, structure rehabilitation, design, and construction is a necessary continuous task so long as public access is available and encouraged. Removal of or removal with relocation is a possible response action for unsafe structures.

4.3.1.5 Relocation/Disposal

Relocation/disposal GRAs consist of either relocation and disposal onsite (mine site) or relocation and offsite disposal in a variety of facilities. Stabilisation technologies eliminate or reduce the risk of physical hazards by relocating unstable land forms with proper disposal. A number of process options follow:

- *Backfilling* – This involves relocation and disposal in open pits, ponds, or voids onsite and has the additional advantage of stabilising features within the backfilled voids. It is accomplished with conventional earthmoving equipment (see section on stabilisation). Onsite backfilling can also occur underground in order to stabilise underground workings.

- *Disposal in Prepared Cells (Onsite)* – New onsite cells can be constructed for disposal of excavated (possibly treated) source materials, contaminated media, or generated solid treatment waste. Cells are engineered repositories designed to isolate the materials from the environment; e.g., by construction of a liner and cap.

- *Disposal in Existing Facility (Offsite)* – Excavated (possibly treated) source materials or contaminated media could be disposed of in an existing offsite facility. The existing facility would have to have been properly engineered for acceptance of the untreated, or treated, source material.

- *Disposal in New Facility (Offsite)* – A new offsite disposal facility or facilities could be constructed for disposal of excavated (possibly treated) source materials or contaminated media. The facility would have to be properly engineered for acceptance of untreated, or treated, source materials.

- *Relocation of Historic Structures* – Unstable structures that cannot be remediated at their current locations could be relocated to a more suitable location (e.g., ore bins).

4.3.2 Solid Sources and Media Technologies and Process Options

This section discusses various technologies and process options for solid contamination sources and media that address human health and ecological concerns. Some of the technologies and process options are the same as those used to address physical hazards.

GRAs for solid contamination sources (e.g., spoil piles, tailings) and associated contaminated solid media (e.g., soils, sediments) include no action (with monitoring), institutional controls, containment, removal, relocation/disposal, and treatment.

4.3.2.1 No Action or No Action with Monitoring

No action means that no remedial activities will be conducted to reduce or clean-up the contamination on the sites associated with the solid sources and contaminated media. While the no action (with monitoring) GRA serves as a baseline for comparison with other GRAs, in some cases it may be the appropriate solution where there is no immediate risk but one may develop in the future. No specific technology or process option is associated with this GRA. However, additional monitoring of the source and contaminated media is prescribed in the form of periodic inspections, monitoring, and/or characterisation.

4.3.2.2 Institutional Controls

Institutional controls are a means to limit or prevent risks to human and/or ecological health exerted through governing agencies in the form of planning restrictions, covenants, and/or physical restrictions on access to physical and/or health hazards, and use of the contamination source and contaminated media. Fences or other barriers and signage may be installed to discourage, limit, or prevent access. Use restrictions may also be implemented through public education, whereby residents are educated as to physical hazards and the hazards of using or contacting the contaminated media. Restrictive covenants may be used to restrict development. Such institutional controls address human health exposure by attempting to prevent the population (receptors) from entering potentially hazardous areas or contacting the contaminated media.

4.3.2.3 Containment

Containment GRAs for solid sources and contaminated media involve the use of a barrier to limit contaminant mobility (i.e., eliminate transport pathways). Certain barriers may also limit exposure by removing the exposure route (direct contact, ingestion, etc.). Technology types include regrading, cap/cover, revegetation, groundwater control to prevent leaching of solid sources, and surface water management to prevent leaching and erosion of solid sources. Brief descriptions of the various process options follow:

Regrading Technologies

- *Earthwork* – Regrading is accomplished with the use of conventional earthwork equipment and methods. Regrading, as opposed to removal, shapes the in-place solid materials in preparation for capping and covering, and for reestablishment of surface drainage, so there will be positive drainage from the spoil piles.

Cap/Cover Technologies

- *Soil Cover Only* – This technology includes placement of imported clean soil and top soil cover over solid sources or contaminated media to provide a direct contact barrier and growth medium for indigenous vegetation. Addition of fertilizers, mulch, and other soil amendments may be applied to enhance plant growth. The viability of this option also depends on how much reduction in infiltration can be accomplished via the vegetated surface.

- *Clay Cap/Soil Cover* – This technology includes the placement and compaction of clayey soil over solid sources or contaminated media to prevent erosion, reduce infiltration and leaching, and provide a direct contact barrier. A plant growth medium (top soil) is placed over the clay cap. Addition of fertilizers, mulch, and other soil amendments may be applied to enhance growth of native indigenous vegetation for additional effectiveness.

- *Synthetic Cap/Soil Cover* – A synthetic, geotextile, or asphaltic cover, such as high density polyethylene (HDPE) is placed over the solid contamination source or contaminated media to prevent erosion, reduce infiltration and leaching, and provide a direct contact barrier. The soil cover is placed over the synthetic cap, as described in Clay Cap/Soil Cover.

- *Rock/Grout Cap* – This process includes the placement of crushed rock and/or cementitious grout (e.g., shotcrete) over the surface of the solid source or contaminated media to prevent erosion, reduce infiltration and leaching, and provide a direct contact barrier. No soil cover is added.

- *Pozzolans/Neutralising Material/Soil Cover* – A neutralising agent (e.g., lime or limestone) is incorporated with the surface of the contamination source (tailings, spoils, and waste rock) to prevent generation of acid drainage and leaching. Pozzolans can be added to enhance the physical characteristics of the cover. Pozzolans are fine grained, vitreous, siliceous, or alumina materials used to enhance the cementitious properties of lime containing media. A soil cover may be placed over the prepared surface to promote revegetation and long term stability. This process option is also discussed under the treatment GRA.

- *Microbiological Inhibitors/Soil Cover* – Detergents/surfactants are incorporated into the surface of the contamination source to inhibit growth of acid-producing bacteria and, therefore, reduce generation of acid drainage and acid leachate. A soil cover may be placed over the prepared surface to promote revegetation and long term stability.

Revegetation Technologies

- *Plant Indigenous Vegetation* – Planting of locally available indigenous vegetation on solid sources and media to resist erosion, reduce infiltration and leaching, and provide a direct contact barrier. Addition of fertilizers, mulch, and other amendments may be necessary to enhance plant growth on spoils and tailings sources. Use of indigenous plants is consistent with the local character and vegetated landscape of the area.

Groundwater Control Technologies to Limit or Prevent Leaching Of Solid Sources

- *Soil Bentonite Walls and Grout Curtains* – Soil bentonite walls or grout curtains are installed to control/prevent interaction of subsurface materials, or other contaminated solid media (soil), with groundwater. Soil bentonite walls are installed vertically into the subsurface are used to intercept and prevent migration of contaminated groundwater. Typically, wells located upgradient of the soil bentonite wall are used to extract the groundwater.

- *Drainage Galleries* – Drainage galleries are trenches filled with granular materials. They are installed along predetermined lines to control the phreatic groundwater surface in a way that groundwater flows into the galleries and is removed by gravity or pumping. Their purpose is to prevent either groundwater from flowing into contaminated material or contaminated seepage from interacting with groundwater or surface water.

- *Drainage Ditches* – In cases of very shallow groundwater, drainage ditches may be constructed deep enough to intercept some groundwater. However, the technology is more likely to be applicable to surface water management (see below).

Surface Water Management Technologies to Limit or Prevent Leaching and Erosion of Solid Sources

- *Improve/Stabilise Drainage Ditches* – Improvements to existing drainage ditches are accomplished by cleaning, reshaping (improving slopes and gradients, widening and deepening), and stabilising ditch surfaces with appropriate erosion protection. In some cases, the improvement may require relocation of the ditches to accommodate the regrading or removal of the solid media.

- *New Perimeter/Diversion Ditches* – Construction of new perimeter or diversion ditches, lined or unlined, may be required because none currently exist, or because of regrading or removal. New ditches/channels may be constructed for either diverting run-on away from the containment facility or collecting and directing run-off from the containment facility.

- *Culverts and Bridges* – Conventional construction, materials and equipment can be used to install culverts and bridges at road/embankment crossings in order to prevent impounding or overtopping of water. For all ditch/channel, culvert and bridge work, it is necessary to place rock or riprap along stream channels and structures in contact with source materials or contaminated media, in order to produce a geomorphically stable channel or embankment and prevent water erosion directly into the channels. In less critical reaches, selected planting of indigenous vegetation within drainages impacted by erosion of soil, source materials, or contaminated media is appropriate to reduce surface water velocity, trap sediments, and retain soil water in the root zone.

- *Detention/Sedimentation Basins* – Detention basins are constructed in critical drainages impacted by erosion of solid source materials or contaminated media to reduce sediment loadings to nearby surface water drainages and streams.

- *Permanent Retaining Structures* – Fence check dams, rock gabions, or other structural devices are installed in critical drainages impacted by erosion of solid source materials or contaminated media to trap sediment, reduce erosion, and stabilise slopes.

- *Temporary Retaining Structures* – Straw bale check dams can be installed in critical drainages impacted by erosion of solid source materials or contaminated media to reduce erosion and trap sediments. Their purpose is similar to permanent retaining structures but they require routine inspection and occasional replacement.

- *Surface Armouring/Sealing* – Crushed rock or riprap can be placed on the surface of the source or contaminated media to protect against wind and water erosion. This option is similar to a rock cap, as described above. Alternatively, application of polymeric/chemical sealers can be made to the surface of the solid source material or contaminated media to reduce wind erosion and transport.

- *Natural or Artificial Wind Breaks* – Wind breaks can be accomplished by planting of adapted trees or construction of artificial wind barriers to reduce wind transport of solid source materials or contaminated solid media.

4.3.2.4 Removal

The removal GRA for solid sources and media consists of physically removing these materials from their present location using various excavation technologies. Removal is an effective response action that eliminates transport pathways and exposure routes. It is used in conjunction with relocation and disposal; i.e., the removed material must be properly relocated or disposed to achieve the remedial action objectives.

- *Earthwork* – Source material or contaminated media is excavated using conventional heavy earth moving equipment, such as scrapers, articulated dump trucks (ADTs), dozers, loaders, backhoes (JCBs), and excavators. The earth work option is viable for both ground (e.g., spoils) excavation and river bank excavation.

- *Blasting* – Source material or contaminated media may include rock surfaces or embedments, that cannot be excavated by conventional means, but can be conditioned for regrading or removal by blasting.

- *Dredging* – The process of dredging – creation of a sediment-water mixture using a water jet followed by removal of the mixture using a pump – is a conventional practice for the removal of submerged sediments from river beds or banks.

4.3.2.5 Relocation/Disposal

Relocation/disposal GRAs consist of either relocation and disposal onsite (mine site) or relocation and offsite disposal of solid sources and media in a variety of facilities.

Mine Site (Onsite)

- *Disposal as Backfill in Mine Workings* – Excavated (possibly treated) solid source materials or contaminated media can be placed/backfilled into underground mine workings or open pits.

- *Disposal in Prepared Cells* – New onsite cells can be constructed for disposal of excavated (possibly treated) solid source materials, contaminated media, or generated solid treatment waste. Cells are engineered repositories designed to isolate the materials from the environment; e.g., by construction of a liner and cap.

Offsite

- *Disposal in Existing Facility* – Excavated (possibly treated) solid source materials or contaminated media could be disposed of in an existing offsite facility. The existing facility would have to have been properly engineered for acceptance of the untreated, or treated, source material.

- *Disposal in New Facility* – A new offsite disposal facility or facilities could be constructed for disposal of excavated (possibly treated) solid source materials or contaminated media. The facility would have to be properly engineered for acceptance of untreated, or treated, source materials.

4.3.2.6 Treatment

The treatment GRA for solid sources and contaminated media involves several technologies designed to remove, stabilise, or eliminate the metals of concern to reduce exposure. Technology types include reprocessing, *ex situ* or *in situ* stabilisation or neutralisation, thermal treatment, and bioremediation.

Reprocessing of Solid Source Materials

- *Pyrometallurgical* – Smelting process for solid source materials that utilises high heat for metals recovery and contamination/toxicity reduction.

- *Hydrometallurgical/In Situ Leaching* – *In situ* leaching of solid source materials for metals recovery and contamination reduction.

- *Hydrometallurgical/Ex Situ Leaching* – *Ex situ* leaching of solid source materials for metals recovery and contamination reduction.

- *Mineral Processing/Flotation* – Screening, flotation, and concentrate dewatering for solid source materials for minerals recovery and contamination reduction.

Ex Situ Stabilisation or Neutralisation

- *Pozzolans/Neutralising Material* – *Ex situ* (after removal) mixing of the solid contamination source with a neutralising agent (e.g., lime or limestone) to prevent generation of acid drainage and acid leachate. Pozzolans can be added to enhance the physical characteristics of the treated material.

- *Sulphides/Phosphates* – *Ex situ* mixing of the solid contamination source with chemical agents containing reactive sulphides and/or phosphates to prevent generation of acid drainage and acid leachate. Soluble metals may react with the sulphides/phosphates to form insoluble phases that resist leaching.

- *Proprietary Methods* – *Ex situ* mixing of the solid contamination source with proprietary chemical agents (e.g., polysulphides, soluble silicates, or permanganate) to prevent generation of acid drainage and acid leachate.

In Situ Stabilisation or Neutralisation

- *Pozzolans/Neutralising Material* – *In situ* mixing of the solid contamination source with a neutralising agent (e.g., lime or limestone) to prevent generation of acid drainage and acid leachate. Pozzolans can be added to enhance the physical characteristics of the treated material. The neutralising agent is either injected into the subsurface materials or physically mixed with them in place.

- *Sulphides/Phosphates* – *In situ* mixing of the solid contamination source with chemical agents containing sulphides and/or phosphates to prevent generation of acid drainage and acid leachate. Soluble metals may chemically bond with the sulphides/phosphates to form insoluble phases that resist leaching. The chemical agent is either injected into the subsurface materials or physically mixed with them in place.

- *Proprietary Methods* – *In situ* mixing of the solid contamination source with proprietary chemical agents (e.g., polysulphide, soluble silicates, or permanganate) to prevent generation of acid drainage and acid leachate. The chemical agent is either injected into the subsurface materials or physically mixed with them in place. Permanganate is surface applied in a liquid form.

- *Grout Injection* – Injection of grout into the solid contamination source to form a solidified material that resists leaching.

Thermal

- *In Situ Vitrification* – Vitrification (melting) of solid source materials into a glass matrix that resists leaching.

Bioremediation

- *Microbiological Inhibitors* – Injection or mixing of detergents/surfactants into the source materials to inhibit growth of acid-producing bacteria and, therefore, reduce generation of acid drainage and acid leachate.

4.3.3 Water Sources and Media Technologies and Process Options

This section discusses various technologies and process options for water contamination sources and media that address human health and ecological concerns. Some of the technologies and process options are the same as those used to address physical hazards and solid media.

GRAs for water contamination sources (acid mine water and acid rock drainage) and associated contaminated water media, such as surface water (Avoca River and tributaries) and groundwater include no action (with monitoring), institutional controls, containment, treatment, collection, and disposal/discharge of treated water. In addition waste material generated from the treatment GRA for water sources will need to be considered.

4.3.3.1 No Action or No Action with Monitoring

No action means that no remedial activities would be conducted to reduce or clean-up the contamination on the Site associated with the water sources and media. While the no action (with monitoring) GRA serves as a baseline for comparison with other GRAs, in some cases it may be the appropriate solution where there is no immediate risk but one may develop in the future. No specific technology or process option is required for this GRA. Usually, however, additional monitoring of the source or contaminated media is prescribed.

4.3.3.2 Institutional Controls

Institutional controls are a means to limit or prevent risks to human and/or ecological health exerted through governing agencies in the form of legal documents, covenants, and/or physical restrictions on access to and use of the contamination source (acid mine water) and contaminated media (surface water, groundwater). Fences or other barriers and signage may be installed to discourage, limit, or prevent access. Use restrictions may also be implemented through public education, whereby residents are educated as to the hazards of using the contaminated media. Laws may be passed prohibiting drilling of new water wells into contaminated groundwater or the use of existing contaminated water wells for drinking water purposes. In addition, alternate drinking water supplies (e.g., group water schemes or supply of tanked water) are a type of institutional control. Planning controls may also be used to restrict development. Such institutional controls address exposure by attempting to prevent the population (receptors) from contacting or ingesting the contaminated media.

4.3.3.3 Containment

Containment GRAs for water sources and contaminated media involve the use of a barrier to limit contaminant mobility (i.e., eliminate the transport pathway). Certain barriers may also limit exposure by removing the exposure route (direct contact, ingestion, etc.). Technology types include source control and discharge control. Various process options are discussed in the following sections:

Source Control

- *Fracture Zone Seals* – Grouting or otherwise sealing fracture zones to reduce water flows and contact with sulphide mineralisation in the underground mine workings to prevent generation of acid mine water (the contamination source).

- *Oxygen Barriers* – Installation of physical barriers to prevent entrance of oxygen into adits or shafts to prevent generation of contaminated water at the source. Potentially used in partially flooded mine workings.

- *Flooding Mine Workings* – Flooding of underground workings by placement of seals or plugs at strategic locations. The option would reduce acid mine water formation by reducing the air supply and, therefore, the oxygen required to generate acid mine water.

- *Backfilling Mine Workings* – Backfilling of underground mine workings with waste material, inert material, and/or cement to reduce subsidence risk, also reduces the potential of surface water in-flows in the mined area and reaction with sulphide minerals.

- *Shaft Plugging* – This process is similar to constructing bulkheads or backfilling in adits; it fills and/or seals shaft openings to reduce water inflow and oxygen contact to prevent generation of acid mine water.

- *Water Diversion/Infiltration Control* – Diversion of surface water to reduce inflow to the underground workings to prevent generation of contaminated water at the source.

Discharge Control

- *Watertight Bulkheads* – Plugging mine openings to prevent/reduce discharge of the source water (acid mine water). The option may also provide source control via flooding of the mine workings (described above).

- *Control Bulkheads* – Construction of underground dams within mine workings that act to regulate discharge of acid mine water by temporary containment. The option provides for the steady, controlled discharge of acid mine water and serves to prevent catastrophic discharges or surge events.

4.3.3.4 Collection/Removal

The collection/removal GRA for water sources and media consists of physically collecting and removing the contaminated surface water and/or groundwater from their present locations using extraction and storage technology options. Various process options follow:

Groundwater Extraction

- *Soil Bentonite Walls*– Soil bentonite walls are installed vertically into the subsurface and are used to intercept and subsequently capture contaminated groundwater using extraction wells installed upgradient of the wall.

- *Drainage Galleries* – Drainage galleries are trenches filled with granular materials. They are installed along predetermined lines to control the phreatic groundwater surface in a way that groundwater flows into the galleries and is removed by gravity or pumping. Their purpose is to prevent either groundwater from flowing into contaminated material or contaminated seepage from interacting with groundwater or surface water.

- *Well Field* – This process utilises either existing groundwater wells currently used for domestic use or new well fields installed in locations that would intercept the contaminated groundwater. Extraction wells may be used in conjunction with soil bentonite walls for containment as well as collection and removal.

Storage

- *Controlled Flow* – The process involves the temporary storage of treated water, followed by controlled release to surface water to reduce impacts of high volumes of treated water. Storage is also used to hold water during upsets, maintenance, and monitoring for active or passive treatment systems. Storage for monitoring is typically accomplished using storage tanks. Storage during upsets may also be achieved by valves in the adit bulkheads that can be closed resulting in storage of water underground.

Channelise Flow/Surface Water/Mine Water

- *Inlet/Outlet Structures, Conveyances* – The process involves the installation of structures at the points of discharge and reception (e.g., headwalls, portals, drop inlets) for mine water and surface water discharges, and the installation of pipes or channels in between.

4.3.3.5 Treatment

The treatment GRA for water media involves several technologies designed to remove metals from the water or reduce acid generation. Technology types include biological, physicochemical, and physical. Various process options associated with these technologies are discussed in the following sections:

Biological

- *Active* – An active system (e.g., an upflow anaerobic solid treatment waste blanket) utilises bacterial action (sulfate reducing bacteria) to precipitate or adsorb metals contained in the contamination water source or contaminated media. Pumping of water and operation/maintenance is required. Biological solid treatment waste requires disposal.

- *Passive* – Passive systems utilise organic substrate (e.g., processed manure, wood chips, and straw) and bacterial activity (sulfate reducing bacteria) to adsorb and precipitate metals as sulphides. Typically requires no pumping (gravity flow cells) and little operation/maintenance. However, depending upon the location, pumping of water to the treatment cells may be necessary. May require large areas, pretreatment for iron and aluminum and potential periodic disposal of large quantities of organic substrate.

- *Microbiological/Inhibitors* – Inhibit growth of acid producing bacteria by recycling acid drainage back to the source (acid mine water in underground workings) or by addition of bacterial inhibitors such as anionic detergents to the water. It is difficult to completely control acid production with this process, particularly for the long term.

Physicochemical

- *Metals Recovery* – Chemical or physical processes to recover metals for economic benefit. Such processes typically require high concentrations of metals in solution. They may be used in combination with other separation techniques.

- I*on Exchange* – Utilises special resin to selectively remove metal ions from the water source or contaminated media. Chemical regeneration of resin to remove metals creates a metal brine that requires disposal.

- *Reverse Osmosis* – High pressure filtration through a membrane to separate metals and other dissolved ions. The process results in significant volume of metal-laden brine (5 percent to 10 percent of total water treated) that requires disposal.

- *Membrane Separation* – Similar to reverse osmosis. The process uses pressure differential across a membrane to remove metals and other dissolved ions.

- *Electrodialysis* – Electrochemical separation of metals from source or water media. The process results in brine or solid treatment waste requiring disposal.

- *Lime Precipitation* – Active treatment system that adds lime to raise pH values to between 9 and 10 and precipitate metals. The process requires pumping, settling tanks or filter presses and operation/maintenance. It creates a solid treatment waste that requires disposal. Water pH may require adjustment before discharge.

- *Caustic Precipitation* – An active treatment system that adds caustic (sodium hydroxide) to raise pH and precipitate metals. This process creates a solid treatment waste that requires disposal, similar to lime precipitation. It requires pumping, settling tanks or filter presses and operation/maintenance.

- *Sulphide Precipitation* – An active system that precipitates metals by addition of sulphides which require disposal. The process is similar to caustic or lime precipitation, except sulphide is used. It may result in lower concentrations of metals in the water than using lime or caustic. It also typically produces a much lower volume of solid treatment waste. While this option is most applicable to treatment of collected surface water and extracted groundwater, it has also been proposed as an *in situ* method for groundwater whereby the reactive sulphides are injected via wells directly into the groundwater.

- *Limestone Drains* – Addition of limestone to add alkalinity to the water source or contaminated media, resulting in precipitation of metals. The process requires upstream uncontaminated water or anoxic conditions so that limestone can dissolve without being coated with iron precipitate. This is a passive system with little operation/maintenance.

- *Iron Oxidation/Precipitation* – Utilises the oxidation of iron to co-precipitate other metals or to serve as an adsorption substrate. The process creates an iron solid treatment waste that requires collection and disposal. This is, in part, the process that is naturally occurring in the streams impacted by acid mine drainage. While this option is most applicable to treatment of collected water, it has also been applied as an *in situ* method for groundwater, in which case a reactive permeable "barrier" filled with zero valent iron filings or other media is typically constructed underground perpendicular to groundwater flow. The groundwater flows through the wall and reacts with the media in the "barrier" removing the metals.

- *Coagulation/Flotation* – An alternative to conventional sedimentation/clarification for removing solids after neutralisation. Solids are removed by entraining and floating precipitates in tiny air bubbles. The process requires the addition of polyelectrolytes and other substances.

Physical

- *Distillation/Evaporation* – Uses heat to boil and then cool and condense the resulting distilled water. This process leaves a metal solid treatment waste that requires disposal. Simple evaporation basins may also be used.

- *Freezing* – Freezing the contaminated water results in the formation of mineral-free ice, while the dissolved metals remain in solution and are concentrated in waste brines.

All of the above treatment options are *ex situ* treatment processes, except for *in situ* treatment by injecting sulphide into the groundwater or using permeable reactive "barriers." As a result, most *ex situ* treatment methods must typically be combined with a collection or removal option. On occasion, depending upon the location, passive treatment may use gravity flow and may not need a collection technique.

4.3.3.6 Disposal/Discharge – Treated Water

Disposal/discharge GRAs consist of either onsite (mine site) or offsite disposal of treated or contaminated water by a variety of process options.

- *Discharge to Surface Water* – This process is simply the discharge of treated water into existing streams and drainages at the Site.
- *Reinjection to Groundwater* – This process requires the injection of treated water into subsurface aquifers via shallow wells, infiltration ponds, or infiltration galleries.
- *Deep Well Injection* – This process requires the disposal of contaminated or treated water into deep wells. The availability of suitable deep aquifers is necessary.

4.3.3.7 Disposal – Solid Treatment Waste

Both active and passive treatment processes generate solid treatment waste, possibly in large volumes, which must be disposed of properly. Options include:

- *Backfill at the Mine Site into Open Pits* – This process is applicable depending on the chemical and physical characteristics of the waste and access to disposal sites (open pits).
- *Backfill to Underground Mine Workings* – This process is applicable depending on the physical conditions of the underground mine workings, the ability to isolate or zone the underground workings for the waste, and the chemical characteristics of the waste.
- *Solid Treatment Waste Disposal Facility* – Disposal of solid treatment waste can be accomplished at the mine site or offsite in a properly designed, constructed, and operated disposal facility.

4.4 Screening of Remedial Technologies and Process Options

4.4.1 Screening Criteria

Section 4.3 identified the initial sets of remedial technologies and process options for physical hazards, solid sources and contaminated media, and water sources and contaminated media for the Avoca Project. These technologies and process options are evaluated (screened) in this section to select appropriate technologies and process options and make them more specific to the Avoca Project.

The screening process uses the following criteria:

Technical Feasibility

Technologies and/or process options are evaluated according to whether they can:

- Effectively address the health and safety concerns at the Site (physical hazards)
- Effectively treat the identified contaminants or contaminated media of concern (solid and water sources and contaminated media).

Technologies may be eliminated based on their:

- Clear limited potential use or ability to be implemented at the Site (e.g., rock bolts)
- Lack of proven track record elsewhere (e.g., *in situ* vitrification)
- Inherent unsuitability for the Site (e.g., freezing, blasting)

The evaluation results in one of the following two conclusions:

Yes – The technology is technically feasible

No – The technology is not technically feasible

If the technology or process option is not technically feasible, the effectiveness, implementability, relative cost, and site compatibility of the technology are not evaluated. If the technology or process option is feasible, the following evaluations are performed:

- *Effectiveness* – Process options are evaluated according to (1) their potential effectiveness in handling the estimated areas or volumes of media and meeting the remedial action objectives and preliminary remediation goals including the physical hazard remedial action objectives discussed in Section 3, (2) the potential impacts to human health and the environment during construction and implementation, and (3) how proven and reliable the process is with respect to the contaminants and conditions at the sites.
- *Implementability* – The technology and process options are evaluated according to whether the physical facilities or physical actions (e.g., excavation) associated with the process options can be constructed or implemented at the site. Process options are also evaluated according to administrative or institutional implementability, including (1) the ability to obtain necessary permits, (2) the availability of necessary treatment, storage, and disposal services, and (3) the availability of necessary materials, equipment, and skilled workers to implement the process.
- *Cost* – Process options are evaluated according to relative capital cost and operation and maintenance costs.

Process options within the same technology are ranked according to their relative effectiveness, implementability, and cost as low, moderate, or high. For screening purposes, effectiveness carries the highest weight, followed by implementability, then cost. The analyses of technical feasibility, effectiveness, implementability, and cost are based on previous experience and professional judgment.

In addition to the evaluation criteria of effectiveness, implementability, and cost, another important evaluation criterion is Site Compatibility. This criterion concerns how compatible the process options will be with the Site heritage and cultural features, overall landscape, existing ecology, future management of the Site, public access, recreational opportunities, and future site uses.

Section 4.4.2 provides the screening evaluation for physical hazards; Section 4.4.3 provides the screening evaluation for solid sources and contaminated media; Section 4.4.4 provides the screening evaluation for water sources and contaminated media; and Section 4.4.5 discusses various Site features and process options in relation to overall Site compatibility.

Techniques with low effectiveness are typically not retained, especially when costs are moderate to high. Where costs are relatively low, such techniques may be retained for use in the development of alternatives.

4.4.2 Physical Hazards

Figure 4-1 presents the remedial technologies and their associated process options for remediation of the physical hazards known to exist at the Avoca mine sites. All of the remedial technologies and process options for physical hazards are technically feasible except for blasting. The figure indicates the hazards addressed by each process option (see "X" on the figure). The screening evaluations are also provided on the figure and include effectiveness, implementability, and relative cost. The process options and technologies that are shaded in Figure 4-1 are retained for potential use in alternative development.

4.4.2.1 No Action or No Action with Monitoring

The no action (with monitoring) general response action is retained for physical hazards for comparison to other alternatives. No action is high in implementability and low cost (monitoring only). However, it is not effective in achieving any of the remedial action objectives or remediation goals. Unsafe conditions and physical hazards would continue to be present.

4.4.2.2 Institutional Controls

Access controls such as fencing and barriers are considered low to moderate in effectiveness, moderate in implementability, and low in cost. Restrictive covenants are considered low in effectiveness, moderate in implementability, and low in cost. Given that the costs are relatively low, these institutional controls are retained for use in alternative development. It should be noted that some institutional controls are currently applied with limited effectiveness.

4.4.2.3 Containment

The containment GRA has two associated remedial technologies: stabilisation and barriers. Each of the process options are shown on Figure 4-1 and discussed below.

Stabilisation Technologies

- *Regrading* – Depending on the in-place materials and surrounding terrain, regrading is a moderate-to-highly effective process for establishing desirable surface water drainage and infiltration control and for stabilising slopes. Regrading is highly implementable and relatively low in cost. It is retained for use in alternative development.

- *Backfilling* – Backfilling in pits is a highly effective process for stabilising highwalls (rock faces) by partially or completely burying them. In the same way, backfilling can eliminate the hazards of pits and pit ponds. Backfilling in underground workings is not typically effective or implementable as a containment or stabilisation action and has not been retained. (It is retained as a disposal option; see below.)

  A coincidental and desirable benefit of backfilling to human health and the environment is that it is a very effective process for localising and isolating widespread solid contaminated media. Backfilling with clean soils or spoils is also a moderately to highly effective process for remediating the surface effects of subsidence.

  Backfilling is highly implementable because it is accomplished with conventional earth moving equipment. Backfilling using nearby material resources is moderate to high in relative cost. Backfilling in pits has been retained for use in alternative development.

- *Rock Bolts* – Rock bolts are considered to be low to moderately effective and have low implementability for the major highwalls at Avoca (Cronebane and East Avoca). The forces of nature (weathering, mass wasting) render rock bolting a temporary solution to highwall stabilisation. The rock faces are very difficult to access, without first backfilling the pits. There is increased risk to workers working close, and with impacting methods, to the rock faces. Rock bolting is moderate in relative cost. Due primarily to implementability concerns, rock bolting is not retained for use in development of remedial action alternatives.

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Physical Hazards Addressed								Screening Evaluation			
			Spoil Heaps	Rock Faces	Rock Falls	Adits/Tunnels	Shafts	Pits/Pit Ponds	Subsidence	Structures	Technical Feasibility	Effectiveness	Implementability	Cost
No Action	None	Not Applicable									NA	NE	NE	NE
	Monitoring	Inspections/ Measurements									YES	L	H	L
Institutional Controls	Access Controls	Fencing/Barriers	X	X	X	X	X	X		X	YES	L - M	M	L
	Use Restrictions	Restrictive Covenants	X							X	YES	L	M	L
Containment	Stabilisation	Regrading	X						X		YES	M - H	H	L
		Backfilling		X	X			X	X		YES	H	H	M - H
		Rock Bolts		X	X						YES	L - M	L	M
		Tunnel Rehabilitation				X					YES	M	L - M	H
		Structure Rehabilitation								X	YES	M	H	L - M
		Scaling/Rock Breaking		X	X						YES	L	H	L - M
		Shotcreting	X	X							YES	L	M - H	M
	Barriers	Reinforced Concrete Bulkheads				X			X		YES	H	M	M - H
		Shaft Sealing/Plugging					X		X		YES	H	M - H	M - H
		Rock Screens		X	X						YES	L - M	L - M	M
		Rock Traps			X						YES	M - H	H	L - M

Legend

☐ Technology or Process Option Eliminated [This does not preclude their limited use in association with another process options]

🟧 Technology or Process Option Retained

Key for Screening Evaluation

L = Low, M = Moderate, H = High, NA = Not Applicable

NE = Not Evaluated

Figure 4-1 Screening of Technologies and Process Options - Physical Hazards (Page 1 of 2)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Physical Hazards Addressed								Screening Evaluation			
			Spoil Heaps	Rock Faces	Rock Falls	Adits/Tunnels	Shafts	Pits/Pit Ponds	Subsidence	Structures	Technical Feasibility	Effectiveness	Implementability	Cost
Removal	Stabilisation	Excavation/Regrading	X						X		YES	H	H	M
		Blasting		X	X						NO	NE	NE	NE
		Scaling/Rock Breaking		X	X						YES	L	H	L - M
		Structure Rehabilitation								X	YES	M	H	L - M
Relocation/Disposal	Stabilisation	Backfill On-Site in Pits	X	X	X			X			YES	H	H	M
		Backfill On-Site in Underground Workings	X			X	X		X		YES	L - M	L - M	H
		Disposal On-Site in Prepared Cells	X								YES	H	H	H
		Off-Site Disposal	X								YES	H	L	H

Legend

☐ Technology or Process Option Eliminated [This does not preclude their limited use in association with another process option

🟧 Technology or Process Option Retainec

Key for Screening Evaluation

L = Low, M = Moderate, H = High, NA = Not Applicable

NE = Not Evaluated

Figure 4-1 Screening of Technologies and Process Options - Physical Hazards (Page 2 of 2)

- *Tunnel Rehabilitation* – Tunnel rehabilitation is a well established process for gaining re-entry to aged underground mine workings. However, there will be inevitable deterioration over time and, consequently, routine maintenance is necessary. It is a moderately effective method, depending on ground conditions. For Avoca, implementability is deemed to be low to moderate and cost to be relatively high. Tunnel rehabilitation is retained in order to facilitate bulkhead construction.

- *Structure Rehabilitation* – Repair and rehabilitation of old and historic structures is moderate in effectiveness. The structural mechanics aspects of rehabilitation are proven, but such repairs can only slow down the temporal degradation to the intrinsic elements of the structure. Rehabilitation or repair of the old structures is highly implementable and ranges from low to moderate in relative cost. Structure rehabilitation is retained.

- *Scaling/Rock Breaking* – Scaling and rock breaking, by themselves, are low in effectiveness and low to moderate in cost but high in implementability for the major highwalls at Avoca. Scaling treats only the apparent loose rock on the rock face. However, scaling and rock breaking are effective for reducing a physical hazard when used in advance of or in conjunction with any process option that places personnel and equipment underground or in the proximity of a highwall. These options are retained for use in combination with other options in the development of alternatives.

- *Shotcreting* – While moderately to highly implementable and moderate in cost, shotcreting is not effective over the long-term requiring maintenance and replacement. It is not retained for development of alternatives.

Barrier Technologies

- *Reinforced Concrete Bulkheads* – Reinforced concrete bulkheads are used in conjunction with the stabilisation option of tunnel rehabilitation. The tunnel rehabilitation necessarily precedes the bulkhead construction. Effectiveness as a barrier is high; implementability is moderate, depending on ground conditions; and relative cost is moderate to high. Bulkheads are retained for use in alternative development.

- *Shaft Sealing/Shaft Plugging* – As a barrier to a physical hazard, shaft sealing is highly effective and plugging of shafts and other mine openings that may occur on the surface is moderately effective. Implementability is moderate to high because common earthwork methods are used. Relative cost is moderate to high depending on the extent and conditions of the underground voids. Shaft sealing and plugging is retained for use in alternative development.

- *Rock Screens* – The implementation of heavy duty rock screens/cables at the Avoca Site would be for the highwalls/rock faces at the pits. In the cases of the Cronebane Pit and East Avoca Pit, the amount of necessary rock screen coverage is very large.

Rock bolts would be used to fasten the screens/cables to the rock faces. Although the rock screens are barriers to falling rock and not a process for stabilising rock faces, they have similar limitations and rankings compared to the application of rock bolts. Rock screens are ranked low to moderate in effectiveness. The screens are subject to failures and long term deterioration. Implementability is low to moderate because of access and equipment limitations, and increased risk to workers. The rock screen process is ranked moderate for relative cost. Due primarily to implementability and effectiveness concerns, rock screens are not retained for use in development of remedial action alternatives.

- *Rock Trap Ditches and Bunds* – Rock Trap ditches and bunds are estimated to be moderate to high in effectiveness as barriers to rock falls, depending on the height and characteristics of the exposed rock faces. They are highly implementable, especially in conjunction with pit backfilling. Rock trap ditches and bunds rank low to moderate in relative cost and are retained.

4.4.2.4 Removal/Relocation/Disposal

These general response actions are discussed together because all three actions occur as one action: after removal, the material is relocated and properly disposed. The process options associated with these actions are discussed below.

- *Excavation/Regrading* – Excavation of spoils is considered highly effective in addressing physical hazards, highly implementable and moderate in cost. It is retained for use in development of alternatives. Regrading was previously discussed under the containment GRA. It is also included in this section because it is typically part of the excavation process and results in removal when implemented.

- *Blasting* – Blasting is a moderately effective but not a permanent process for stabilising rock faces/highwalls. Blasting itself further weakens the rock structure, and it is difficult to determine if a final rock face slope will be stable in the long term. Blasting has low to moderate implementability for two reasons: the amount of land surface that will undergo disturbance will be very large, based on the height and the reclaimed slope of the highwall; blasting can have adverse effects on nearby structures and strong objections from nearby inhabitants. Blasting is relatively high in cost. Overall, blasting is not considered technically feasible and is not retained for alternative development.

- *Scaling/Rock Breaking* – These process options were previously discussed. They are included in this section because implementation of these options will result in some removal of rocks.

- *Structure Rehabilitation* – This process option was previously discussed. It is retained in this section because it may be necessary to remove structures (e.g., the ore bins) as part of rehabilitation.

- *Backfill Onsite in Pits* – Backfill was previously discussed as a containment/ stabilisation option. Backfilling pits is also a relocation/disposal option for spoils. As previously discussed, it is highly effective, highly implementable, and moderate in relative cost.

- *Backfill Onsite in Underground Workings* – Backfilling in underground workings is low to moderate in effectiveness, low to moderate in implementability, and high in cost. It was not retained for consideration in development of alternatives as a containment/stabilisation action; however, it is retained as a disposal option for selected solid media.

- *Disposal Onsite in Prepared Cells* – Disposal in prepared cells is highly effective, highly implementable, and high in relative costs. It is retained.

- *Disposal Offsite* – No existing landfill is currently available to accept contaminated materials from the Avoca site. A new landfill would have to be constructed. Although highly effective, this option is considered to have low implementability and is not retained for use in alternative development.

4.4.3 Solid Sources and Media

Figure 4-2 presents the list of technologies and process options identified for solid sources of contamination and/or contaminated media, along with the exposure elements addressed by each process and the results of the screening evaluation. The process options retained for use in development of remedial action alternatives are shaded. The results of this screening step are discussed in detail in the following sections.

4.4.3.1 No Action or No Action with Monitoring

The no action GRA with monitoring is retained as a potential remedial action for solid sources and media to serve as a basis for comparison to other alternatives. No action is implementable and low cost (monitoring only). However, it is not effective in achieving any of the remedial action objectives or remedial goals. Spoil piles would continue to generate acid seepage and diffuse contamination resulting in impaired and poor status in the Avoca River. Human health concerns for recreational users and industrial/commercial workers would continue to be present. Monitoring is appropriate to further characterise the Site for various geotechnical and hydrological conditions (see Section 6.3) and to enable the evaluation of the effectiveness of implemented options. Some parts of the Site only require continued monitoring.

4.4.3.2 Institutional Controls

Legal restrictions prohibiting site access or land use are considered technically unfeasible and eliminated from consideration. However, restrictive covenants implemented through planning and permit processes are retained for further evaluation. The other identified institutional control technologies and options (e.g., fencing; see Figure 4-2) are considered technically feasible. The retained options are considered low in effectiveness, moderate to high in implementability, and relatively low cost. Institutional controls are retained for use in development of remedial action alternatives in conjunction with other process options.

4.4.3.3 Containment

Regrading

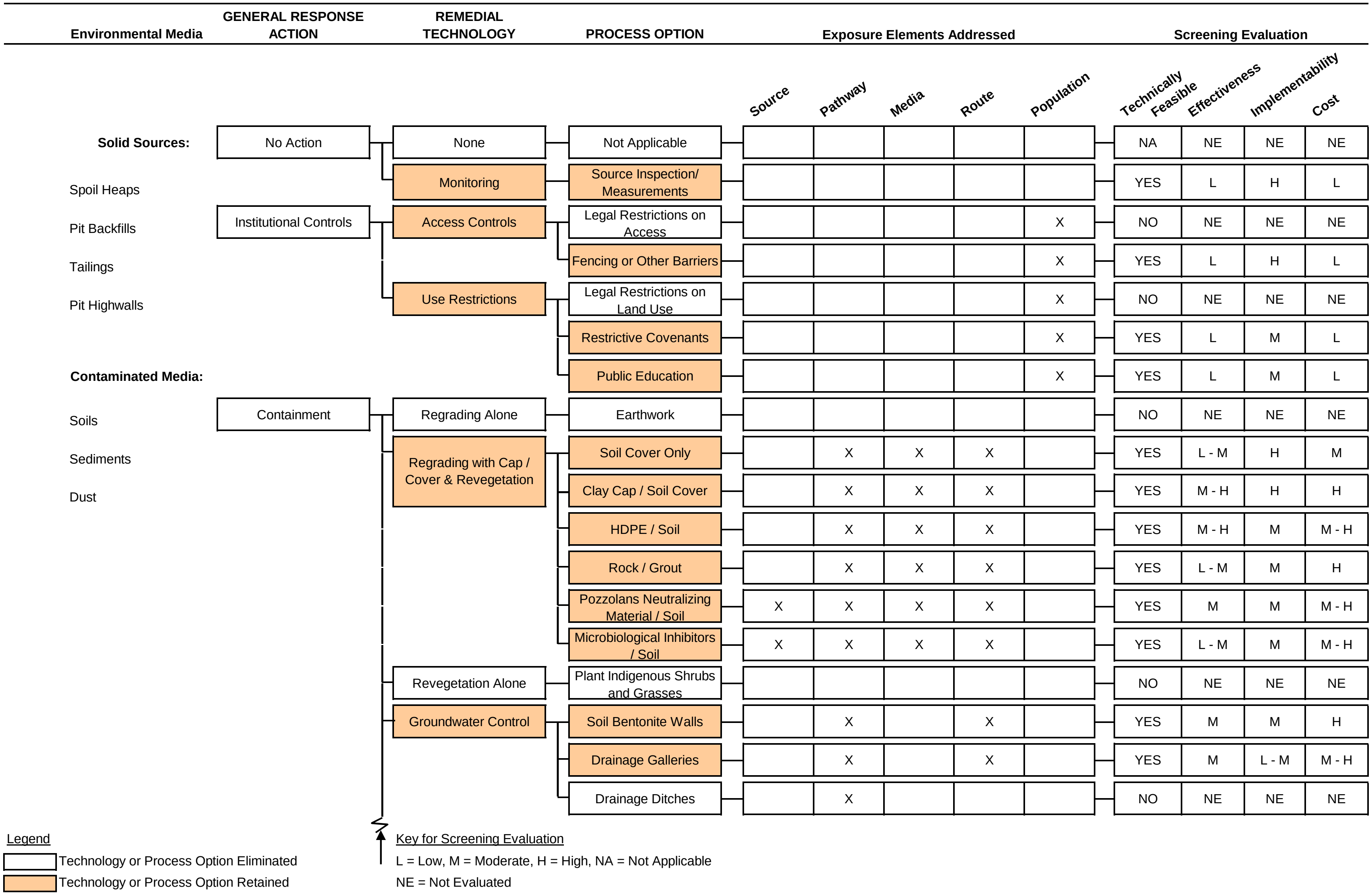
Regrading of solid source or contaminated media by itself does not treat or address the contaminants or contaminated media of concern and therefore is not technically feasible. Therefore, regrading alone is not retained. However, it is a remedial technology that is used in conjunction with, and as a necessary complement to, other technologies or options. By itself, it has no or little effectiveness in addressing human health and ecological concerns. It is highly implementable and relatively low in cost. Regrading is retained for use in development of remedial action alternatives in conjunction with other process options.

Regrading with Cap/Cover

The cap and cover options for the surface of solid sources or contaminated media are considered technically feasible. With the exception of the rock/grout cap, the capping options are complemented by soil covers to enhance plant growth and add effectiveness. The cap/cover combinations range from medium to high in effectiveness, implementability, and relative cost. These process options are retained for use in development of remedial action alternatives.

Revegetation

Revegetation of the surface of solid sources or contaminated media by itself does not treat contaminants or contaminated media of concern and is therefore not considered technically feasible. Therefore, revegetation alone is not retained. Even though the technology is not highly effective in its own right, it is an essential complement to a soil cover. Use of indigenous plant species results in landscape that is consistent with the current character of the Site. It is highly implementable and relatively low in cost. In combination with other process options, revegetation is retained for use in development of remedial action alternatives.



Environmental Media

Solid Sources:

Spoil Heaps

Pit Backfills

Tailings

Pit Highwalls

Contaminated Media:

Soils

Sediments

Dust

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Exposure Elements Addressed					Screening Evaluation			
			Source	Pathway	Media	Route	Population	Technically Feasible	Effectiveness	Implementability	Cost
No Action	None	Not Applicable						NA	NE	NE	NE
	Monitoring	Source Inspection/ Measurements						YES	L	H	L
Institutional Controls	Access Controls	Legal Restrictions on Access					X	NO	NE	NE	NE
		Fencing or Other Barriers					X	YES	L	H	L
	Use Restrictions	Legal Restrictions on Land Use					X	NO	NE	NE	NE
		Restrictive Covenants					X	YES	L	M	L
		Public Education					X	YES	L	M	L
Containment	Regrading Alone	Earthwork						NO	NE	NE	NE
	Regrading with Cap / Cover & Revegetation	Soil Cover Only		X	X	X		YES	L - M	H	M
		Clay Cap / Soil Cover		X	X	X		YES	M - H	H	H
		HDPE / Soil		X	X	X		YES	M - H	M	M - H
		Rock / Grout		X	X	X		YES	L - M	M	H
		Pozzolans Neutralizing Material / Soil	X	X	X	X		YES	M	M	M - H
		Microbiological Inhibitors / Soil	X	X	X	X		YES	L - M	M	M - H
	Revegetation Alone	Plant Indigenous Shrubs and Grasses						NO	NE	NE	NE
	Groundwater Control	Soil Bentonite Walls		X		X		YES	M	M	H
		Drainage Galleries		X		X		YES	M	L - M	M - H
		Drainage Ditches		X				NO	NE	NE	NE

Legend

☐ Technology or Process Option Eliminated

🟧 Technology or Process Option Retained

Key for Screening Evaluation

L = Low, M = Moderate, H = High, NA = Not Applicable

NE = Not Evaluated

Figure 4-2 Screening of Technologies and Process Options - Solid Sources and Media (Page 1 of 3)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Exposure Elements Addressed					Screening Evaluation			
			Source	Pathway	Media	Route	Population	Technically Feasible	Effectiveness	Implementability	Cost
Containment (Con't)	🟧 Surface Water Management	🟧 Improve / Stabilize Ditches		X				YES	M	H	L - M
		🟧 New Perimeter Ditches		X				YES	H	H	M
		🟧 Culverts / Bridges		X				YES	H	M - H	L - M
		🟧 Detention / Sedimentation Basins		X	X			YES	M	M	M
		🟧 Permanent Retention Structures		X	X			YES	M	M	M
		🟧 Temporary Retention Structures		X	X			YES	L - M	M	L
		🟧 Surface Armouring / Sealing		X		X		YES	L - M	M	M
		🟧 Natural or Artificial Wind Breaks		X				YES	L	M	L
Removal	🟧 Excavation	🟧 Earthwork	X	X	X	X		YES	H	H	M
		☐ Blasting						NO	NE	NE	NE
		🟧 Dredging	X		X	X		YES	L - M	L - M	M - H
Relocation/Disposal	🟧 Mine Site	🟧 Dispose as Backfill	X	X				YES	H	H	M - H
		🟧 Dispose in Prepared Cells	X	X	X	X		YES	H	M	H
	🟧 Off-site	☐ Dispose in Existing Facility	X	X	X	X		NO	NE	NE	NE
		🟧 Dispose in New Facility	X	X	X	X		YES	H	L - M	H

Legend

☐ Technology or Process Option Eliminated

🟧 Technology or Process Option Retained

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Figure 4-2 Screening of Technologies and Process Options - Solid Sources and Media (Page 2 of 3)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Exposure Elements Addressed					Screening Evaluation			
			Source	Pathway	Media	Route	Population	Technically Feasible	Effectiveness	Implementability	Cost
Treatment	Reprocessing of Source Materials	Pyrometallurgical	X		X			NO	NE	NE	NE
		Hydrometallurgical / In situ Leaching	X		X			NO	NE	NE	NE
		Hydrometallurgical / Ex situ Leaching	X		X			NO	NE	NE	NE
		Mineral Processing / Flotation	X		X			NO	NE	NE	NE
	Ex situ Stabilization or Neutralization	Pozzolans / Neutralizing Material	X	X				YES	M - H	M	M
		Sulfides / Phosphates	X	X				YES	M - H	L - M	H
		Proprietary Methods	X	X				YES	M - H	L - M	H
	In situ Stabilization or Neutralization	Pozzolans / Neutralizing Material	X	X				YES	L	M	M
		Sulfides / Phosphates	X	X				YES	L	M	H
		Proprietary Methods	X	X				YES	L	M	H
		Grout Injection	X	X				NO	NE	NE	NE
	Thermal	In situ Vitrification	X	X				NO	NE	NE	NE
	Bioremediation	Microbiological / Inhibitors		X				YES	L	M	M

Legend

☐ Technology or Process Option Eliminated

🟧 Technology or Process Option Retained

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Figure 4-2 Screening of Technologies and Process Options - Solid Sources and Media (Page 3 of 3)

Groundwater Control
For solid sources and media, soil bentonite walls or drainage galleries are containment process options. Soil bentonite walls and drainage galleries are technically feasible options for preventing or controlling groundwater interaction with contaminating solids or contaminated media. They are moderate in effectiveness and implementability at the Avoca Project, and relatively high in cost. Drainage galleries are typically more difficult to implement at the required depths and are therefore rated low to moderate in implementability. These options are retained for use in development of remedial action alternatives. Because of the depth of groundwater, drainage ditches would not be effective and are not retained for use in alternative development for groundwater control (they are retained for surface water management).

Surface Water Management
All of the surface water management process options are technically feasible for application to one aspect or another of the Avoca Project. The options for improving, stabilising, or constructing new channels/ditches, culverts, or bridges range from moderate to high in effectiveness and implementability, and low to moderate in relative cost. Detention/sedimentation basins and permanent retention structures are moderate in effectiveness, implementability, and relative cost. Temporary retention structures, erosion control by surface amouring, and windbreaks range from low to moderate in effectiveness, implementability, and relative cost. These options are retained for use in development of remedial action alternatives.

4.4.3.4 Removal

The removal response action is typically used in association with relocation/disposal and containment process options. The sequence that the remediation would follow typically includes: upon removal of solid sources/contaminated media from one location (relocation), they would be placed (disposal), covered (containment), and revegetated in another location. The earthwork option ranks high in effectiveness and implementability, and moderate in relative cost. Blasting applies particularly to degrading/reshaping of the highwalls; however, due to its effect on the community and other implementability concerns, it is not retained for use in development of remedial action alternatives. Dredging is a process that is applicable to sediment removal from the river banks and bottoms. Dredging is low to moderate for effectiveness and implementability and moderate to high in relative cost. These options, with the exception of blasting, are retained for use in development of remedial action alternatives. Dredging is retained as it is the most viable option for the removal of river sediments.

4.4.3.5 Relocation/Disposal

All onsite and offsite disposal options for contamination source materials and media at the site are considered technically feasible except for disposal in an offsite existing facility. Because the West Avoca Pond Lode (Ballymurtagh) landfill is closed, no existing repository facility is present at or near the site. Disposal by backfilling at the mine site ranks high in effectiveness, high in implementability and moderate in relative cost. Disposal at the mine site in prepared, lined cells is moderate to high in effectiveness, high in implementability and moderate to high in relative cost. Construction of prepared cells is more expensive than direct backfill due to installation of a liner in the cells. Disposal in a new offsite facility is high in effectiveness and relative cost, and low to moderate in implementability. These disposal options are retained for use in development of remedial action alternatives. Disposal offsite in a new facility was retained during this preliminary screening, but eliminated during development of alternatives (see Section 5.5).

4.4.3.6 Treatment

Reprocessing of Source Materials

All of the options for reprocessing of source materials are deemed to be not technically feasible because there are not sufficient quantities of source materials available and metal concentrations are not high enough to be economically feasible. A reprocessing technology may become feasible if a new mineral extraction/processing operation were developed at the Avoca mine site. This option is not retained for use in development of remedial action alternatives.

Ex Situ Stabilisation or Neutralisation

All of the *ex situ* stabilisation or neutralisation process options are technically feasible and rank moderate to high in effectiveness. The pozzolans/neutralising materials option is moderate for both implementability and relative cost. The other *ex situ* options are low to moderate in implementability and high in relative cost. These process options are retained for use in development of alternatives.

In Situ Stabilisation or Neutralisation

Grout injection is considered not technically feasible because it is extremely difficult if not impossible to implement the technology so it effectively treats the contaminants or contaminated media of concern. Therefore, it is not retained for further consideration.

All of the other *in situ* stabilisation or neutralisation process options rank low in effectiveness and moderate in implementability. The pozzolans option is moderate in relative cost; the other process options are high in relative cost. In particular, phosphate based proprietary chemicals have become very expensive, typically 8 to 10 times more expensive than lime. Applications of proprietary chemicals typically must also be repeated with time (approximately every 5 years). Typically, *in situ* treatment is less effective than *ex situ* treatment because it is difficult to contact all contaminated media using *in situ* techniques. Because of their low effectiveness, *in situ* process options are not retained for further use in alternative development.

Thermal

The thermal *in situ* vitrification option is not technically feasible due to extremely high energy requirements and uncertainty of treatment success. This option is therefore not retained for use in development of remedial action alternatives.

Bioremediation

The bioremediation option of using microbiological inhibitors is technically feasible; it is low in effectiveness and moderate in implementability and relative cost. Because of the low effectiveness, this option is not retained for use in development of remedial action alternatives.

4.4.4 Water Sources and Media

Figure 4-3 presents the list of technologies and process options identified for water sources of contamination and/or contaminated media, along with the exposure elements addressed by each process and the results of the screening evaluation. The process options retained for use in development of remedial action alternatives are shaded. The screening process and results are discussed in the following sections.

4.4.4.1 No Action or No Action with Monitoring

The no action GRA with monitoring is retained as a potential remedial action for water sources and contaminated media to serve as a basis for comparison to other alternatives. No action is implementable and low cost (monitoring only). However, it is not effective in achieving any of the remedial action objectives or remediation goals. Acid discharges and diffuse contamination would continue to result in impaired and poor status in the Avoca River. Monitoring is appropriate to further characterise the Site for various hydrological conditions and to enable the evaluation of the effectiveness of implemented remedial options. In addition, some parts of the Site only require continued monitoring.

4.4.4.2 Institutional Controls

Legal restrictions prohibiting site access, land use, or water use and banning drilling of groundwater wells are considered technically unfeasible and eliminated from consideration. However, restrictive covenants implemented through planning and permit processes are retained for further evaluation. The remaining identified institutional control technologies and options are considered technically feasible. The retained use restriction options range from low to medium in effectiveness, moderate to high in implementability and low in relative cost. The alternate water supply options range from low to high in effectiveness and moderate to high in implementability and relative cost. Institutional controls are retained for use in development of remedial action alternatives in conjunction with other process options.

Environmental Media	GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Exposure Elements Addressed					Screening Evaluation			
				Source	Pathway	Media	Route	Population	Technically Feasible	Effectiveness	Implementability	Cost
Water Sources:	No Action	None	Not Applicable						NA	NE	NE	NE
AMD / ARD		▨ Monitoring	▨ Source Monitoring						YES	L	H	L
Pit Water	Institutional Controls	▨ Access Controls	Legal Restrictions on Access					X	NO	NE	NE	NE
			▨ Fencing or Other Barriers					X	YES	L	H	L
		▨ Use Restrictions	Legal Restrictions on Land Use					X	NO	NE	NE	NE
Contaminated Media:			▨ Restrictive Covenants					X	YES	L	M	L
Surface Water (Avoca R., Streams)			▨ Public Education					X	YES	L	M	L
Groundwater			Well or Surface Water Restrictions					X	NO	NE	NE	NE
Pond Water			Banning Wells					X	NO	NE	NE	NE
		Alternate Supply	Tanked Water					X	YES	M	H	M
			▨ Group Water Scheme					X	YES	H	H	M
			▨ New Wells					X	YES	L	M	H
	Containment	▨ Source Control / Mine Water	Fractured Zone Seals	X					NO	NE	NE	NE
			Oxygen Barriers	X					NO	NE	NE	NE
			Flooding Mine Workings	X					NO	NE	NE	NE
			Backfilling Mine Workings	X					NO	NE	NE	NE
			▨ Plugging Shafts and Adits	X					YES	L - M	M - H	M - H

Legend

☐ Technology or Process Option Eliminated

▨ Technology or Process Option Retained

Key for Screening Evaluation

L = Low, M = Moderate, H = High, NA = Not Applicable

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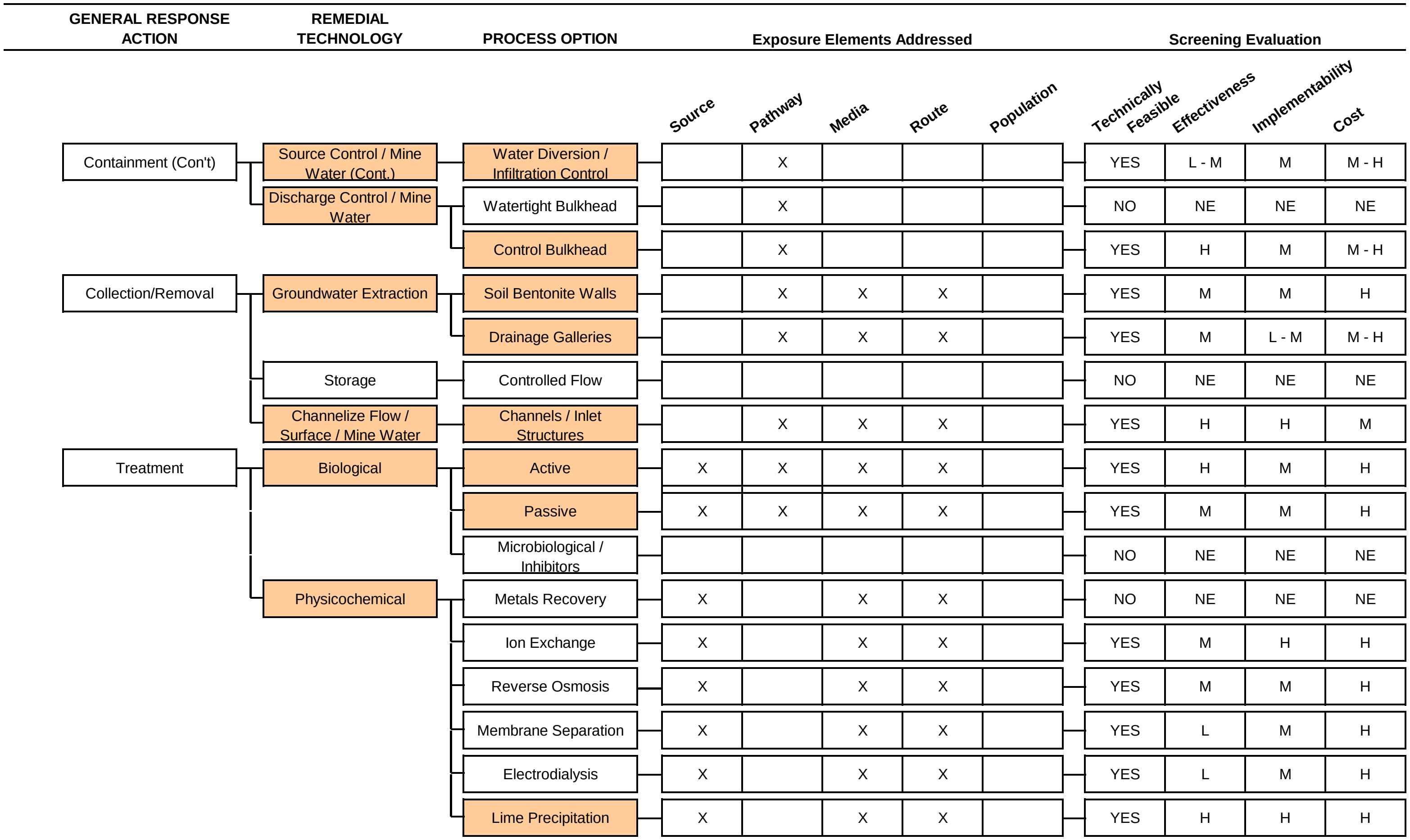
Figure 4-3 Screening of Technologies and Process Options - Water Sources and Media (Page 1 of 3)



GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Exposure Elements Addressed					Screening Evaluation			
			Source	Pathway	Media	Route	Population	Technically Feasible	Effectiveness	Implementability	Cost
Containment (Con't)	Source Control / Mine Water (Cont.)	Water Diversion / Infiltration Control		X				YES	L - M	M	M - H
	Discharge Control / Mine Water	Watertight Bulkhead		X				NO	NE	NE	NE
		Control Bulkhead		X				YES	H	M	M - H
Collection/Removal	Groundwater Extraction	Soil Bentonite Walls		X	X	X		YES	M	M	H
		Drainage Galleries		X	X	X		YES	M	L - M	M - H
	Storage	Controlled Flow						NO	NE	NE	NE
	Channelize Flow / Surface / Mine Water	Channels / Inlet Structures		X	X	X		YES	H	H	M
Treatment	Biological	Active	X	X	X	X		YES	H	M	H
		Passive	X	X	X	X		YES	M	M	H
		Microbiological / Inhibitors						NO	NE	NE	NE
	Physicochemical	Metals Recovery	X		X	X		NO	NE	NE	NE
		Ion Exchange	X		X	X		YES	M	H	H
		Reverse Osmosis	X		X	X		YES	M	M	H
		Membrane Separation	X		X	X		YES	L	M	H
		Electrodialysis	X		X	X		YES	L	M	H
		Lime Precipitation	X		X	X		YES	H	H	H

Legend

☐ Technology or Process Option Eliminated

🟧 Technology or Process Option Retained

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Figure 4-3 Screening of Technologies and Process Options - Water Sources and Media (Page 2 of 3)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Exposure Elements Addressed					Screening Evaluation			
			Source	Pathway	Media	Route	Population	Technically Feasible	Effectiveness	Implementability	Cost
Treatment (Con't)	🟧 Physicochemical (Cont.)	🟧 Caustic Precipitation	X		X	X		YES	H	H	H
		🟧 Sulfide Precipitation	X		X	X		YES	H	H	H
		🟧 Limestone Drains	X		X	X		YES	L	M	M
		🟧 Iron Oxidation / Precipitation	X		X	X		YES	L	M	M
		🟧 Coagulation / Flotation			X	X		YES	L	M	M
	🟧 Physical	Distillation / Evaporation			X	X		NO	NE	NE	NE
		Freezing			X	X		NO	NE	NE	NE
Disposal/Discharge	🟧 Treated Water	🟧 Discharge to Surface Water				X		YES	H	H	L
		Reinjection to Groundwater				X		YES	L	L	H
		Deep Well Injection				X		NO	NE	NE	NE
	🟧 Solid Treatment Waste	Pit Backfill			X	X		YES	L	L	L - M
		Underground Backfill			X	X		YES	L	L	H
		🟧 Prepared Facility			X	X		YES	H	H	H

Legend

☐ Technology or Process Option Eliminated

🟧 Technology or Process Option Retained

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Figure 4-3 Screening of Technologies and Process Options - Water Sources and Media (Page 3 of 3)

4.4.4.3 Containment

Source Control/Mine Water

Four of the six acid mine water drainage source control technology options are not technically feasible for the Avoca Project. Fracture zone seals, oxygen barriers, and flooding mine workings are not retained because of the large extent and complex nature of the underground mine workings and the numerous entrance/exit zones for air to enter or acid mine water to discharge. Backfilling mine workings while technically feasible is low in effectiveness in controlling acid mine water generation and is not retained for alternative development. The remaining options – shaft plugging and water diversion/infiltration control – are technically feasible and are retained for use in development of remedial action alternatives. They range from low to moderate in effectiveness and moderate to high in implementability and relative cost.

Discharge Control/Mine Water

The watertight bulkhead is not technically feasible because of the numerous exit zones for acid mine water to escape in proximity to any opening that would be suitable for a watertight bulkhead installation and is therefore not retained. The control bulkhead is technically feasible and retained for use in development of remedial action alternatives; it is a relatively common option used at abandoned underground mine sites. For the Avoca project, it is high in effectiveness, moderate in implementability, and moderate to high in relative cost.

4.4.4.4 Collection/Removal

Groundwater Extraction

For water sources and media, soil bentonite walls or drainage galleries are collection/ removal process options. They are used to direct or channel groundwater flow. Groundwater extraction utilises well fields in conjunction with soil bentonite walls or drainage galleries to remove contaminated groundwater. Both process options are technically feasible. They are moderate in effectiveness, moderate in implementability, and moderate to high in relative cost. Typically soil bentonite walls and drainage galleries combined with extraction wells are highly effective. However, because of the thickness of the alluvial aquifer, the soil bentonite walls and extraction wells will not completely intersect all groundwater (only more shallow zones). Therefore, the technology is rated moderate in effectiveness. These options are retained for use in development of remedial action alternatives.

Storage

Not to be confused with detention of treated water as a polishing process, storage for purpose of controlled discharge (i.e., constant flow rate) is not applicable for the Avoca Project because of the large storage volumes required for constant flow. Therefore it is not retained for use in development of remedial action alternatives. However, storage tanks will be used to contain water for monitoring before discharge. In addition, valves will be included on the pipes in the adit bulkheads. This will allow for "storage" of water in the adits and tunnels during upset conditions in the treatment plant.

Channelise Flow – Surface Water/Mine Water
Channelising flows of surface water or mine water is technically feasible for the Avoca Project. It is high in effectiveness and implementability, and moderate in relative cost, and is therefore retained for use in development of remedial action alternatives.

4.4.4.5 Treatment

Biological
Both active and passive biological treatment options for contaminated water media (surface water and groundwater) are technically feasible. The active biological process ranks high in effectiveness and relative cost, and moderate in implementability. The passive process is moderate in implementability, moderate in effectiveness, and high in relative cost. Pilot testing of passive techniques could potentially demonstrate increased effectiveness and decreased costs. Recycling of biological inhibitors to the acid mine water source is not applicable and was not retained for use in development of remedial action alternatives. Both the active and passive treatment options are retained for use in development of remedial action alternatives.

Physicochemical
All physicochemical treatment options for acid mine and acid rock drainage and contaminated water media are technically feasible, except for metals recovery. Metals recovery for economic benefit is not technically feasible due to expected low concentrations of metals in the acid mine and acid rock drainage waters and is not retained for use in development of remedial action alternatives. Ion exchange, reverse osmosis, membrane separation, and electrodialysis are not retained for use in development of remedial action alternatives due to high relative costs and lower effectiveness compared to other technologies. Lime, caustic, and sulphide precipitation are high for all screening criteria and are retained for further use in the Site alternatives. Limestone drains, iron oxidation, and coagulation/flotation are low for effectiveness, moderate for implementability, and moderate in cost. These options are by themselves typically low in effectiveness and would not be retained. However, they are used in combination with other process options and are therefore retained for use in development of remedial action alternatives.

Physical
The process options of distillation/evaporation and freezing are determined to be not technically feasible for the Avoca Project because of the large volume of source and contaminated water requiring treatment, and the extremely high energy and land area requirements of the processes. These options are not retained for use in development of remedial action alternatives.

4.4.4.6 Disposal/Discharge

Treated Water

The options of discharging treated water to surface water and re-injecting treated water to shallow groundwater options are technically feasible. Comparatively, discharge to surface water is high in effectiveness and implementability, and low in relative cost; re-injection is low in effectiveness and implementability, and high in relative cost. Because of its low effectiveness and high cost, re-injecting treated water to shallow groundwater is not retained. Deep well injection is not technically feasible due to a comparatively high cost, a remote need for the option and a lack of information on a suitable deep aquifer. This option is not retained for use in development of remedial action alternatives. The discharge of treated water to surface water is retained for use in development of remedial action alternatives.

Solid Treatment Waste

High volumes of solid treatment waste from the selected active treatment process, and occasional large masses of expended materials from the passive treatment process will require disposal. The process options of pit backfill, underground backfill, and disposal in a prepared facility, onsite or offsite, are technically feasible. Pit backfill ranks low for effectiveness and low to moderate for implementability. Pit backfill is low to moderate for relative cost. Underground backfill is low in effectiveness and implementability and moderate to high in relative cost. Because of the low effectiveness, pit and underground backfill options are not retained. A prepared solid waste disposal facility is high for all of the screening criteria and is retained for alternative development.

The solid treatment waste from any treatment facility must be properly classified and disposed of in an appropriately designed facility according to *Criteria and Proceedings for the Acceptance of Waste at Landfills* (2003/331EC pursuant to Article 16 of and Annex II to Directive 1999/31/EC). Solid treatment waste from the pilot plant trials (*Avoca Mines Pilot Plant Treatment Trials*, Unipure Europe 2007) were subject to the classification/leaching tests required by the Directive. Based on these tests, the solid waste is inert waste. Because of the high sulphate concentrations, a more rigorous upflow percolation test (compared to the standard test) was used for the classification. The sample tested, passed this more rigorous test. If the waste did not pass this test, it would be classified based on the standard leaching test, as a non-hazardous waste (B1 or B1b).

4.4.5 Site Compatibility

Besides the technical evaluations of effectiveness, implementability, and relative costs, the process options were also evaluated for site compatibility. Site compatibility includes:

- Preservation of historical structures of industrial archaeological importance including engine houses, the tramway arch, chimneys, ore bins, etc.

- Preservation of mining and landscape features including spoil piles, adits, shafts, and pit highwalls
- Preservation of Site ecology
- Improvement of Site access
- Improvement of future land use
- Improvement in ability to manage the site
- Improvement in recreational and educational opportunities
- Overall site compatibility

Select remedial technologies and process options are evaluated against the above compatibility items in Figure 4-4. The ability of various technologies and process options to be compatible or consistent with each of the above items is rated as low, medium, or high in Figure 4-4. Each compatibility item is discussed in the following paragraphs.

Preservation of Historic Structures

The historic structures of industrial archaeological importance identified by Seán Harrington Architects will be preserved by all the proposed remedial technologies and process options. The structures are discussed in Section 2.1.6 and include the Tramway Arch, Ballygahan engine house and chimney, Tramway engine house chimney, Twin Shafts engine house and chimney, Williams engine house, Baronets (Farmers) engine house, chimney to former Waggon engine house, and the Ore Bins at Tigroney. Due to stability and human health issues, the Ore Bins must be removed. However, instead of removal and disposal, the Ore Bins are proposed to be relocated and rehabilitated (see Section 5.1). All other structures would be left in place, stabilised, and rehabilitated as necessary. Many of the proposed options do not affect the preservation of historic structures and are therefore rated as Not Applicable (NA). As discussed later, access to all historic structures will be improved by the proposed remedial actions.

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Screening Evaluations							
			Preservation of Structures	Preservation of Mining Features	Preservation of Ecology	Site Access	Future Land Use	Site Management	Recreational Opportunities	Overall Site Compatibility
No Action	Monitoring	Inspections/Monitoring	L	L	L	L	L	L	L	L
Institutional Controls	Access Controls	Fencing/Barriers	L	L	L	L	L	L	L	L
	Use Restrictions	Restrictive Covenants	L	L	L	L	L	L	L	L
Containment (Physical Hazards)	Stabilisation	Regrading	NA	L	M	M - H	H	H	M	M
		Backfilling	NA	L	M	H	M - H	H	L - M	M - H
		Structure Rehabilitation	H	NA	NA	M	L	M	M	M - H
	Barriers	Adit Bulkheads/ Shaft Plugging	NA	L	NA	H	M	H	H	H
Containment (Solids)	Caps/Cover	HDPE/Soil/Vegetation	NA	L	M	H	M	H	M	M
		Lime Addition/ Soil/Vegetation	NA	L	M	H	M	H	M	M
Removal (Solids)	Stabilisation	Excavation	L	L	M	H	H	H	M	M - H
		Regrading	L	L	M	H	H	H	M	M - H
		Dredging	NA	NA	H	L	M	M	H	M - H
Relocation/Disposal (Solids)	Stabilisation	Backfilling On-Site	NA	L	M	H	H	H	M	M - H
Containment (Water)	Discharge Control	Control Bulkheads	NA	L	NA	H	M	M	L - M	M - H
	Surface Water Control	Water Diversion/ Infiltration Control	NA	M	M	M	M	H	M	M

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Note: Impacts can be positive or negative

Figure 4-4 Evaluation of Technologies and Process Options - Site Compatibility (Page 1 of 2)

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION	Screening Evaluations							
			Preservation of Structures	Preservation of Mining Features	Preservation of Ecology	Site Access	Future Land Use	Site Management	Recreational Opportunities	Overall Site Compatibility
Collection/Removal (Water)	Groundwater Extraction	Soil Bentonite Walls	NA	NA	M	NA	M	M	M	M
	Surface Water Control	Channels/Ditches	NA	M	M	M	M	M	M	M
Treatment (Water)	Physicochemical	Lime Precipitation	NA	NA	H	H	H	H	H	H
	Biological	Passive	NA	L	H	H	M	H	H	H
Disposal (Water)	Solids Treatment Waste	On-Site Facility	NA	L	M	M	M	H	M	M

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L = Low, M = Moderate, H = High, NA = Not Applicable/No Effect

Note: Impacts can be positive or negative

Figure 4-4 Evaluation of Technologies and Process Options - Site Compatibility (Page 2 of 2)

Preservation of Mining and Landscape Features

Many of the proposed remedial options address physical hazards and human health and ecological concerns using process options that contain or remove contaminated solid media. Therefore, these options are rated low to moderate in preservation of the existing mining landscape including exposed spoil piles and pit highwalls in their current condition. However, as previously discussed, spoil piles and pit highwalls need to be addressed because of physical hazards and human health and ecological health concerns. Use of indigenous vegetation will result in landscape consistent with the current character of the Site. Other proposed options (e.g., water treatment) will have no or little effect on the mining landscape (except for the associated bulkheads in discharging adits) and are rated moderate to high in preservation of the existing mining landscape.

Preservation of Site Ecology

Most of the proposed remedial options rate moderate in preservation of the current site ecology. Habitats of protected species will be maintained or in some cases improved. Where appropriate, access by bats to underground workings will be maintained with properly designed containment structures.

Habitat for native fish will be improved by reduction of metal concentrations in the Avoca River and tributaries. Therefore, water treatment is rated high in preservation of ecology. Habitat for macroinvertebrates will also be improved. No unique plant species were observed at the Site. Establishment of spoil covers and use of amendments such as lime will enhance indigenous vegetation.

Improvement of Site Access

Most of the proposed remedial options rate high in improving Site access. As a result of removing physical hazards, the public will be better able to access the Site. All historic structures will also be rehabilitated if necessary and therefore public access will be improved. Human health concerns will also be mitigated and therefore access will be made safe.

Improvement of Future Land Use

Most of the proposed remedial options rate moderate to high in improving future land use. For example, elimination of physical hazards and human health concerns improves the site for construction of trails, livestock grazing, and some construction of buildings.

Improvement in Ability to Manage the Site

Most proposed remedial options rank high in improving the ability to manage the Site. As previously discussed, access to all areas will be improved so inspections can occur easily. Also, monitoring will provide routine information to better manage and evaluate site conditions. Process options such as water diversion, channels, and ditches will control erosion and sedimentation allowing for better site management.

Improvement of Recreational and Educational Activities

Most proposed remedial actions rate moderate to high in improving recreational activities. As already discussed, habitat for fish will be improved and therefore recreational fishing will be improved. Physical hazards and human health concerns will be eliminated opening the area for safe access, construction of trails, potential construction of picnic areas, and potential construction of quad bike paths. Access to historical structures will enhance educational opportunities.

Overall Site Compatibility

Overall, the proposed remedial options rate moderate to high in their ability to address site compatibility issues. Even though many of the mining related landscape features as they currently exist will not be preserved, site access, habitat for site ecology, recreational opportunities, and future land use will be enhanced by the proposed remedial actions.

Section 5
Development of Preliminary Remedial Action Alternatives

Preliminary remedial action alternatives (Alternatives) are developed following the screening of technologies and process options (Section 4, as summarised in Figures 4-1, 4-2, 4-3, and 4-4). Alternatives are developed by selecting and combining retained process options that are effective and implementable at specific geographic portions of the Site for each media. This process is shown in Figure 1-1. The goal of each Alternative is to satisfy the related remedial action objectives and preliminary remediation goals for the Avoca Site (see Section 3). At this stage of the feasibility study process, Alternatives covering a range of technologies/process options were developed to present both a range of actions and costs. In the final step of the feasibility study process (see Section 6), site-wide combined alternatives that are considered the most cost-effective and implementable are developed selecting from the Alternatives.

Five Alternatives were developed for the East and West Avoca (East/West Avoca) sites for solid sources and contaminated media and four Alternatives were developed for the East/West Avoca sites for water sources and contaminated media. Two Alternatives were developed for the Shelton Abbey site for solid sources and contaminated media and three for water sources and contaminated media. Alternatives were also developed for contaminated river sediments and the Emergency Tailings Pond. In addition to the human health and ecological remedial action objectives, the Alternatives address the physical hazard and safety remedial action objective. During the selection of the Alternatives to address physical hazards, human health, and ecological concerns, actions were also evaluated to preserve sites of industrial archaeological importance and enhance access to such sites. In particular, the Tigroney Ore Bins are restored and the engine houses, chimneys, and tramway arch will be retained. Access to all sites is improved.

5.1 East/West Avoca Preliminary Remedial Action Alternatives

5.1.1 East/West Avoca Physical Hazards and Solids

5.1.1.1 East/West Avoca Alternative No. 1 – Solids

The various technologies and process options used to address physical hazards, solids sources and contaminated media in Alternative No. 1 follow:

- **Institutional Controls** – The full suite of options for access controls and restrictive use covenants will be used for this remedial action alternative. The mine sites are high risk areas for public safety, so the implementation of several relatively low-cost controls/restrictions such as gates, compatible fencing and other barriers, and restrictive use covenants will be included in this alternative.

- **Containment** – Spoils material at each location within the East/West Avoca mine areas will be contained through installation of a soil cap and topsoil cover. The soil cap/cover containment is selected because it is an effective barrier to human contact, it provides for vegetative growth that enhances evapotranspiration (lowers infiltration), and it is a practical, relatively low-cost alternative. As part of this Alternative, regrading and relocation of selected spoil piles will be performed to address the physical hazards (pile and highwall stability) and prepare surfaces for cover. Applications at each site follow:

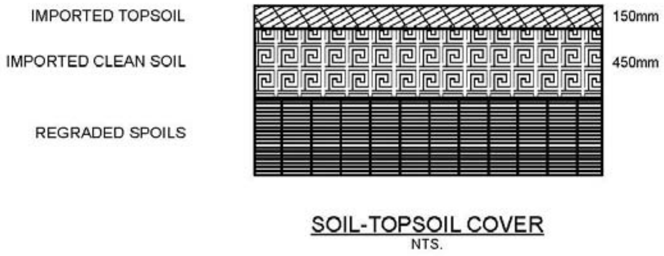
  - *Connary, Portions of East Avoca, Tigroney West, and West Avoca* – Spoils heaps in each of these Site locations will be regraded to establish proper surface water runoff control. These spoils areas will then be covered with clean earth fill followed by a layer of topsoil and indigenous vegetation. Figure 5-1 shows schematic diagrams of each of the types of spoil cover discussed in this section. The top diagram shows the soil-topsoil cover used in this Alternative.

  - *Mt. Platt and portions of the East Avoca/Tigroney West* – The spoil piles nearest the East Avoca Pit will be relocated to the Cronebane and East Avoca Pits, respectively. Both the remaining excavated spoils areas and the Cronebane and East Avoca Pits infills will be compacted and regraded to establish proper surface water runoff control. These areas will then be covered with clean earth fill, followed by a layer of topsoil and indigenous vegetation. Excavated areas will be filled with clean soil and regraded to promote surface water drainage. These areas will then be covered with clean earth fill followed by a layer of topsoil and indigenous vegetation.

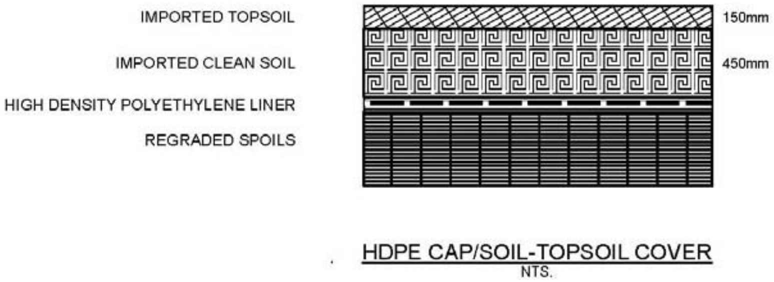
    For all Alternatives, whenever spoils are excavated and relocated, the contaminated soils beneath the spoils will also be removed and relocated onsite.

    Also for all Alternatives, whenever there is work to be done, such as backfilling in the vicinity of a highwall or rehabilitating an adit, the work will be preceded by the process of scaling in order to reduce the risk of rock falls. There will be limitations to scaling with the higher rock faces such as at the Cronebane Pit and the East Avoca Pit. Equipment reach will be limited, so successive applications of scaling may occur as the pit floor is raised by backfilling. In every application of scaling, measures will be necessary to protect/shield personnel and equipment.

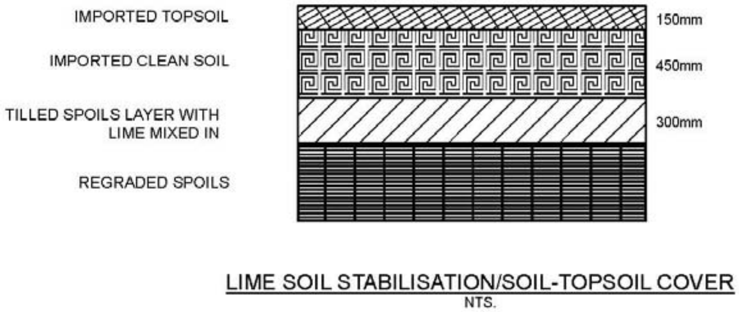
    When filling open pits, any ponded water and debris will be removed first. Surface contouring and backfill compaction will occur during the filling process.



Alternative 1



Alternatives 2 and 4



Alternative 3

FIGURE 5-1

**Typical Cap/
Cover Options
Schematic Diagram**

CDM

The relocation aspect of this Containment alternative addresses the remediation of a number of physical hazards while establishing an effective barrier to human contact. The relocation of Mt. Platt eliminates a source of runoff and infiltration contamination and solid contamination migration via erosion. The risk of slope failures and landslides at Mt. Platt is also eliminated. Complementing these attributes is the fact that the Cronebane Pit would be substantially backfilled, thus eliminating or greatly reducing the physical hazards associated with highwalls, rock falls, and pit water.

The East Avoca Pit would be partially backfilled by relocating select spoil piles at East Avoca/Tigroney West. Consequently, the rock face/rock fall hazards would be reduced, but not eliminated. The highly unstable walls in the southwest area of the pit would also not be completely stabilised by backfilling (i.e., not enough materials exist in the relocated spoil piles). Large or problematic spoil piles/ areas (e.g., the spoil area in the vicinity of the Deep Adit that contributes to diffuse flow contamination) would be relocated to the East Avoca Pit, thereby affecting greater control against surface water and groundwater contamination and solid contaminant migration.

Construction of rock trap ditches and bunds to reduce rock fall hazards will be an integral part of the regrading effort at the Cronebane and East Avoca Pits.

- The spoils areas at West Avoca will be regraded in place except for the spoils areas near Weaver's Lode Pit. The spoils areas near the Weaver's Lode Pit will be relocated to the base of the pit's highwall for the purpose of rock face stabilisation. Construction of a rock trap ditch and bund will be an integral part of the earthwork.

  Spoil piles nearby the former Pond Lode Pit (now the Ballymurtagh Landfill) will be used to construct a rock trap ditch and bund at the base of the Pond Lode highwall to reduce or eliminate the physical hazard of potential rock falls.

- Surface water management components will be constructed as necessary to establish positive drainage from the pits and covered spoils areas. Surface water management will include new perimeter ditches, culverts and bridges for access roads, and detention and sedimentation basins.

  Surface water management is an essential part of each remedial action alternative. The purposes of surface water management are to collect and direct surface water runoff to appropriately protected ditches and channels, temporarily impound runoff for sedimentation control, and prevent ponding of runoff in unplanned locations. Surface water management includes routine, periodic maintenance and repair of the various water control structures.

- **Relocation** – Relocation of the historic Tigroney Ore Bins will be performed both with equipment and hand excavation. Temporary supports will be installed as needed to safely excavate the bins. After excavation is complete, the ore bins will be relocated to the Deep Adit site where they will be restored. The Deep Adit area will also be used for the active water treatment building.

Relocation of the Tigroney Ore Bins serves two important purposes. The ore bins and adjacent crib walls are in poor condition; they are a physical hazard. As well, the surrounding spoils contain relatively high levels of contamination and high acid generation potential. As a result, the ore bins must be removed. Instead of removal and disposal, the proposed action is relocation and restoration. The ore bins are among the more attractive features to visitors to the area, as they readily relate to the Avoca mining history. Relocation and restoration eliminate the physical hazards and enhance interest in the area's mining history.

- As previously discussed, Mt. Platt, portions of East Avoca/Tigroney West spoils and the Deep Adit spoils will be relocated to the Cronebane and East Avoca Pits;

- Spoils near Weaver's Lode Pit will be relocated to the pit's highwall.

5.1.1.2 East/West Avoca Alternative No. 2 – Solids

The various technologies and process options used to address physical hazards, solids sources and contaminated media in Alternative No. 2 follow:

- **Institutional Controls** – The access controls and use restrictions are the same as for East/West Avoca Alternative No. 1 - Solids.

- **Relocation**– The spoil piles/areas in East/West Avoca and historic Tigroney Ore Bins will be relocated as described below:

  - The Connary spoils and the Mt. Platt spoils will be relocated to the Cronebane Pit. All identified East Avoca, Tigroney West, and Deep Adit spoils will be relocated to the East Avoca Pit. West Avoca spoils, including the spoils adjacent to the Avoca/Rathdrum Road and in the vicinity of the Road Adit (SP39), will be relocated to the Weaver's Lode Pit and its vicinity. Excavated areas will be filled with clean soil and regraded to promote surface water drainage. These areas will then be covered with clean earth fill followed by a layer of topsoil and indigenous vegetation.

    The Connary site is somewhat unique because it is within a residential and agricultural site. There is no more effective way to eliminate the human health and ecological risks associated with the contaminated spoils than to remove them from the site. Additionally, a number of shafts or openings to the underground mine workings are suspected to be buried beneath the Connary spoils area. Excavation may expose these and allow for shaft sealing/plugging and backfilling of mine voids, thus reducing the number of physical hazards.

The same prospect for remedying buried physical hazards exists for East Avoca/Tigroney West and West Avoca. Cronebane Pit would be substantially backfilled thus eliminating or greatly reducing the physical hazards associated with highwalls and rock falls. Additionally, with more spoils being relocated to the East Avoca Pit and Weaver's Lode Pit, the physical hazards associated with highwall rock faces and rock falls are further mitigated (and virtually eliminated from the Weaver's Lode Pit). Construction of rock trap ditches and bunds would occur where necessary to protect against rock falls.

  - Removal of the Tigroney Ore Bins will be completed as described under Alternative No. 1 - Solids.

- **Containment** – Placed spoils will be regraded as required to promote surface water drainage. High density polyethylene (HDPE) caps will be placed over the relocated spoils material in the Cronebane, East Avoca, and Weaver's Lode Pits. Installation of these caps will be followed by placement of clean earth fill, topsoil, and indigenous vegetation. The middle diagram in Figure 5-1 shows this type of cap/cover option.

  The major difference of this selected remedial action compared to other alternatives is the placement of an HDPE cap over each of the spoils repositories. Its purpose is to prevent infiltration of surface water into the spoils, thus reducing the generation of acid rock drainage that would occur as surface seepage or contribute to mine water and groundwater contamination.

  Capping the spoils repositories with HDPE represents a practical but higher cost option that provides the long-term benefits of reduction in the amounts of contaminated surface seepage, mine water, groundwater, and surface water, and a higher level of protection against human and animal contact with the contaminated spoils. It is also more effective, reliable, and permanent over long time periods than soil covers and vegetation alone.

  Historically, the area below the East Avoca Pit and upgradient of Tigroney West has been an area of known or suspected subsidence. During relocation and grading of spoil piles in this area, unstable and weakened areas will be addressed by backfilling. An HPDE will also be placed over this area and will further stabilise the surface by bridging any remaining voids.

  - Surface water management technology will be the same as Alternative No. 1 - Solids.

5.1.1.3 East/West Avoca Alternative No. 3 – Solids

The various technologies and process options used to address solids sources and contaminated media, and physical hazards in Alternative No. 3 follow:

- **Institutional Controls** – The access controls and use restrictions are the same as for East/West Avoca Alternative No. 1 - Solids.

- **Relocation** – The Relocation actions for Alternative No. 3 - Solids will be the same as for Alternative No. 1 - Solids:

  - Mt. Platt, portions of East Avoca/Tigroney West spoils, and the Deep Adit spoils will be relocated to the Cronebane and East Avoca Pits.

  - At West Avoca, the spoil areas near Weaver's Lode Pit will be relocated to the base of the pit's highwall.

  - Relocation and restoration of the Tigroney Ore Bins will be completed as described under Alternative No. 1 - Solids.

- **Containment** – The solid source materials and contaminated media will be contained in the same way as Alternative No. 1 - Solids (i.e., with soil cover and vegetation). The notable difference for this remedial action is that an alternative approach to enhanced capping is used, as compared to Alternative No. 2 - Solids where HDPE is used. For this alternative, a lime-soil stabilisation of the regraded spoils surface will be accomplished by mixing (discing or tilling) an imported lime amendment within the top 300 mm of the spoils. This type of capping is intended to neutralise the surficial acid spoils and buffer the infiltrating water that passes through it, thus reducing the amount of acid water generation. Further, the additional 300 mm of lime-amended spoil offers a greater rooting depth for the indigenous vegetation. The bottom diagram of Figure 5-1 provides a schematic of this cap/cover. Each area of the Site is discussed below:

  - *Connary, Portions of East Avoca/Tigroney West, and West Avoca* – The spoil piles/areas to be reclaimed in place will be regraded to promote surface water drainage. The lime-soil stabilisation will be applied to the regraded spoil surfaces. Clean earth fill, topsoil, and indigenous vegetation will overlay the amended spoil surface.

  - *Cronebane, East Avoca, and Weaver's Pits* – The pit infills will be compacted and regraded to reduce or eliminate physical hazards and establish proper surface water runoff control. The lime-soil stabilisation will be applied to the regraded spoil surfaces. Clean earth fill, topsoil, and indigenous vegetation will overlay the amended spoil surface.

  - Surface water management technology will be the same as Alternative No. 1 - Solids.

5.1.1.4 East/West Avoca Alternative No. 4 – Solids

The various technologies and process options used to address solids sources and contaminated media, and physical hazards in Alternative No 4 follow:

- **Institutional Controls** – The access controls and use restrictions are the same as for East/West Avoca Alternative No. 1 - Solids.

- **Relocation** – The Relocation action for Alternative No. 4 - Solids will be the same as for Alternative No. 2 - Solids. However, prior to relocation, the pit areas will be prepared in a special way for this remedial action alternative, as described below under Containment.

  - Spoils and contaminated soils from Connary and Mt. Platt will be relocated to the prepared Cronebane Pit. The preparation is described under Containment.

  - Spoils and contaminated soils from East Avoca/Tigroney West/Deep Adit will be relocated to the prepared East Avoca Pit.

  - Spoils and contaminated soils from West Avoca, including the spoils adjacent to Avoca/Rathdrum Road and in the vicinity of the Road Adit (SP39), will be relocated to the prepared Weaver's Lode Pit and its vicinity.

  - Removal of the Tigroney Ore Bins will be completed as described under Alternative No. 1 - Solids.

  - Excavated areas will be filled with clean soil and regraded to promote surface water drainage. These areas will then be covered with clean earth fill followed by a layer of topsoil and indigenous vegetation.

- **Containment** – This response action provides for placement of the spoils in prepared cells lined with HDPE. The pit repository sites will be leveled and graded to provide a platform for cell construction. The cell foundation will consist of a layer of compacted fine-grained soil overlain by an HDPE liner. The HDPE will be overlain by a protective sand and gravel drain layer that will incorporate underdrain piping for collecting and directing water that leaches through the placed spoils. Depending on the spoil gradation, a geotextile may cover the drain layer. The spoils will be placed on the drain or geotextile layer. The water that leaches through the spoils repository will be captured and directed to treatment.

  - The spoils repository will be constructed so its sides are contained by the pit highwalls or will be mildly sloped for stabilisation and to provide for cover placement, revegetation, surface water control, and maintenance.

  - When the spoils repository is filled, the lime stabilisation process option will be applied to the spoil surfaces in order to limit the generation of acid drainage and enhance vegetative growth. Soil/topsoil cover and indigenous vegetation will overlay the lime-amended spoils.

  - This remedial action is intended to condition and direct any infiltrating surface water and capture and direct to treatment any seepage or intermittent tunnel discharges that may enter the repository from the backfilled highwalls. For this remedial action, this type of spoils repository will be located at the Cronebane, East Avoca, and Weaver's Lode Pits.

- Surface water management technology will be the same as Alternative No. 1 - Solids.

5.1.1.5 East/West Avoca Alternative No. 5 - Solids

The various process options identified for Solid Alternatives Nos. 1 to 4 would be used in development of this Alternative. The only difference in this Alternative is the proposed option for Mt. Platt. Evaluations indicate that it is not necessary to completely remove Mt. Platt to accomplish stabilisation. Accordingly, this alternative removes from Mt. Platt only the material necessary to establish structural stability and a shape suitable for reclamation and long-term maintenance. Mt. Platt will remain, but its peak will be a little lower and the peak will be set back from the East Avoca Pit highwall by about 200 m. To achieve stable slopes (i.e., 3-to-1 slopes), approximately 80 percent of Mt. Platt will be removed. Spoils samples from the Cronebane Pit area and the Mt. Platt boreholes showed the materials to be well graded and unsaturated. Materials of this nature and condition will be structurally stable and workable if placed at an overall slope ratio of 3 horizontal to 1 vertical (3-to-1) or 18.4 degrees. Currently, Mt. Platt side slopes typically range from 33 degrees to 48 degrees with steeper slopes in some localised areas. Unsaturated Mt. Platt spoils placed at 18.4 degrees should have a conservative Factor of Safety (FOS) of approximately 1.5. This FOS is consistent with the Best Available Techniques (BATs) Reference Documents (BREFs) provided by the European Integrated Pollution Prevention and Control (IPPC) Bureau (European Parliament IPPC Directive 2008/1/EC). Chapter 5 of BREF 12.01, Non-Ferrous Metal Processes, states that the BAT for a "waste-rock management facility" is to "apply a safety factor of at least 1.3 to all heaps."

5.1.2 East/West Avoca Water

5.1.2.1 East/West Avoca Alternative No. 1 – Water

The various technologies and process options used to address water sources and contaminated media, and physical hazards in Alternative No. 1 follow:

- **Institutional Controls** – The access controls and use restrictions are the same as East/West Avoca Alternative No. 1 - Solids. Another option is added to account for the prospect of mine-contaminated groundwater supply. The selected process option for an alternative water supply is installation of new house wells, based on an assumption that only a few domestic wells, if any, are affected by acid mine water. However, most all homeowners have been connected to public water supplies.

- **Containment** – Containment in the context of water sources and contaminated media relates to source control (keeping water from entering the underground mine workings) and discharge control (capturing contaminated drainages/ discharges and directing them to treatment).

- *Source Control* – The selected process option is shaft sealing/shaft plugging. There are an estimated 25 shafts that are visible or suspected of being uncovered/discovered at East/West Avoca. A shaft seal/plug constructed in the following manner will be applicable to all or most of the shaft sites. A circular, reinforced Concrete "T-Plug" will be used. The T-Plug cap section (top of the T) will be about 3.4 m in diameter; it will extend one m from the bottom of the T-Plug cap. Grout tubes will be installed through the T-Plug cap to the face of the T-Plug leg. A mastic seal or air bladder seal will be located around the perimeter, at the bottom of the T-Plug leg. The T-Plug will be fabricated onsite and its dimensions will be adjusted to fit individual shaft conditions. To place the plug, an excavation will occur, centered on the shaft to be plugged. The excavation will be approximately 7 m in diameter at the surface, and 4 m in diameter at its total depth of 3 m. A smooth platform, approximately 1 m wide will be prepared around the shaft at the bottom of the excavation. The T-Plug will be lowered into the shaft. The T-Plug leg will extend 1 m into the shaft. The bottom of the T-Plug cap will sit on the prepared platform. Cementitious grout will be injected between the shaft wall and the T-Plug leg. The excavation will be backfilled; the shaft site will be covered with soil/topsoil and revegetated. Where appropriate, the seal/plug will accommodate access by bats. This option will be effective in eliminating or substantially reducing surface water entry. As well, it acts as a barrier to eliminate the physical hazard.

  The procedure of excavation to expose or better define unidentified surface or near-surface mine voids/cave-ins/subsidence features, then backfilling the opening or depression, is selected as a cost-effective process option for source control. Such features are anticipated to be small and can be filled with the spoils during regrading. Again, the same remedial action eliminates or reduces the physical hazards associated with mine openings.

- *Discharge Control* – The selected remedial action for the major discharges at the Deep Adit and Road Adit is the installation of control bulkheads at some distance within the adits, where there is competent rock for anchoring the bulkheads. Tunnel rehabilitation will precede the bulkhead construction. Piping will extend through the reinforced concrete bulkheads and direct the mine water to the active treatment plant. Valves will be installed on the piping to control the mine discharge when necessary (e.g., upset conditions or maintenance at the treatment plant). The bulkheads serve the additional function of eliminating the danger of mine entry.

  In addition to the Road and Deep Adits, there are an estimated nine mine adits/ mine openings that flow perennially or intermittently; the significant ones require discharge control. With one exception (Cronebane Shallow), these are relatively low-flow discharges. Most are located at or above the East Avoca Pit elevation. The Cronebane shallow discharge contributes a substantial metal load to the Deep Adit. While the other adits currently do not contribute substantial loads, water control at all accessible source areas is typically very cost-effective and past data indicate loads can vary. In addition, bulkheads provide surge control, stabilise openings, and prevent entry. A type of reinforced concrete bulkhead, termed a shallow leaky bulkhead, can be installed in the openings following site preparation, including portal construction and tunnel rehabilitation for a short distance into the opening. A drain pipe, with no valve for discharge control, will extend through the bulkhead and transport water to either a collection location or a treatment facility, depending on the treatment option. Where appropriate, the structure would allow access by bats. The bulkheads will also prevent unauthorised entry to the mine workings and eliminate physical hazards.

- **Collection/Removal** – The transport of acid mine and acid rock drainage water between effluent locations, treatment facilities, and eventual treated water discharge will be accomplished with installation of inlet/outlet structures, channels, and piping. The active treatment system will be located in the vicinity of the Deep Adit, several metres above the Avoca River. The likely location for a passive treatment facility is downgradient from the East Avoca Pit in the East Avoca area. Consequently, all or most of the low-flow adit discharges would be contained in pipes and flow by gravity to the passive treatment facility.

- **Treatment** – An active treatment-lime precipitation facility is the selected process option for at least the major portion of acid water discharges, including the Deep Adit and Road Adit discharges, at East/West Avoca. The treatment process will be based on the successful pilot plant studies conducted in 2006 at the Avoca Mine Site (*Avoca Mines Pilot Plant Treatment Trials*, Unipure Europe, 2007; www.celtic-copper.eu/page.asp?id=2170.). Figure 5-2 provides a schematic diagram of the proposed treatment system.

  As shown in Figure 5-2, the treatment process includes the following process units:

  - Mine water transfer system (pump and pipe)
  - Lime silo, slaker, and dosing system
  - Reactor tanks, mixers, and blowers (aeration)
  - Polymer dosing system
  - Lamella clarifiers
  - Filter press
  - Sludge holding tanks
  - Treated water monitoring and discharge system

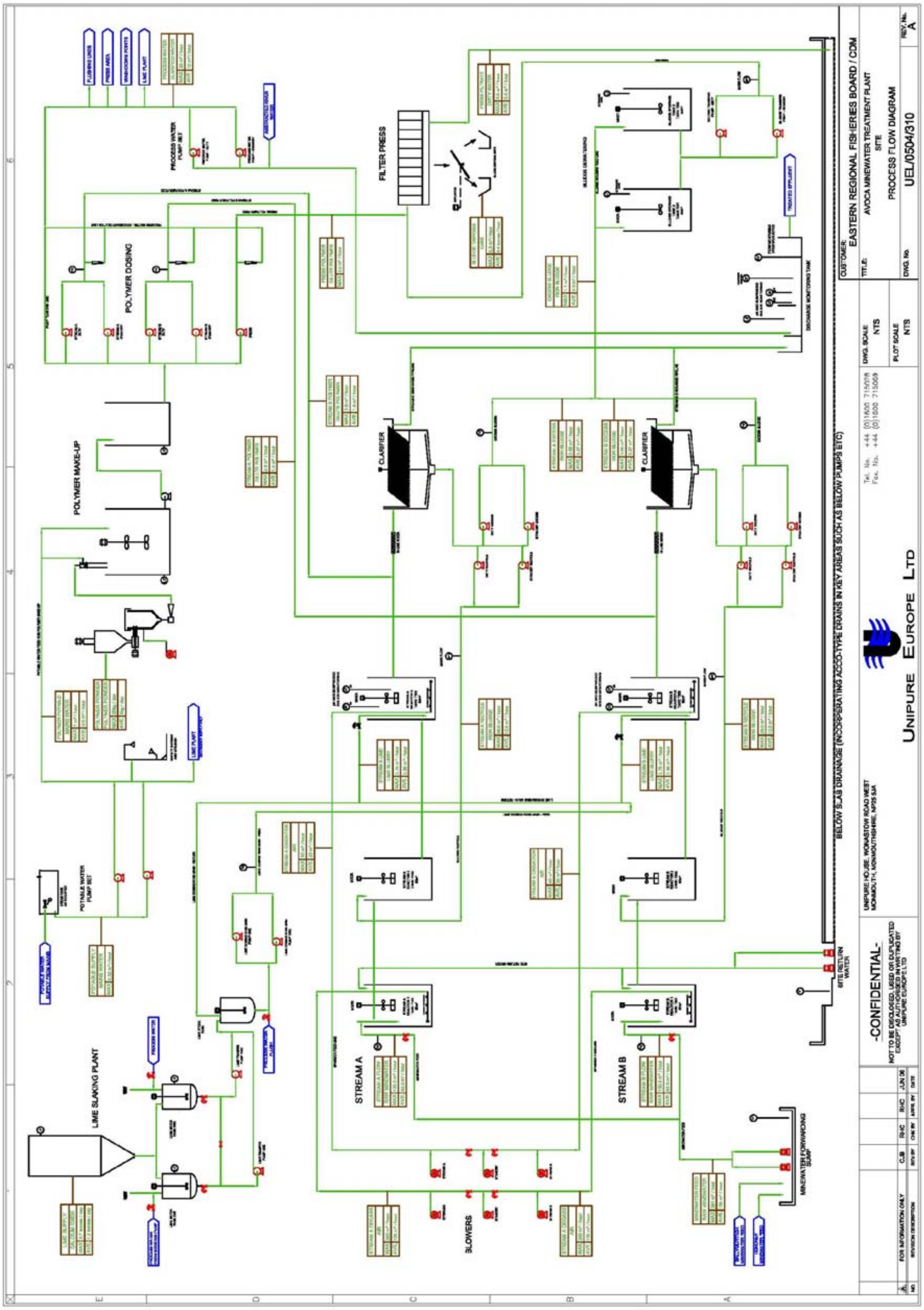


Figure 5-2 Process Flow Diagram

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The plant is sized to handle up to 72.5 l/s with an average flow rate of 35 l/s. The anticipated quality of the discharge water follows:

Parameter	Dissolved Concentration (mg/L)
Fe	0.08
Zn	0.07
Al	0.36
Cu	0.01
Cd	0.007

As discussed in Section 2.7.6, treatment of both diffuse flow (groundwater) and adit discharges (Deep and Road Adits) will result in water quality in the Avoca River near applicable Water Quality Regulations. Approximately 1.85 metric tonnes /day of treatment solids will be generated.

A passive treatment system is the selected process option for some or all of the higher elevation low flow/intermittent flow discharges. A preliminary treatment process, based on the high metal concentrations (Fe, Al, Zn), includes pretreatment by diffusion wells (lime columns) and settling, then an anaerobic wetland followed by one or more natural aeration processes. The combination of these processes is required to remove aluminum and iron in addition to the base metals such as copper and zinc.

- **Disposal/Discharge**
  - Treated water from passive systems would be discharged to a detention basin, then to a surface drainage channel. The discharge would be intercepted upgradient from the active treatment plant for water quality testing. Depending on test results, the passive treatment discharge would be diverted to the active treatment plant or directed to the Avoca River.
  - Active treated water would be monitored and recycled through the treatment plant or discharged to the Avoca River, depending on monitoring results.
  - For Alternative No. 1 - Water, treatment waste generated from both active and passive treatment would be collected and transferred by truck to an offsite location for disposal.

5.1.2.2 East/West Avoca Alternative No. 2 - Water

The various technologies and process options used to address physical hazards, water sources and contaminated media in Alternative No. 2 follow:

- **Institutional Controls** – except for the groundwater supply component, the access controls and use restrictions are the same as for East/West Avoca Alternative No. 1

- Water. The selected process option for an alternative water supply is the development of a small municipal water supply system.

- **Containment** – The Containment response action for Alternative No. 2 - Water is the same as for East/West Avoca Alternative No. 1 - Water:

  - Source control includes the process options of shaft sealing/plugging, excavation, and backfilling.

  - Discharge control includes the process options of control bulkheads and shallow leaky bulkheads.

- **Collection/Removal**

  - The surface/mine water remedial technology and process options of inlet/outlet structures, ditches and channels, piping, and pumping are the same for Alternative No. 2 as for Alternative No. 1 - Water.

  - *Groundwater Extraction* – The very important consideration of capturing and treating contaminated groundwater is accounted for in this East/West Avoca remedial alternative for water sources and contaminated media. Degradation of Avoca River quality from diffuse flows (groundwater discharge to the river) proximate to the mine areas has long been suspected. Results from investigations undertaken in the course of this study indicate that the Avoca River is being impacted by diffuse flows from the east side of the river in the vicinity of the Deep Adit, and from the west side of the river from the north end of the Emergency Tailings Pond south to the vicinity of the Road Adit. Evaluations indicate that this diffuse flow component must be captured and treated to maximise the probability that water quality standards will be achieved in the Avoca River.

    A combination of process options are selected for this remedial action, including the construction of soil bentonite walls and the installation and operation of groundwater extraction wells. A soil bentonite wall is constructed by excavating a deep trench, mixing the soil from the trench with liquefied bentonite, and returning the mixture to the trench. The mixture becomes virtually impermeable as it solidifies. It performs effectively as a wall or barrier to groundwater flow. A series of extraction wells would be installed upgradient from the soil bentonite wall. The wells would direct the contaminated groundwater into a pipe network that would transmit the groundwater to the Avoca Project treatment plant.

    It is desirable for the soil bentonite walls to tie into bedrock below alluvium. Investigations indicate that the alluvium near the river is deep, on the order of 30 m or deeper. Consequently, depending on the soil bentonite wall locations and characterisation of the depth of contaminated groundwater, grouting below the walls could become part of the process option because soil bentonite walls are typically not constructed over 25 m in depth with a long-arm backhoe (JCB).

The length of the proposed soil bentonite wall and well field on the east side of the river is 375 m. It would be located between the river bank and the railway. The estimated length of the soil bentonite wall and well field on the west side of the river is 750 m. It would be located between the river bank and the west side of Avoca/Rathdrum Road. Anticipated depths are 23 to 25 m.

- **Treatment** – This Alternative is the same as for East/West Avoca Alternative No. 1 - Water:
  - An active treatment, lime precipitation facility, located in the vicinity of the Deep Adit, will be used for at least the major portions of the acid water discharges. There is no change to this process option except to note that the contaminated groundwater from the groundwater extraction remedial action will also be delivered to the plant. It is estimated that this additional water will not change the process configuration or the overall size of the treatment facility.
  - A passive treatment system, located at East Avoca, downgradient from the East Avoca Pit, will be used to treat the higher elevation low flow discharges.
- **Disposal/Discharge**
  - The discharge process options for the active treatment plant and the passive treatment system are the same for this remedial action as they are for Alternative No. 1 - Water.
  - There is a major change in the disposal process option for this remedial action, compared to Alternative No. 1 - Water. Solid treatment waste from the active and passive treatment facilities will be disposed in a constructed onsite solid treatment waste disposal facility. The facility will be located in the reclaimed Cronebane/Mt. Platt area. It will be constructed as a permanent storage cell for the solid treatment wastes. The cell will be constructed on compacted fine grained soil, overlain by an HDPE liner. The liner will be overlain by a gravel and pipe underdrain system that will be covered by geotextile. Leachate or seepage from the overlying solid waste will be captured by the underdrain system and directed to treatment. The repository will be contained by earth embankments on all sides. A schematic diagram of the waste facility is provided in Figure 5-3.

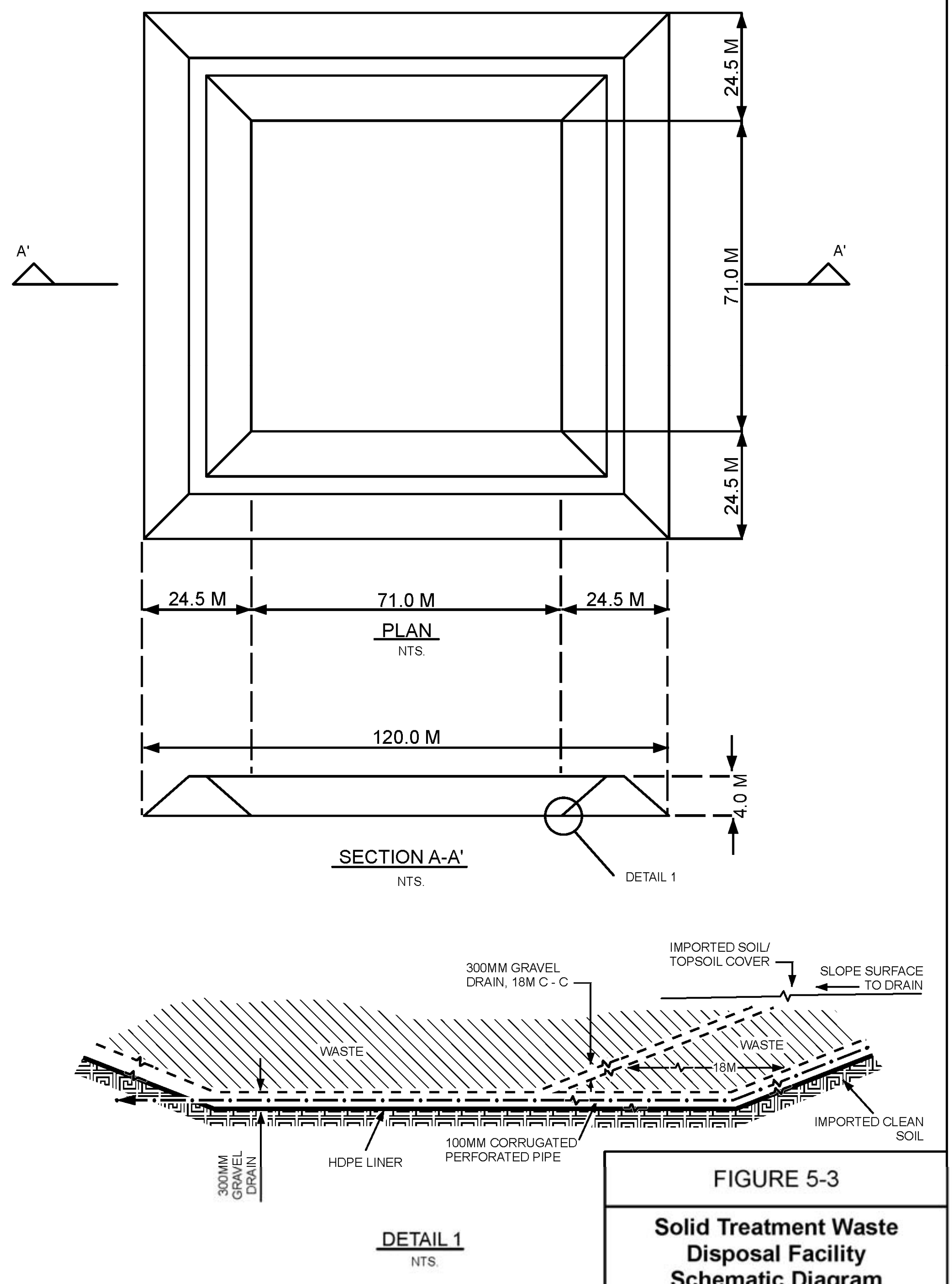


FIGURE 5-3

Solid Treatment Waste Disposal Facility Schematic Diagram

The solid treatment waste from the active treatment plant will be a filter cake derived from the plant's filter press. It will be suitable for loading, hauling, and placing with conventional equipment. The treatment plant is estimated to generate 2 tonnes (about one truck load) of solid treatment waste per day. A private all-weather road between the treatment plant and the waste repository will provide ingress and egress that does not interfere with public traffic.

The solid treatment waste from the passive treatment system will require removal and disposal infrequently (estimated once every 5 years) when the substrate, consisting of straw, limestone, gravel, wood chips, processed manure, and soil type materials, has to be replaced. It will be conditioned and loaded, hauled, and placed in the onsite disposal facility using conventional equipment.

A representative size for a facility that would contain 10 to 12 years of the generated solid treatment waste is 120 m square by 4 m high. Infrastructure for the facility may include a small building and garage. After 10 to 12 years, the facility can be raised to handle more waste or an additional facility can be constructed. When the facility is filled, its surface will be reclaimed with a soil/topsoil cover and indigenous vegetation. See Figure 5-3 for a schematic of the facility.

5.1.2.3 East/West Avoca Alternative No. 3 - Water

The various technologies and process options used to address physical hazards, water sources, and contaminated media in Alternative No. 3 follow:

- **Institutional Controls** – The access controls and use restrictions are the same as East/West Avoca Alternative No. 1 - Water. If required, the alternative water supply will be installation of a few house wells.

- **Containment** – This alternative will have the same containment measures as those outlined for Alternative No 1 - Water. However, source control would be enhanced and acid mine water generation decreased by the additional process of backfilling mine workings. Backfilling will reduce subsidence and the occurrence of pathways for surface water to enter the mine workings resulting in acid water generation. This technology could also be part of the solids alternative in that subsidence is addressed. However, it is discussed in this section because it is mainly used to address generation of acid mine water. Backfilling of underground mine workings is the only difference between this remedial action and Alternative No. 1 - Water.

  - The typical process of backfilling abandoned underground mine voids that cannot be filled from the surface is to access the voids/mine workings through large diameter drill holes. The success of backfilling underground mine workings in this way is highly dependent on the conditions in the mine. If extensive reaches of open workings can be discovered, backfilling by sluicing or other hydraulic methods is viable. If there are frequent roof falls/cave-ins within the mine workings, the backfilling process becomes inefficient and more expensive. If the underground workings are close to the surface, hydraulic backfilling can cause more subsidence to occur. In the case of Avoca, another consideration for backfilling the underground mine workings is the short-term impacts on the Avoca River. The backfilling procedures require large volumes of water to be injected to the mine workings, in order to move solids into the voids. A consequence will be a flushing affect in the mine, causing surges of acid mine drainage to the river.

  - The surface water management technology for this remedial action is the same as East/West Avoca Alternative No. 1 - Water.

- **Collection/Removal, Treatment** – These response actions incorporate the same remedial technologies and process options as East/West Avoca Alternative No. 1 - Water.

- **Disposal/Discharge** – This response action incorporates the same remedial technologies as East/West Avoca Alternative No. 1 - Water.

5.1.2.4 East/West Avoca Alternative No. 4

The various technologies and process options used to address water sources and contaminated media, and physical hazards in Alternative No. 4 follow:

- **Institutional Controls** – The access controls and use restrictions are the same as East/West Avoca Alternative No. 1 - Water. If required, the selected process option for an alternative water supply is installation of a few house wells.

- **Containment** – The Containment response action for Alternative No. 4 - Water is the same as for East/West Avoca Alternative No. 1 - Water:

  - Source control includes the process options of shaft sealing/plugging, excavation, and backfilling.

  - Discharge control includes the process options of control bulkheads and shallow leaky bulkheads.

- **Collection/Removal**

  - The surface/mine water remedial technology and process options of inlet/outlet structures, ditches and channels, piping, and pumping are the same for this remedial action as for Alternative No. 1 - Water.

  - The groundwater extraction remedial technology and process options of soil bentonite walls and well fields located on the east side and west side of the Avoca River are the same for this remedial action as for Alternative No. 2 - Water.

- **Treatment** – Only the process option of active treatment–lime precipitation will be used for this remedial action. All contaminated mine water and groundwater discharges at East/West Avoca will be directed to the active treatment plant located in the vicinity of the Deep Adit. The conveyance process will be pipelines in all cases—Deep Adit and Road Adit discharges, higher elevation low-flow discharges, and groundwater extraction discharges.

- **Disposal/Discharge**

  - Discharge from the active treatment plant will be monitored and recycled through the treatment plant or discharged to the Avoca River, depending on monitoring results. Storage tanks will be required.

  - The solid treatment waste from the active treatment plant will be disposed in the onsite solid treatment waste disposal facility as described in the East/West Avoca Alternative No. 2 - Water.

5.2 Avoca River Sediments Preliminary Remedial Action Alternative

Observations, sampling, and testing of the sediments in the Avoca River study area indicate impairment to the benthic and macroinvertebrate communities, and elevated concentrations of copper, lead, and zinc in the sediments. Also, the sediments with high concentrations of metals near the discharge points of the Deep and Road Adits contribute dissolved metals to the Avoca River water. In some cases, removal of contaminated river sediments is thought to be more harmful than leaving the contaminated sediments in place due to the disturbance and release of suspended materials during removal. Sediments could be left in place and no further action taken. This approach, referred to as monitored natural recovery, assumes that if the contamination sources (discharges and diffuse flows) are effectively treated that the sediments will recover over time.

Monitored natural recovery may be the only viable option for reaches of the river downgradient from the Avoca Mine area. However, this approach is questionable for the reach of the Avoca River that has received the heaviest mine-related contamination. There are large ferricrete deposits on both sides of the river in the vicinities of the Deep Adit discharge on the east bank, and the Road Adit discharge on the west bank. These sediments may be in some stage of steady state where new deposition occurs as a result of the acid-metal discharges, while contaminated sediments also are transported downgradient as a result of erosion and other river-related mechanisms. As previously discussed, these deposits also act as secondary sources and contribute dissolved metals to the Avoca River.

Even with the capture and treatment of the adit discharges and diffuse flows, the ferricrete masses will continue to release contaminated sediments and dissolved metals to the river system for some period of time. Monitored natural recovery for these sediments and ferricrete deposits does not fit the desired or expected recovery time for the Avoca River. Monitored natural recovery is the No Action (with monitoring) alternative and is not acceptable for the ferricrete deposits and contaminated sediments in the Avoca River at the discharge points of the Deep and Road Adits.

The ferricrete masses are in two concentrated locations along the Avoca River banks. The locations can be made accessible to conventional earth moving equipment. Primarily because the Avoca River is relatively shallow in the reach of concern, reasonable and practical precautions can be taken to control/reduce the release of suspended materials to the downstream, and at least some of the suspended materials may be recovered and disposed of using suitable river dredging equipment.

The following remedial action is removal and disposal of the Avoca River sediments and ferricrete deposits in the vicinity of the Avoca Mine area.

5.2.1 Avoca River Sediments Alternative No. 1

The various technologies and process options used to address removal of Avoca River sediments and ferricrete deposits follow. The response actions are ordered, more or less, in the sequence of construction.

- **Containment, Phase 1**

  - *Regrading, Earthwork*

    Access/Haul Roads to River – Construct a river access/haul road on the east bank to cross through the Deep Adit spoils area, then follow the river bank south to downgradient from the ferricrete deposits on the east bank. On the west side of the river, construct a river access/haul road between the Avoca/Rathdrum Road and the river, in the vicinity of the south end of the Wicklow County Council maintenance yard.

    Work Platform and Flow-Through/Check Dam – Extend a work platform from the west side river bank into the river, then south, parallel to the river bank, to a location south of all visible ferricrete deposits. The work platform will be constructed by dumping large rip rap in the river, and progressively advancing south on the rip rap surface (work platform).

    Using the same dumping-advancing procedure, construct a flow-through/check dam across the river. Install a geofabric (filter) material on the upstream face of the dam.

    Ferricrete/Sediment Repositories – Construct a ferricrete repository on the east side of the river, in the vicinity of the lower end of the East Avoca area or in the Tigroney West area. The repository will be constructed in a similar manner as the solid treatment waste disposal facility—prepared foundation, HDPE liner, gravel/pipe underdrain, earth embankment on all sides. A facility separate from the solid treatment waste facility is required because the dredged sediments will contain water and require dewatering via drainage. Construct a dredged sediment basin/repository on the west side of the river, in the vicinity of the south end of the Wicklow County Council maintenance yard. Construct the repository in a similar way as the solid waste treatment repository, with one notable difference. The dredged sediment repository will receive sediments directly from a river dredge. The pumped material from the dredge will be mostly river water. Thus, the repository has to be configured as a sedimentation basin with the utility to decant the water back to the river. Under-drainage and decant from the repositories will be piped to the active treatment plant. When the drainage and decant is completed, the structures will be closed.

- *Surface Water Management*

  Culverts and lined ditches, channels, and berms will be installed to account for road drainage, sediment repository discharge, and peripheral drainages from work areas and repositories.

- **Removal**

  - *Excavation, Earthwork*

    Use conventional track-mounted earthmoving equipment, such as excavators and front-end loaders, to remove the ferricrete deposits from the river. The ferricrete deposits will be accessed from the prepared river bank on the east side of the river. The deposits will be accessed from the work platform on the west side of the river.

    Load lined highway haulers, haul, and place the ferricrete in the ferricrete repository.

  - *Excavation, Dredging*

    Following removal of the ferricrete deposits by conventional earthmoving equipment, employ a river dredge to dredge the areas of the ferricrete masses for remaining deposits, and dredge for sediments in the river and along the river banks upstream of and at the face of the flow-through check dam. The dredge will pump the sediments to the sediment repository.

    The total volume of ferricrete deposits removed by excavation or dredging is estimated to be 1,340 cubic metres on the west side and 1,760 cubic metres on the east side of the Avoca River.

- *Decommission Flow-through/Check Dam, Repair River Bed/Banks*

  Using conventional, track-mounted earth moving equipment, remove the rip rap from the dam and work platform. Use the rip rap to repair the disturbed areas of the river bed and banks. Relocate the remaining rip rap along each side of the river in proportion to the volume of ferricrete deposits that was removed.

- **Containment, Phase 2**
  - *Regrading* – Work areas and access/haul roads will be regraded to final stable contours.
  - *Cap/Cover* – Soil and topsoil covers will be placed on the completed repositories. Topsoil will be placed on areas to be revegetated.
  - *Revegetation* – Disturbed areas will be revegetated.
  - *Surface Water Management* – Culverts and ditches will be stabilised.
- **Institutional Controls**
  - Fencing, gates, and signage will restrict access and surround the repositories. Legal restrictions on access will be established and posted.

5.3 Emergency Tailings Ponds Preliminary Remedial Action Alternative

The Emergency Tailings Pond (ETP) at West Avoca is located between Avoca/ Rathdrum Road and the Avoca River in the vicinity of the old mine company offices and north of the Wicklow County Council maintenance yard (see Figure 2-3). Two alternatives were formulated: a relocation remedial action and no action with monitoring. A relocation remedial action was evaluated based on the assumption that the ETP was a significant contaminant source to the Avoca River. The tailings would be removed from the ETP and relocated, via R752 (Avoca/Rathdrum Road) and R747, to a prepared containment repository at the Shelton Abbey Tailings site. Transportation through Avoca Village would not occur and access to the repository would be achieved by using the bridge (currently closed) near the former fertiliser plant – about a 12 km trip. Both the ETP site and the Shelton Abbey repository site would be stabilised and reclaimed following the relocation. This action is ETP Alternative No. 1. Site characterisation has shown that the emergency tailings are relatively dry (i.e., no water moves through the tailings). In addition, groundwater upgradient of the ETP is already contaminated. No major additional metal load is introduced into the groundwater by interaction with the emergency tailings. The upgradient contaminated groundwater is addressed by East/West Avoca Water Alternatives (see Section 5.1.2). Therefore, a No Action with Monitoring Alternative was also evaluated for the ETP. This is Alternative No. 2. Each Alternative is described in more detail in the next sections**.**

5.3.1 Emergency Tailings Pond (ETP) Alternative No. 1

The general response actions, technologies, and process options used to address the relocation of the tailings from the ETP follow. The response actions are ordered, more or less, in the sequence of construction.

- **Containment, Phase 1**
  - *Regrading, Earthwork*

    Access/Haul Roads – A gravel access/haul road will be constructed from R752 (Rathdrum/Avoca Road) into and across the ETP. Paved road improvements will be constructed between R747 and the Shelton Abbey Tailings site. A gravel access/haul road will be constructed into the new repository site.

    Shelton Abbey Tailings Site, New Repository – A containment repository will be constructed in the southeast part of the Shelton Abbey Tailings site to receive the ETP tailings. The area will be cleared and the foundation materials will be rolled. An earthen embankment will be constructed on all sides.

    ETP Site – Clear the site. Remove and store soil/topsoil from the ETP surface.

  - *Surface Water Management*

    Install culverts, ditches, and sedimentation traps for drainage control during construction at the ETP site and the new repository site.

- **Relocation**
  - *Excavation, Earthwork*

    The ETP tailings, which are dry, will be excavated and loaded into highway trucks with conventional earth moving equipment. They will be hauled to and dumped at the new repository site. Conventional earth moving equipment will place the tailings in the repository.

- **Containment, Phase 2**
  - *Cap, Cover, and Revegetate*

    An HDPE cap will be placed over the surface of the new, filled repository. Underdrains will be located over the HDPE to direct precipitation infiltration to peripheral drainage. The cap will be covered with soil and topsoil and revegetated. Figure 5-1 (middle diagram) shows the cap/cover configuration.

Except for a maintenance access track, all disturbed areas will be covered with topsoil and revegetated.

Clean fill will be placed and compacted where the ETP tailings were removed. The ETP site will be regraded to final contours. A soil/topsoil cover will be placed over the disturbed areas. Except for a maintenance access track, all disturbed surfaces will be revegetated.

- *Surface Water Management*

  Final drainage configurations will be established at both sites, including culverts, drainage ditches, channels, and sedimentation basins.

- **Institutional Controls**

  - Fencing, gates, and signage will restrict access to the new repository at the Shelton Abbey Tailings site and the reclaimed ETP site. Restrictions on access will be established and posted.

5.3.2 Emergency Tailings Pond (ETP) Alternative No. 2

As previously discussed, the emergency tailings do not appear to contribute metal loads to the Avoca River. The metal concentrations in the solid tailings are relatively low and do not present a human health risk. As a result, a No Action Alternative with Monitoring is included as a potential alternative. The proposed monitoring is discussed in Section 6.3 and will include surface water monitoring upgradient and downgradient of the ETP.

5.4 Shelton Abbey Tailings Preliminary Remedial Action Alternatives

Two Alternatives were developed for the Shelton Abbey Tailings site for solid sources and contaminated media, and two Alternatives were developed for the Shelton Abbey Tailings site for water sources and contaminated media. The remedial actions were selected to evaluate the range between effective but relatively lower cost technologies and effective but higher cost technologies and process options. The focus is on achieving the human health and ecological remedial action objectives. The physical hazards remedial action objective is a lesser consideration because most of the physical hazards associated with the mine sites are not present at the Shelton Abbey Tailings site. The tailings are covered and the high tailings embankment is evidently stable, representing a very low to low risk physical hazard.

Current site conditions result in water ponding in the southeast portion of the Shelton Abbey Tailings facility on the inside (upgradient side) of the tailings embankment. This ponding is the most significant source of seepage into the tailings and subsequent impact on the groundwater below the tailings and surface water ponds at the base of the embankment. The seepage may also contribute to future unstable conditions in the embankment. The ponding is caused by the current conditions of the perimeter drainage ditches and culverts and the fact that the area of ponding is currently a low area where water can accumulate relative to the rest of the Site. The condition of the ditches and culverts and the low area in the southeast part of the Site must be addressed. The low area is most easily and cost-effectively addressed by addition of clean fill to raise the elevation of the area and eliminate ponding. Other appropriate actions such as regrading to achieve an appropriate drainage gradient or installation of ditches or pipes would require significant excavation into tailings and would not be as cost-effective as addition of fill. Therefore, both of the Alternatives formulated below address surface water management by the addition of clean fill to the low portion of the Site. As discussed below, the difference in the two alternatives is the type of cover selected for the Site.

5.4.1 Shelton Abbey Tailings Solids

5.4.1.1 Shelton Abbey Tailings Alternative No. 1 – Solids

The various technologies and process options used to address solid sources and contaminated media in Alternative No. 1 - Solids follow. The focus is on regrading the Site to improve the drainage from the covered and vegetated tailings repository surface. Ponding water in the southeast corner of the Site is the most significant source of seepage into the main tailings site embankment and possibly into weak or cracked zones in the tailings. The tailings facility surface and perimeter drainages as currently operating are more conducive to small areas of standing water than drainage control.

- **Institutional Controls** – Access controls, including legal restrictions on access, as well as fencing, gates, signage, or other barriers are used for this remedial action alternative. There are two accesses into the Site – the lower perimeter road and the upper road. Both will require fencing and gating. Institutional controls, especially legal restrictions, may be relatively complicated because of the present land uses and present claims to access and land uses.

- **Containment –**

  - *Regrading, Earthwork (to address surface water management)*

    Access/Haul Road – A gravel access/haul road will be constructed along the upper entrance road and into the Site.

    Clearing and Topsoil Stockpiling – Work areas along the perimeter of the Site and the upgradient side (inside) of the main embankment will be cleared. Where feasible, topsoil will be excavated and stockpiled for use in site reclamation.

    Earthwork – Imported clean earth will be used to fill in low areas, and for construction of a wide, mild-sloping buttress against the inside of the main embankment and extending into the tailings site surface. Regrading will occur to establish positive drainage, typically to the north and east.

- *Cover and Revegetation* – Regraded and built-up areas will be covered with topsoil. The disturbed areas will be planted with indigenous vegetation.
- *Drainage Ditches and Culverts (to address surface water management)* – New cross-drainage and perimeter drainage ditches will be constructed. Culverts will be installed at road crossings and under berms. One or more sedimentation ponds will be located at or near discharge points.

5.4.1.2 Shelton Abbey Tailings Alternative No. 2 – Solids

The various technologies and process options used to address solid sources and contaminated media in Alternative No. 2 - Solids follow: The focus is on covering the tailings site surface with a geosynthetic cap (HDPE) to limit to a great extent any infiltration to the tailings that may occur. Surface water management would establish positive runoff drainage control throughout the resurfaced site.

- **Institutional Controls** – Institutional controls will be the same as Alternative No. 1 - Solids.
- **Containment** –
  - *Regrading, Earthwork (to address surface water management)*

    Access/Haul Road – The access/haul road will be the same as for Alternative No. 1 - Solids.

    Clearing and Soil/Topsoil Stockpiling – The Site will be cleared of vegetation. Topsoil will be excavated and stockpiled for use in site reclamation. Soil will be excavated and stockpiled for use in contouring the Site surface prior to liner installation and cover following the installation.

    Earthwork – The tailings surface will be regraded and rolled in preparation for liner placement.

  - *Cap, Cover, and Revegetation* – An HDPE liner will be placed on the prepared tailings site surface. The liner will be covered with clean fill and topsoil. The disturbed areas will be planted with indigenous vegetation. Figure 5-1 (middle diagram) shows the cap/cover configuration.
  - *Drainage Ditches and Culverts (to address surface water management)* – Surface water management will be the same as Alternative No. 1 - Solids.

5.4.2 Shelton Abbey Tailings - Water

5.4.2.1. Shelton Abbey Tailings Alternative No. 1 - Water

The various technologies and process options used to address water sources and contaminated media in Alternative No. 1 - Water follow: Alternative No. 1 - Solids had practical, but not totally effective actions to reduce infiltration through the tailings site surface. In addition, groundwater upgradient of the tailings may interact with the base of the contaminated tailings resulting in contaminated groundwater. To address contaminated groundwater, a relatively high cost alternative of groundwater extraction using a soil bentonite wall and a well field is selected for this remedial action.

- **Institutional Controls** – Institutional controls will be the same as for Alternative No. 1 - Solids.

- **Collection/Removal**

  - *Groundwater Extraction* – A combination of process options are selected for this remedial action, including the construction of a soil bentonite wall and the installation and operation of extraction wells at the base of the main embankment along the lower perimeter road. The soil bentonite wall/extraction wells would extend from about the middle of the north-south face to about half way around the west-east face (800 m). A soil bentonite wall is constructed by excavating a deep trench (9 m), mixing the soil from the trench with liquefied bentonite, and returning the mixture to the trench. The mixture becomes virtually impermeable as it solidifies. It performs effectively as a wall or barrier to groundwater flow. A series of wells would be installed upgradient from the soil bentonite wall. The wells would direct the contaminated groundwater into a pipe network that would transmit the water to an active treatment plant located at the Shelton Abbey Tailings site.

- **Treatment** – An active treatment lime precipitation facility, located either along the lower perimeter road or at the tailings site, will be used to treat the discharge from the well field. The treatment facility would employ the same type of process technology as the main Avoca mine site water treatment facility. The facility size and treatment capacity is estimated to be 20 per cent of the facility for the East/West Avoca area.

- **Disposal/Discharge** – Treated water will be disposed of in a detention basin, monitored for quality, returned to treatment if necessary, or discharged to the Avoca River. Solid treatment waste from the active treatment plant will be disposed of onsite in a constructed solid treatment waste disposal facility. The facility will be similar to but about 30 per cent of the size of the solid treatment waste disposal facility at the Cronebane/Mt. Platt site.

5.4.2.2 Shelton Abbey Tailings Alternative No. 2 – Water

The various technologies and process options used to address water sources and contaminated media in Alternative No. 2 - Water follow: Alternative No. 2 - Solids utilised an HDPE cap on the Shelton Abbey Tailings surface in order to achieve a major reduction in precipitation infiltration through the tailings. Consequently, a reduction in seepage from the Site to the river would be expected. An effective, but relatively lower cost option of groundwater extraction by drainage gallery is selected for this alternative. Also, a passive treatment system is selected because there would be less seepage to treat.

- **Institutional Controls** – Institutional controls will be the same as for Alternative No. 1 - Solids.

- **Collection/Removal**

  - *Groundwater Extraction* – The selected process option for groundwater extraction is a drainage gallery. The drainage gallery will be located between the toe of the main embankment and the lower perimeter road; it will extend from about the middle of the north-south face to about half way around the west-east face (800 m). The gallery is constructed by excavating a deep trench (9 m), lining a portion of the trench with geofabric, backfilling the lower two-thirds of the trench with a gravel drain containing a collection-drain pipe, and filling to surface with the excavated trench materials. The collection-drain pipe directs the seepage that enters the trench to a manhole-sump containing a submerged pump. The seepage is pumped from the sump to treatment.

- **Treatment** – A passive treatment system, located either along the lower perimeter road or at the tailings site, will be used to treat the discharge from the drainage gallery. The passive treatment system will employ the same type of process stream as the passive treatment system at the Avoca mine site.

- **Disposal/Discharge** – Treated water will be disposed of in a detention basin, monitored for quality, returned to treatment if necessary, or discharged to the Avoca River. Spent passive treatment system substrate will be disposed of onsite in a constructed solid treatment waste disposal facility. The facility will be a smaller version of the solid treatment waste disposal facility at the Cronebane/Mt. Platt site.

5.4.2.3 Shelton Abbey Tailings Alternative No. 3 – Water

As previously discussed, site characterisation has shown that the Avoca River water quality is not impacted by diffuse groundwater flow or run-off from the Shelton Abbey Tailings. Therefore, a No Action Alternative with monitoring is appropriate for consideration. Because the conclusion of no impact is based on limited sampling, monitoring should be continued on a routine basis. The information would be evaluated to determine whether any additional actions are necessary. Proposed monitoring is discussed in Section 6.3.

5.5 Screening of Alternatives

Prior to development of Site-wide combined alternatives, the different options proposed under each Alternative discussed in this section were evaluated for effectiveness, implementability, and relative costs at each individual site location. During this evaluation, the following process options were deleted from further consideration in the development of Site-wide combined alternatives:

- The additional costs for relocating all spoils and pit material into HPDE lined, under-drained cells (East/West Avoca Alternative No. 4 - Solids) did not provide a greater level of protection commensurate with the additional relative costs for this option. Therefore, placement of relocated spoils into under-drained cells was eliminated from further consideration.

- Estimated large area requirements and relative high cost eliminated the passive treatment process option for the East/West Avoca water alternatives, but the passive treatment option for the Shelton Abbey site is retained. However, construction of a pilot plant passive treatment system is added for East/West Avoca so site-specific design, cost, and effectiveness information may be developed. The hope is that the pilot plant will provide more cost-effective processes than currently proposed.

- Disposal of solid treatment waste offsite was eliminated as an option for all water alternatives due to anticipated high costs of transportation and the uncertainty of long-term access to a disposal facility able to receive the solid treatment waste.

- The larger costs for excavation and relocating the emergency tailings to Shelton Abbey (ETP Alternative No. 1) were considered not to be cost-effective. The emergency tailings are relatively impermeable and dry and therefore do not leach contamination via infiltration or upgradient groundwater. The upgradient groundwater is contaminated and any interaction with the bottom of the tailings does not substantially increase metal concentration in the groundwater. This groundwater contamination and interaction is addressed by the proposed soil bentonite wall and extraction wells discussed in East/West Avoca Alternative No. 2 - Water. The selected alternatives will not include relocation of the emergency tailings.

- Avoca River Sediments Alternative No. 1 only addresses sediments in the vicinity of the Deep Adit and Road Adit discharges to the Avoca River. These are the sediments with the highest metal concentrations that impact river water quality. Sediments downgradient of those locations will not be removed. Instead, these locations downgradient will be monitored to evaluate improvement in quality and macroinvertebrate habitat after water treatment. Therefore, the selected option for these downgradient sediments is monitoring and natural recovery.

- East/West Avoca Alternative No. 3 – Backfilling underground mine workings potentially reduces subsidence; however, backfilling may generate acid mine and rock water. This alternative is also eliminated from further consideration because of difficulty in implementation, anticipated low effectiveness, and relatively high cost.

Section 6
Site-Wide Combined Alternatives

Based on the alternatives presented in Section 5, two site-wide combined alternatives were developed to address physical hazards and both solid and water contamination for all locations at the Avoca Site. Each combined alternative comprises process options evaluated for each individual site location. Both combined alternatives are designed to protect human health and the environment as well as address the physical hazard health and safety concerns outlined in the Site remedial action objectives (see Section 3). In addition heritage and long term site management are considered.

Each specific area of the Site (e.g., Cronebane, Connary, etc.) and each media (solid and water) were evaluated individually to select the most effective remedial action for the area. These actions were combined into site-wide Combined Alternative 1. Some areas or media had secondary remedial actions that were similar but not as effective as the actions in Alternative 1. These remedial actions were selected for Combined Alternative 2. Combined Alternative 2 cost less than Combined Alternative 1. The two alternatives were also selected to provide decision makers with a range of options and costs for each area of the Avoca site. The main differences in the two alternatives are summarised in Tables 6-1 (solids) and 6-2 (water). The selected process options and rationale for selection are provided in the next sections.

Table 6-1 Solids Process Options

	Alternative 1		Alternative 2	
Area	**Spoils Relocate**	**Cover**	**Spoils Relocate**	**Cover**
Connary Spoils	No	Lime/soil/vegetation	No	Soil/vegetation
Mt. Platt Spoils	Yes	Lime/soil/vegetation	80%	Soil/vegetation
Cronebane Pit	—	HDPE/soil/vegetation	—	Soil/vegetation
East Avoca Pit	—	HDPE/soil/vegetation	—	Soil/vegetation
East Avoca (unstable area)	Yes	HDPE/soil/vegetation	Yes	Soil/vegetation
Tigroney West/Ore Bins Spoils	Yes	Replace with clean soil/vegetation	No	Soil/vegetation
Deep Adit Spoils	Yes	Replace with clean soil/vegetation	Yes	Replace with clean soil/vegetation
SP39 Spoils	No	Lime/soil/vegetation	No	Soil/vegetation
West Avoca Spoils	Yes	Lime/soil/vegetation	Yes (only large piles)	Soil/vegetation
Weaver's Lode Pit	—	HDPE/soil/vegetation	—	Soil/vegetation
River Sediments	Yes	Onsite Disposal	Yes	Onsite Disposal
Emergency Tailings	No	—	No	—
Shelton Abbey Tailings	No	Enhanced drainage/ some cover/vegetation	No	Enhanced drainage/ some cover/vegetation

Table 6-2 Water Process Options

	Alternative 1	Alternative 2
East/West Avoca Acid Mine and Rock Discharges	Active water treatment plus pilot passive facility	Active water treatment
East/West Avoca Groundwater Diffuse Flow	Soil bentonite wall plus extraction wells	Soil bentonite wall plus extraction wells
Shelton Abbey Groundwater Diffuse Flow	Soil bentonite wall, extraction wells, active water treatment	No action with monitoring

6.1 Combined Alternative 1

Of the two combined alternatives, Combined Alternative 1 presents a more effective, permanent, and sustainable combination of remedial options for each site location when compared to Combined Alternative 2. Plan views of Combined Alternative 1 are illustrated graphically in Figures 6-1 through 6-5. Digital elevation, 3-D models illustrating implementation of this alternative at various site locations are included in Appendix A. Road construction as required to access spoils areas and transport materials into and away from the Site is included with each combined alternative.

6.1.1 Solids

The remedial technologies and process options applied to each site and the importance of their application follow:

Connary (Figure 6-1)

- The Connary spoil heaps/areas will be regraded, stabilised, and covered. Regrading of the spoils results in stabilisation of eroding and steep slopes, and creates mildly sloping and sustainable land forms. Regrading may also uncover buried, near surface physical hazards such as shafts or other mine openings, allowing for the hazards to be mitigated.

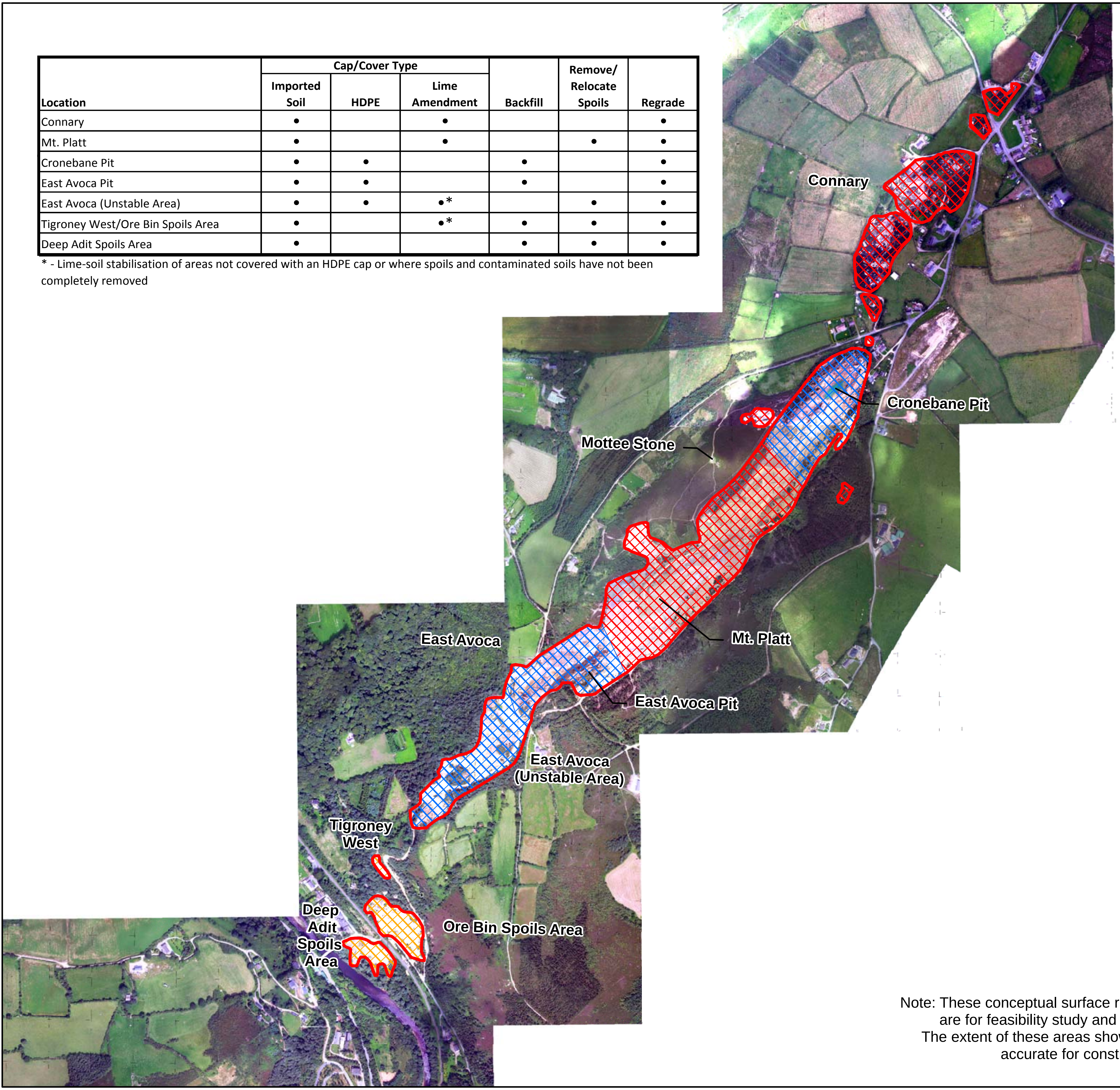
- Lime-soil stabilisation of the surface spoils reduces infiltration contamination and impact to groundwater. It also provides greater opportunity for diverse and enhanced vegetative growth.

- Cover with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability and potential enhanced land use of the reclaimed surfaces. Revegetation also reduces infiltration.

- Surface water management – ditches, culverts, sedimentation basins – provides sedimentation and erosion control and long-term stability to the reclaimed Connary sites.

Location	Cap/Cover Type Imported Soil	HDPE	Lime Amendment	Backfill	Remove/ Relocate Spoils	Regrade
Connary	•		•			•
Mt. Platt	•		•		•	•
Cronebane Pit	•	•		•		•
East Avoca Pit	•	•		•		•
East Avoca (Unstable Area)	•	•	•*		•	•
Tigroney West/Ore Bin Spoils Area	•		•*	•	•	•
Deep Adit Spoils Area	•			•	•	•

* - Lime-soil stabilisation of areas not covered with an HDPE cap or where spoils and contaminated soils have not been completely removed



Legend

- ▨ - Imported Soil Cover
- ▨ - HDPE Cap, Imported Soil Cover
- ▨ - Add Lime Amendment, Imported Soil Cover
- — - Reclamation Areas

* - All reclaimed areas will include indigenous revegetation, surface water management, and institutional controls.

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

FIGURE 6-1

Combined Alternative 1 - Solids

Connary, Cronebane/Mt. Platt and East Avoca/Tigroney West

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Mt. Platt/ Cronebane (Figure 6-1)

- The Mt. Platt spoils heap/spoils area will be relocated to the Cronebane Pit. Relocation of the Mt. Platt spoils to the Cronebane Pit accomplishes the stabilisation of this high risk spoils pile, eliminates, or substantially reduces the degradation of surface water quality, and mobility of contaminated spoils. Relocation, capping, and vegetation eliminates human contact to contaminated waste. In addition, it has the highly desirable complement of backfilling most of the Cronebane Pit, thereby eliminating or substantially reducing the physical hazards of falling, rock slides, and a contaminated pit pond.

- Regrading of the Mt. Platt spoils area will establish mildly sloping and long-term sustainable land forms.

- Lime-soil stabilisation of the former Mt. Platt area reduces infiltration contamination and degradation of groundwater. It also provides greater opportunity for diverse and enhanced indigenous vegetative growth that is compatible with current vegetated landscape.

- Scaling in the Cronebane Open Pit precedes work in the vicinity of the rock faces to improve worker safety and to reduce the potential of rock slides from unstable highwalls.

- Compaction and regrading of the relocated spoils in the Cronebane Pit provides a number of benefits. It stabilises the highwall and backfill (via compaction), shapes and prepares the surface for installation of an HDPE cap, and facilitates the establishment of surface water management/surface water control. Regrading also provides for the construction of rock trap ditches and bunds as further protection to falling rock.

- Installation of a HDPE cap over the Cronebane Pit backfill minimises the infiltration of water through the spoils and into the underground workings and groundwater. Some seepage from the highwall will enter into the spoils. However, the amount of seepage is very small and no additional adverse impact should result. In addition, the HDPE cap eliminates the human health risk of contact with contaminated spoils. Use of HDPE is a long-term effective, reliable, and sustainable option.

- Covering the reclaimed Cronebane Pit surface with imported soil and topsoil further reduces the risk of human contact with contaminated spoils and is essential for establishing vegetative growth.

- Covering the reclaimed Mt. Platt surface with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and helps establish vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces that is compatible with current vegetated landscape.

- Surface water management (ditches, culverts, sedimentation basins) applied to the Cronebane Pit/Mt. Platt area provides sedimentation and erosion control and long-term stability to the reclaimed site.

- Appendix A provides three figures showing the existing conditions of the Mt. Platt/Cronebane Pitt area and one figure after the proposed actions ("remediated" figure):
  - Figure 1: Cronebane and Mt. Platt looking southwest
  - Figure 2: Cronebane looking northeast
  - Figure 3: Cronebane and Mt. Platt looking northeast (note: large slope failure)
  - Figure 4: Cronebane looking northeast ("restored")

East Avoca and Tigroney West (Figure 6-1)

- The East Avoca and Tigroney West spoils will be relocated to the East Avoca Pit. Relocation of these spoil heaps/ spoil areas eliminates the stability hazards and the sources of degradation of surface water and groundwater quality.

- Relocation and restoration of the Tigroney Ore Bins to the reclaimed Deep Adit spoils area will eliminate a major physical hazard and restore an important historic feature of the Avoca mining heritage.

- The excavated areas (Tigroney West in the vicinity of the Ore Bins and the Deep Adit spoils area) will be backfilled with imported soils and regraded to create a gently sloping and sustainable land form, providing for a higher land use. The Deep Adit spoils area (Tigroney area west of the railway) will be contoured to accommodate the water treatment facility and other land use (e.g., picnic area).

- Scaling within the East Avoca Pit precedes work to improve worker safety.

- Compaction and regrading of the relocated spoils in the East Avoca Pit stabilises the spoils and partially stabilises the highwall, eliminates the pit pond, shapes and prepares the surface for installation of an HDPE cap, and facilitates the establishment of surface water management/surface water control. If necessary to achieve a minimum acceptable height of backfill, some of the Mt. Platt spoils will be relocated to the East Avoca Pit. Regrading also provides for the construction of rock trap ditches and bunds as further protection to falling rock. The very unstable highwall in the southwest area of the pit near the road will be stabilised fully.

- Installation of an HDPE cap over the East Avoca Pit backfill minimises the infiltration of water through the spoils and into the underground workings and groundwater. Some seepage from the highwall will enter the spoils; however, any impact will be minimal. It eliminates the human health risk of contact with contaminated spoils. HDPE is an effective, reliable, and long-term sustainable option.

- Covering the reclaimed East Avoca Pit surface with imported soil and topsoil further reduces the risk of human contact with contaminated spoils and is essential for establishing vegetative growth.

- An HDPE cap will be installed over all of the East Avoca spoils area, below the pit and upgradient from Tigroney West, that is known or suspected to have subsided ("unstable area"). The cap, placed over the reclaimed and regraded surface, will minimise infiltration of water through the surface and into the underground workings and groundwater, and limit further weakening of the caved ground. The HDPE will further stabilise the surface by bridging small void areas. In addition, the HDPE cap also eliminates the human health risk of contact with contaminated spoils. HDPE is an effective, reliable, and long-term sustainable option.

- Lime-soil amendment and covering the remainder of the reclaimed East Avoca and Tigroney West surfaces with imported soil and topsoil further reduces the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces and is compatible with current vegetated landscape.

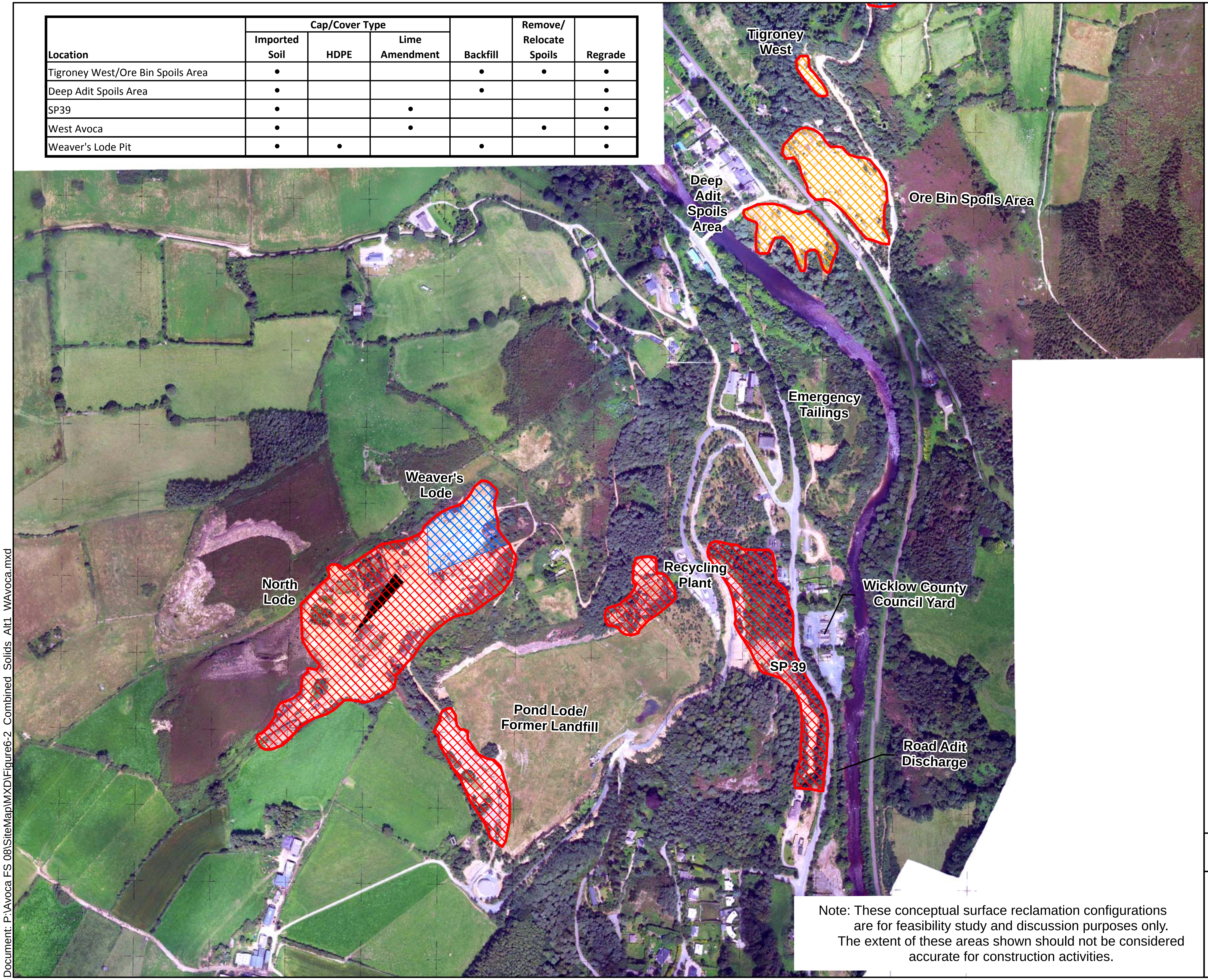
- Surface water management (ditches, culverts, sedimentation basins) applied to the East Avoca Pit, East Avoca, and Tigroney West areas provide sedimentation and erosion control and long-term stability to the reclaimed sites.

- Appendix A provides four figures of the East Avoca pit area. Two figures show the existing conditions and two figures show the area after the proposed actions. Appendix A also provides an overview of the total East Avoca area; one illustrating current conditions and one showing the area after proposed actions are completed. The titles of the figures follow:
  - Figure 5: East Avoca Pit looking northeast
  - Figure 6: East Avoca Pit looking northeast ("restored")
  - Figure 7: East Avoca Pit looking southwest
  - Figure 8: East Avoca Pit looking southwest ("restored")
  - Figure 9: East Avoca from West Avoca (overview)
  - Figure 10: East Avoca from West Avoca (overview showing completed actions - "restored")

West Avoca (Figure 6-2)

- The West Avoca spoils piles/spoils areas, except for the area adjacent to the Avoca/Rathdrum Road (SP39), will be relocated to the vicinity of the Weaver's Lode Pit. Relocation of the spoils to the Weaver's Lode Pit eliminates the stability hazards of the spoil piles and reduces the sources of contamination to surface water and groundwater quality. It also has the highly desirable complement of backfilling the Weaver's Lode Pit, thereby stabilising the highwall and eliminating or substantially reducing the physical hazards of slope failure and rock falls.

Location	Cap/Cover Type Imported Soil	 HDPE	 Lime Amendment	Backfill	Remove/ Relocate Spoils	Regrade
Tigroney West/Ore Bin Spoils Area	•			•	•	•
Deep Adit Spoils Area	•			•		•
SP39	•		•			•
West Avoca	•		•		•	•
Weaver's Lode Pit	•	•		•		•



Legend

- ▨ - Imported Soil Cover
- ▨ - HDPE Cap, Imported Soil Cover
- ▨ - Add Lime Amendment, Imported Soil Cover
- — - Reclamation Areas

* - All reclaimed areas will include indigenous revegetation, surface water management, and institutional controls.

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

CDM

FIGURE 6-2

Combined Alternative 1 - Solids

West Avoca

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- Regrading of the West Avoca spoils areas, including the area adjacent to the Avoca/Rathdrum Road (SP39), will establish stable slopes and sustainable land forms. Regrading may also uncover buried, near surface physical hazards such as shafts or other mine openings, allowing for the hazards to be mitigated.

- Lime-soil stabilisation of the West Avoca surface spoils sites, including the area adjacent to the Avoca/Rathdrum Road (SP39), reduces degradation to groundwater, and provides greater opportunity for diverse and enhanced vegetative growth.

- Scaling within the Weaver's Lode Pit precedes work in the vicinity of the rock faces to improve worker safety.

- Compaction and regrading of the relocated spoils in the Weaver's Lode Pit and its vicinity stabilises the backfill and the highwall, shapes and prepares the surface for installation of an HDPE cap and facilitates the establishment of surface water management/ surface water control. Regrading also provides for the construction of rock trap ditches and bunds as further protection to falling rock.

- Installation of an HDPE cap over the backfill at the Weaver's Lode Pit and its vicinity minimises the infiltration of water through the spoils and into the underground workings and groundwater. It eliminates the human health risk of contact with contaminated spoils.

- Covering the reclaimed surface of the Weaver's Lode Pit and its vicinity with imported soil and topsoil further reduces the risk of human contact with contaminated spoils and helps establish vegetative growth.

- Covering the reclaimed West Avoca spoils area surfaces, including the area adjacent to the Avoca/Rathdrum Road (SP39), with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces that is compatible with the current vegetated landscape.

- Surface water management (ditches, culverts, sedimentation basins) applied to the West Avoca area provides sedimentation and erosion control and long-term stability to the reclaimed sites.

- Appendix A provides four figures: two show existing conditions and two show the area after the proposed actions are completed. The titles of the figures follow:
  - Figure 11: Weaver and North Lode looking south
  - Figure 12: Weaver and North Lode looking south ("restored ")
  - Figure 13: West Avoca from Williams Engine House (overview)
  - Figure 14: West Avoca from Williams Engine House (overview showing completed actions - "restored")

Avoca River Sediments

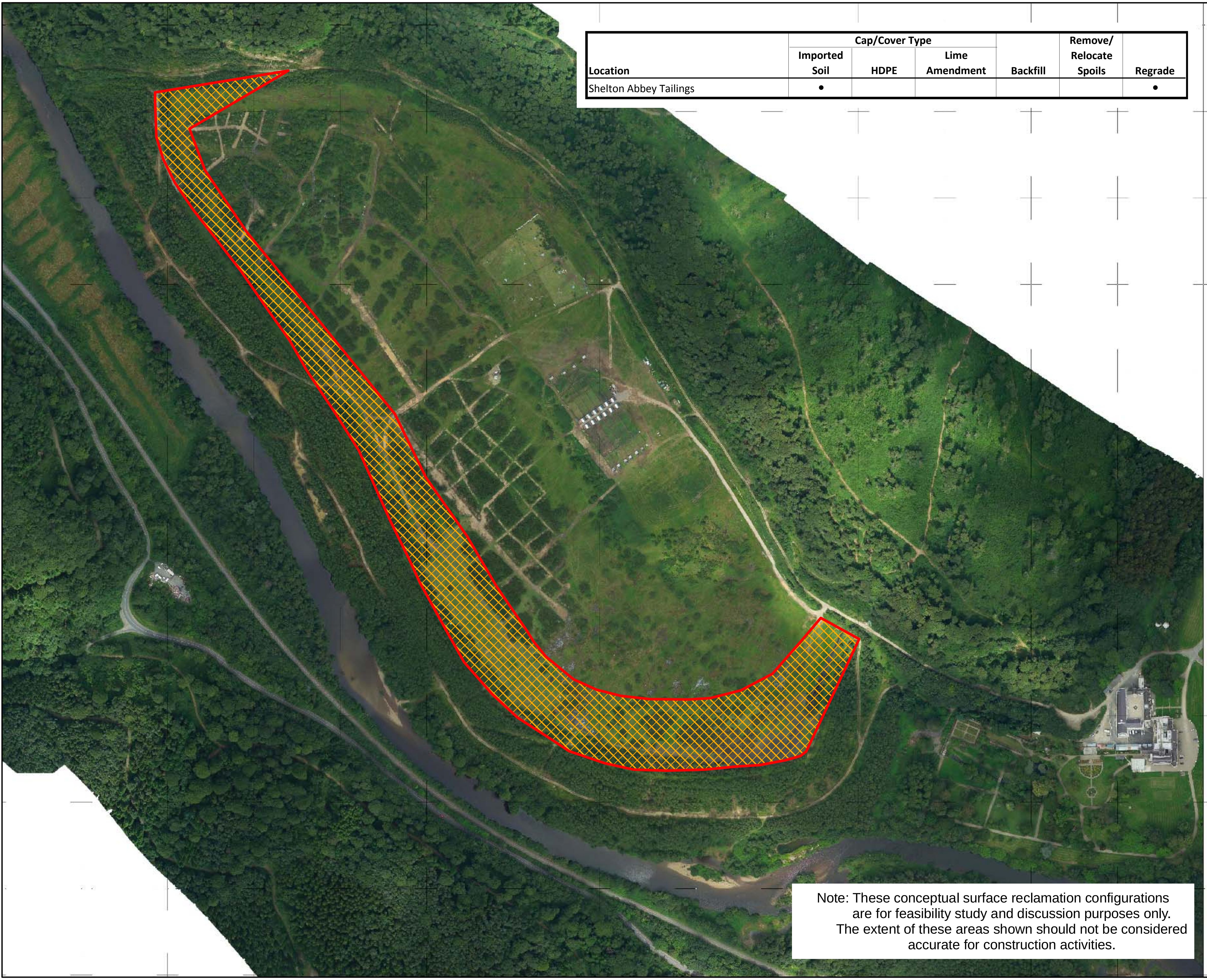
Avoca River sediments and ferricrete deposits in the vicinity of the Deep and Road Adit discharges will be removed, relocated, and stabilised. This will reduce continued release of metals into the water and improve both macroinvertebrate habitat and Avoca River water quality. The following section outlines the remedial actions/process options:

- Construction of access/haul roads at strategic locations on each side of the Avoca River.
- Construction of a work platform in, and a flow-through/check dam across the Avoca River downgradient from the Wicklow County Council Maintenance Yard.
- Excavation and dredging of ferricrete deposits and sediments on the east bank of the Avoca River downgradient from and in the vicinity of the Deep Adit discharge and on the west bank of the river downgradient from and in the vicinity of the Road Adit discharges.
- Reclamation of excavated and disturbed areas in the Avoca River and along the stream banks.
- Disposal of excavated/dredged sediments in onsite repositories constructed for dewatering, stabilisation, and containment of the ferricrete deposits and the sediments.
- Placement of soil covers and indigenous vegetation over the onsite ferricrete and sediment repositories.

Shelton Abbey Tailings (Figure 6-3)

The Shelton Abbey Tailings site will be reclaimed by making the following improvements to the covered and revegetated tailings repository surface:

- Clear work areas along the perimeter of the repository surface, the upgradient side (inside) of the main embankment, and low, poor draining areas.
- Regrading will occur to establish positive drainage, typically to the north and east. Import clean earth to fill in low areas, and for construction of a wide, mild-sloping buttress against the inside of the main embankment and extending into the tailings site surface.
- Cover regraded and built-up areas with topsoil.
- Surface Water Management – Construct and stabilise cross-drainage and perimeter drainage ditches. Install culverts at road crossings and under berms. Direct drainage to the east and north. Construct one or more sedimentation basins, located at or near discharge points.



Location	Cap/Cover Type			Backfill	Remove/ Relocate Spoils	Regrade
	Imported Soil	HDPE	Lime Amendment			
Shelton Abbey Tailings	•					•

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

Legend

▨ - Imported Soil Cover

▬ - Reclamation Areas

* - All reclaimed areas will include revegetation, surface water management, and institutional controls.

FIGURE 6-3

Combined Alternative 1 - Solids

Shelton Abbey

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- Plant the disturbed and bare areas with indigenous vegetation.

- Proper surface water management will reduce ponding and infiltration reducing contamination to the groundwater and Avoca River. It will also provide long-term effectiveness and sustainability of the Site, which has degraded and will continue to do so unless upgraded and maintained.

6.1.2 Water

East/West Avoca Water (Figure 6-4)

The selected remedial technologies and process options for East/West Avoca Water are those described in East/West Avoca Alternative No. 4 – Water (Section 5.1.2.4) with one addition (outlined below). The actions are described below.

- Installation of a few house wells is included with the Institutional Controls. This option applies if there are some house wells affected by mine drainage.

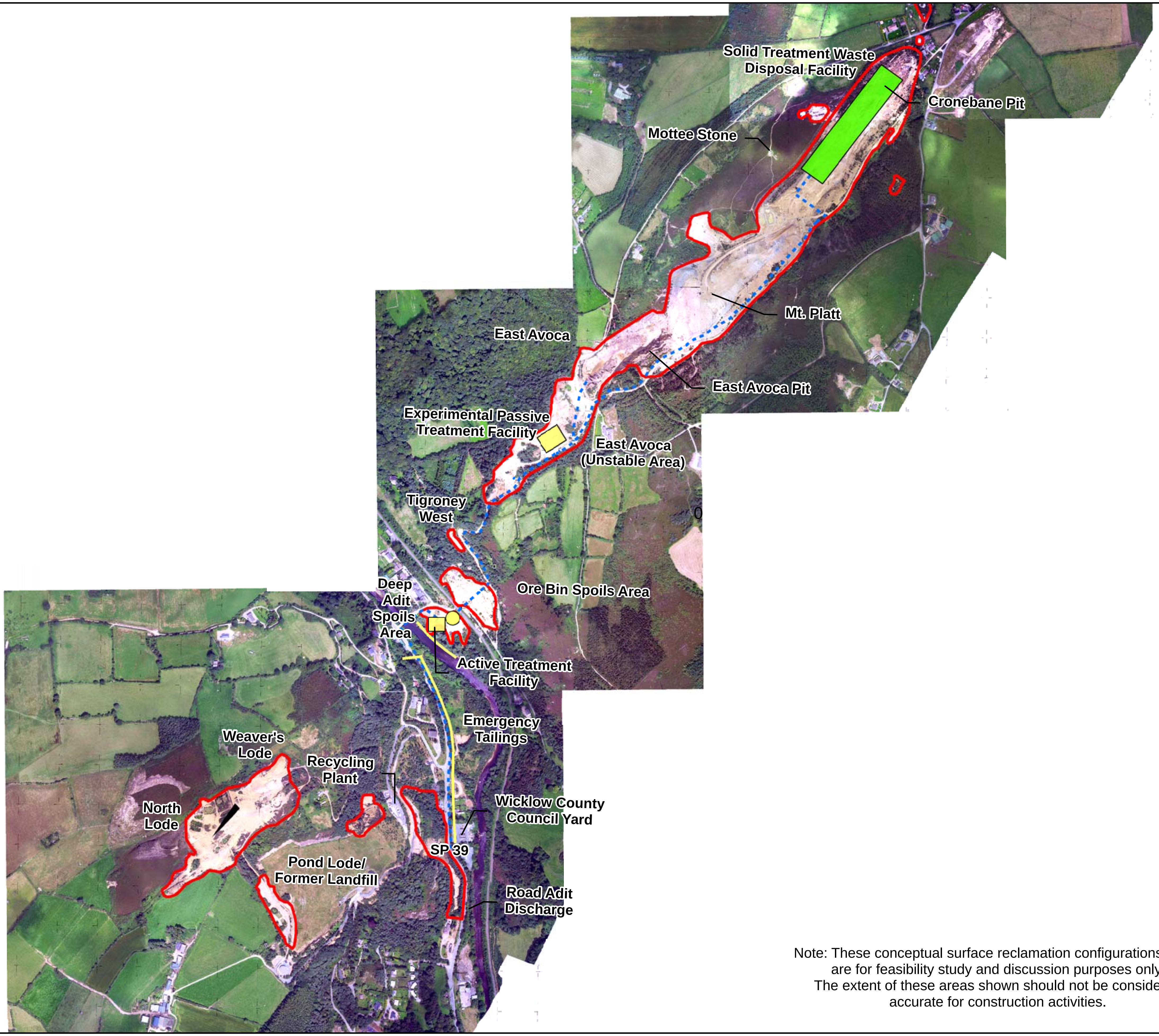
- Implement source control/discharge control measures for acid mine water discharges, including shaft sealing and plugging, excavation and backfilling, discharge control (control bulkheads), and shallow, leaky bulkheads. Many of these measures are required in any case to eliminate or substantially reduce the physical hazards associated with dangerous underground mine workings.

- Implement groundwater containment and extraction at East/West Avoca through soil bentonite walls and extraction wells located in the vicinity of the Deep Adit spoil areas on the east side of the river and the Emergency Tailings Pond on the west side of the river. This action is intended to intercept contaminated diffuse groundwater flows and transport the water to treatment.

- Implement surface/mine water control by construction of inlet/outlet structures, ditches and channels, piping, and pumping facilities to direct acid mine water discharges to treatment.

- Construct and operate an active water treatment-lime precipitation plant, located in the vicinity of the Deep Adit spoils area, to treat all East/West Avoca acid mine water discharges and extracted groundwater. The plant will provide the most important improvement to the Avoca River water quality.

- The added remedial option is the construction and operation of an experimental, pilot scale, passive treatment system located at the reclaimed East Avoca area, downgradient from the East Avoca Pit. The experimental passive treatment system is essential to determining the efficacy, design, and cost of an East/West Avoca passive treatment system.



Legend

- ● - Tank
- ▬ - Soil-Bentonite Barrier and Pump-Back System
- ▪▪▪▪▪ - Pipe
- ▬ - Reclamation Areas

* - Implement appropriate institutional controls, such as fencing and gates around reclaimed areas, and deed restrictions.

N
W E
S

Meters

0 50 100 200 300 400 500

1 centimeter equals 100 meters

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

CDM

FIGURE 6-4

Combined Alternative 1 - Water

East/West Avoca

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- Monitor treatment plant discharges. Recycle through the active water treatment plant or discharge to the Avoca River, depending on measured water quality. A storage tank will be provided for monitoring to minimise the possible release of contaminated water into the Avoca River. For upset and maintenance conditions, flow from the adits will be controlled by pipes with valves in the bulkheads.
- Construct and operate a solid treatment waste disposal facility at the reclaimed Cronebane/Mt. Platt area. The facility will safely contain the solid wastes generated from water treatment. Under-drainage will be directed to the water treatment plant.
- Extend roadways as needed to access both water treatment and solid treatment waste disposal facilities.

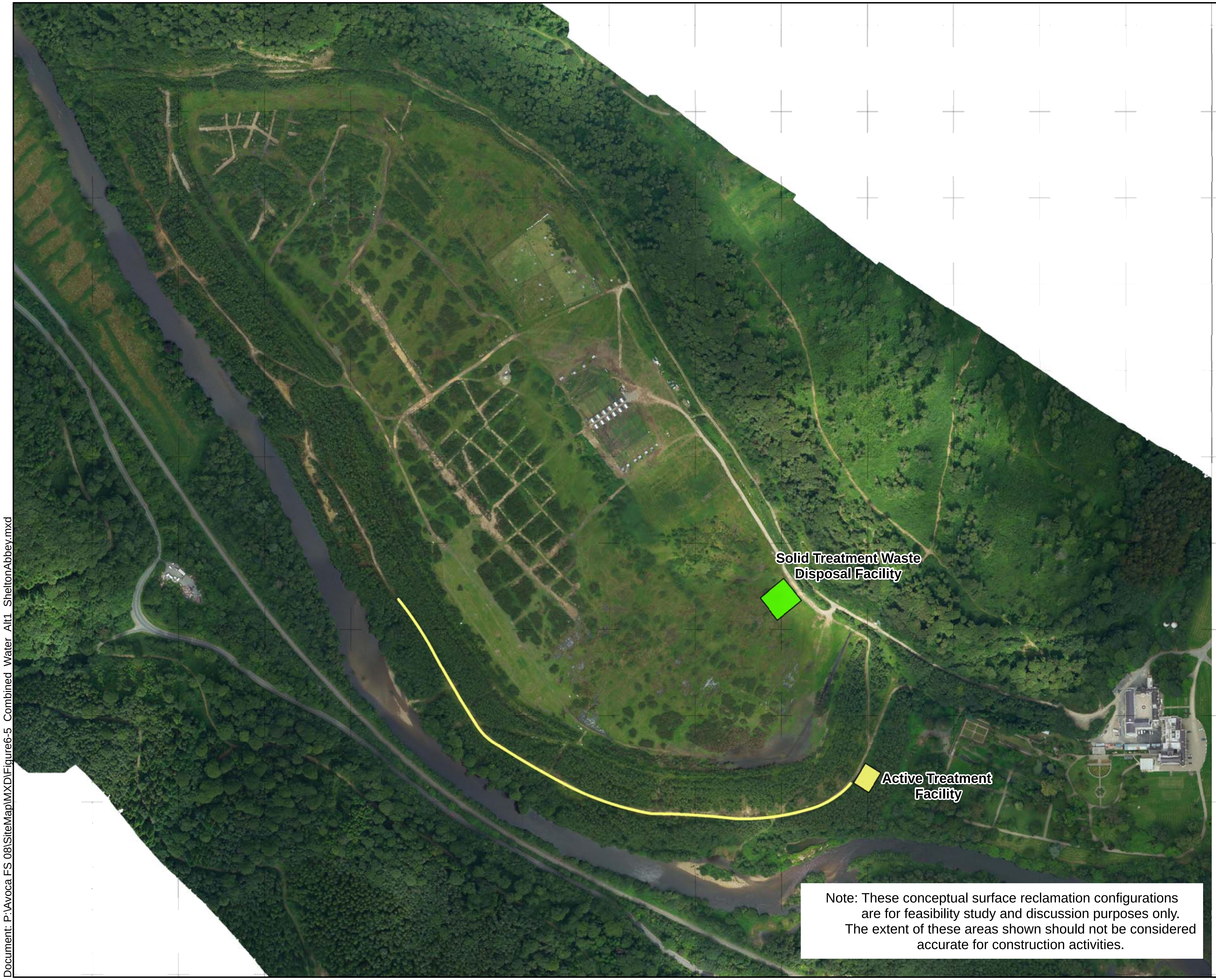
Shelton Abbey Water (Figure 6-5)

The selected remedial technologies and process options for Shelton Abbey – Water are those described in Shelton Abbey Tailings Alternative No. 1 – Water (Section 5.4.2.1). The actions are described below.

- Implement groundwater extraction by constructing a soil-bentonite wall and installing and operating extraction wells at the base of the main embankment, along the lower perimeter road. This action will intercept seepage from the Shelton Abbey Tailings site and transport the water to the treatment facility.
- Construct and operate an active water treatment-lime precipitation facility, located either along the lower perimeter road or at the surface of the Shelton Abbey Tailings site. The facility will treat the water from the groundwater extraction system.
- Monitor treatment plant discharges. Recycle through the active water treatment plant or discharge to the Avoca River, depending on measured water quality.
- Construct and operate an onsite solid treatment waste disposal facility, located on the surface of the Shelton Abbey Tailings site. The facility will safely contain the solid wastes generated from water treatment. Under-drainage will be directed to the water treatment plant.

6.1.3 Institutional Controls, All Locations

The institutional controls for all locations will generally be as described in Section 5.1.1.1 East/West Avoca Alternative No. 1 – Solids. Implement access controls/restrictions such as gates, barriers, and fencing at and around access points, work areas, and facilities. Utilise legal restrictions and covenants, including signage and legal documents/agreements where appropriate. A berm and fence will be included between the reclaimed Mt. Platt area and the East Avoca Pit.



Legend

▬ - Soil-Bentonite Barrier and Pump-Back System

* - Implement appropriate institutional controls, such as access control (fencing, gates) and legal restrictions.

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

CDM

FIGURE 6-5

Combined Alternative 1 - Water

Shelton Abbey

Document: P:\Avoca FS 08\SiteMap\MXD\Figure6-5 Combined Water Alt1 SheltonAbbey.mxd

6.2 Combined Alternative 2

Combined Alternative 2 typically presents less effective, but less costly, combinations of remedial technologies and process options for each site location. Plan views of Combined Alternative 2 are illustrated graphically in Figures 6-6 through 6-9. Road construction as required to access spoils areas and transport materials into and away from the Site is included with each combined alternative.

6.2.1 Solids

The remedial technologies and process options applied to each site and the importance of their application follow:

Connary (Figure 6-6)

- The Connary spoil piles/areas will be regraded, stabilised, and covered. Regrading of the spoils results in stabilisation of eroding and steep slopes, and creates mildly sloping and sustainable land forms. Regrading may also uncover buried, near surface physical hazards such as voids, shafts, or other mine openings, allowing for the hazards to be mitigated.

- Cover with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces and reduces infiltration.

- Surface water management (ditches, culverts, sedimentation basins) provides sedimentation and erosion control and long-term stability to the reclaimed Connary sites.

Mt. Platt/ Cronebane (Figure 6-6)

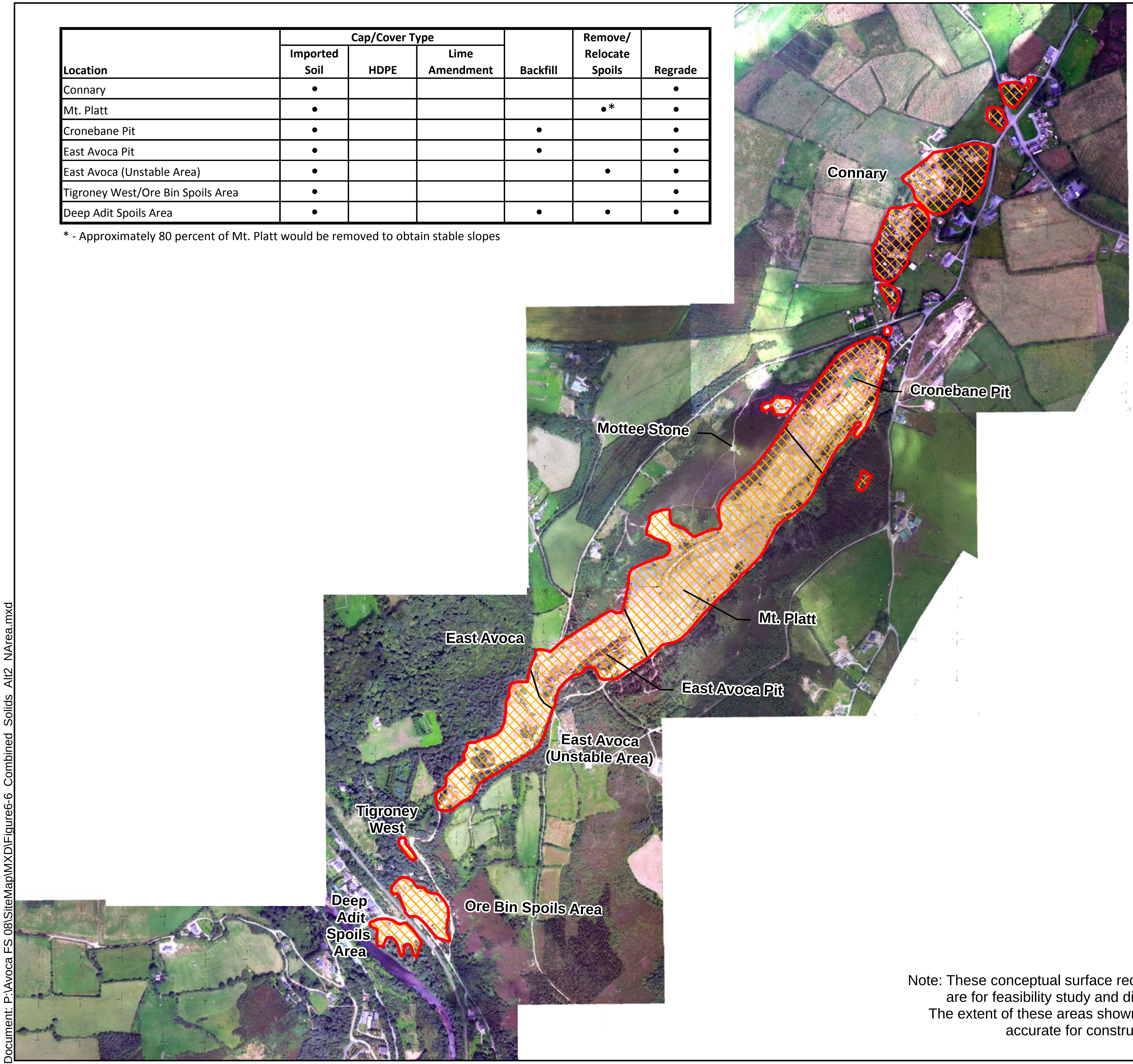
- The Mt. Platt spoils piles/spoils area will be partially removed and relocated to the Cronebane Pit. Partial removal is accomplished by excavating only those spoils necessary to achieve a stable and maintainable land form free of physical hazards. Partial removal of the Mt. Platt spoils and their relocation to the Cronebane Pit accomplishes the stabilisation of this high risk spoils pile, eliminates or substantially reduces the degradation of surface water and groundwater quality. It has the highly desirable complement of substantially backfilling the Cronebane Pit, thereby eliminating or substantially reducing the physical hazards of falling, rock slides, and a contaminated pit pond. Under this alternative, approximately 80 percent of Mt. Platt would be removed to obtain stable slopes.

- Regrading Mt. Platt spoils area will establish mildly sloping and long-term sustainable land forms.

- Scaling within the Cronebane Pit precedes work in the vicinity of the rock faces to improve worker safety.

Location	Cap/Cover Type Imported Soil	 HDPE	 Lime Amendment	Backfill	Remove/ Relocate Spoils	Regrade
Connary	•					•
Mt. Platt	•				•*	•
Cronebane Pit	•			•		•
East Avoca Pit	•			•		•
East Avoca (Unstable Area)	•				•	•
Tigroney West/Ore Bin Spoils Area	•					•
Deep Adit Spoils Area	•			•	•	•

* - Approximately 80 percent of Mt. Platt would be removed to obtain stable slopes



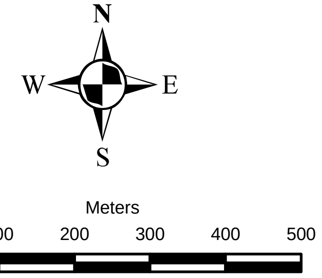
Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

Legend

▨ - Imported Soil Cover

━ - Reclamation Areas

* - All reclaimed areas will include indigenous revegetation, surface water management, and institutional controls.



1 centimeter equals 100 meters

CDM

FIGURE 6-6

Combined Alternative 2 - Solids

Connary, Cronebane/Mt. Platt
and East Avoca/Tigroney West

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- Compaction and regrading of the relocated spoils in the Cronebane Pit stabilises the backfill and the highwall, shapes and prepares the surface for establishment of surface water management/surface water control. Regrading also provides for the construction of rock trap ditches and bunds as further protection from falling rock.

- Covering the reclaimed Cronebane Pit surface with imported soil and topsoil eliminates the risk of human contact with contaminated spoils and is essential for establishing vegetative growth. Vegetation also reduces infiltration.

- Covering the reclaimed Mt. Platt surface with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces.

- Surface water management (ditches, culverts, sedimentation basins) applied to the Cronebane Pit/Mt. Platt area provides sedimentation and erosion control and long-term stability to the reclaimed site.

East Avoca and Tigroney West (Figure 6-6)

- The East Avoca spoil piles/areas and the Deep Adit spoils area will be relocated to the East Avoca Pit. Relocation of the spoil piles/spoil areas eliminates the stability hazards and the sources of degradation to surface water and groundwater quality. All spoil piles with elevated metal concentrations and net acid generation potential will be relocated.

- The Tigroney West spoil piles/area will be regraded to establish mildly sloping and sustainable land forms. This will result in the reduction of stability hazards and shape the surface to reduce the sources of degradation of surface water and groundwater quality.

- Relocation and restoration of the Tigroney Ore Bins to the reclaimed Deep Adit spoils area will eliminate a major physical hazard and restore an important historic feature of the Avoca mining heritage.

- Backfilling of the excavated Deep Adit spoils area with imported soils and regrading will establish mildly sloping and sustainable land forms, providing a higher land use. The Deep Adit spoils area will be contoured to accommodate the water treatment facility and other land use (e.g., picnic areas). Removal of the spoils will reduce groundwater contamination and the diffuse contamination entering the Avoca River.

- Scaling within the East Avoca Open Pit precedes work in the vicinity of the rock faces to improve worker safety.

- Compaction and regrading of the relocated spoils in the East Avoca Pit stabilises the backfill and partially stabilises the highwall, eliminates the pit pond, shapes and prepares the surface for establishment of surface water management/surface water control. The southwest area of the pit near the road will be fully stabilised. If necessary to achieve a minimum acceptable height of backfill, some of the Mt. Platt spoils will be relocated to the East Avoca Pit. Regrading also provides for the construction of rock trap ditches and bunds as further protection from falling rock.

- Covering the reclaimed East Avoca Pit surface with imported soil and topsoil reduces the risk of human contact with contaminated spoils and is essential for establishing vegetative growth.

- Covering the reclaimed East Avoca and Tigroney West surfaces with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces. Vegetation also reduces infiltration.

- Surface water management (ditches, culverts, sedimentation basins) applied to the East Avoca Pit, East Avoca, and Tigroney West areas provide sedimentation and erosion control and long-term stability to the reclaimed sites.

West Avoca (Figure 6-7)

- Only the larger West Avoca spoils piles/spoils areas, except for the area adjacent to the Avoca/Rathdrum Road (SP39), will be relocated to the vicinity of the Weaver's Lode Pit. Relocation of the spoils to the Weaver's Lode Pit eliminates the major stability hazards and reduces the sources of degradation of surface water quality and mobility of contaminated spoils. It also has the highly desirable complement of backfilling the Weaver's Lode Pit, thereby stabilising the highwall, and eliminating or substantially reducing the physical hazards of falling and rock slides.

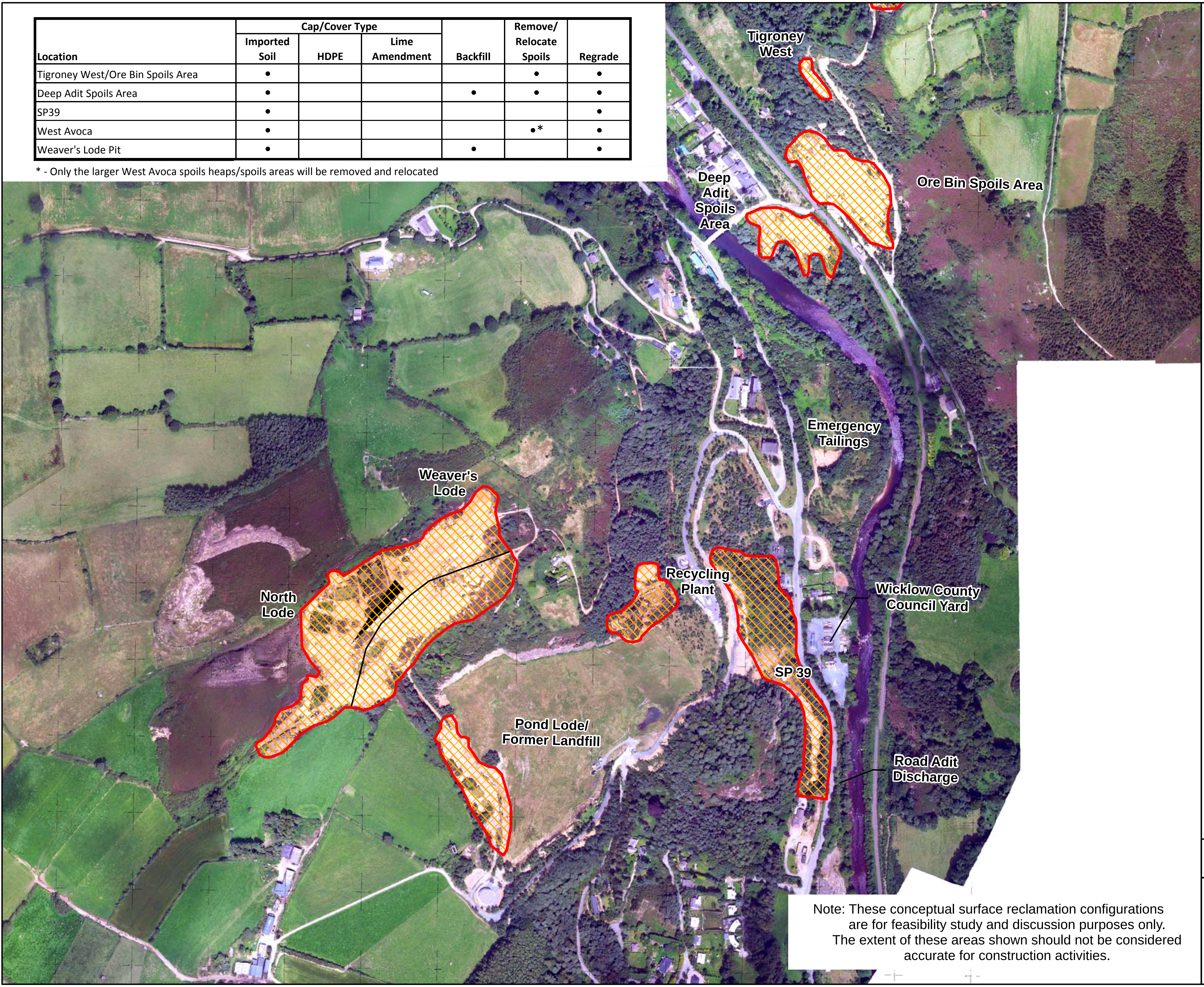
- Regrading of the West Avoca spoils areas, including the area adjacent to the Avoca/Rathdrum Road (SP39), will establish stable slopes and sustainable land forms. Regrading may also uncover buried, near surface physical hazards such as voids, shafts, or other mine openings, allowing for the hazards to be mitigated.

- Scaling within Weaver's Lode Open Pit precedes work in the vicinity of the rock faces to improve worker safety.

- Compaction and regrading of the relocated spoils in the Weaver's Lode Pit and its vicinity stabilises the backfill and the highwall, shapes and prepares the surface for establishment of surface water management/surface water control. Regrading also provides for the construction of rock trap ditches and bunds as further protection from falling rock.

Location	Cap/Cover Type			Backfill	Remove/ Relocate Spoils	Regrade
	Imported Soil	HDPE	Lime Amendment			
Tigroney West/Ore Bin Spoils Area	•				•	•
Deep Adit Spoils Area	•			•	•	•
SP39	•					•
West Avoca	•				•*	•
Weaver's Lode Pit	•			•		•

* - Only the larger West Avoca spoils heaps/spoils areas will be removed and relocated



Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

Legend

▨ - Imported Soil Cover

— - Reclamation Areas

* - All reclaimed areas will include indigenous revegetation, surface water management, and institutional controls.

CDM

FIGURE 6-7

Combined Alternative 2 - Solids

West Avoca

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- Covering the reclaimed surface of the Weaver's Lode Pit and its vicinity with imported soil and topsoil eliminates the risk of human contact with contaminated spoils and is essential for establishing vegetative growth.

- Covering the reclaimed West Avoca spoils area surfaces, including the area adjacent to the Avoca/Rathdrum Road (SP39), with imported soil and topsoil eliminates the human health risk of contact with contaminated spoils and is essential for establishing vegetative growth. Revegetation with indigenous species provides long-term stability to the reclaimed surfaces. Revegetation also reduces infiltration.

- Surface water management (ditches, culverts, sedimentation basins) applied to the West Avoca area provides sedimentation and erosion control and long-term stability to the reclaimed sites.

Avoca River Sediments

This alternative is the same as the Avoca River Sediments in Combined Alternative 1. Avoca River sediments and ferricrete deposits will be removed, relocated, and stabilised. This will reduce continued release of metals into the water and improve both macroinvertebrate habitat and Avoca River water quality. The following section outlines the remedial actions/process options:

- Construction of access/haul roads at strategic locations on each side of the Avoca River.

- Construction of a work platform in, and a flow-through/check dam across the Avoca River downgradient from the Wicklow County Council maintenance yard.

- Excavation and dredging of ferricrete deposits and sediments on the east bank of the Avoca River downgradient from and in the vicinity of the Deep Adit discharge and on the west bank of the river downgradient from and in the vicinity of the Road Adit discharges.

- Reclamation of excavated and disturbed areas in the Avoca River and along the stream banks.

- Disposal of excavated/dredged sediments in onsite repositories constructed for dewatering, stabilisation, and containment of the ferricrete deposits and the sediments.

- Placement of soil covers and indigenous vegetation over the onsite ferricrete and sediment repositories.

Shelton Abbey Tailings (Figure 6-8)

This alternative is the similar to Shelton Abbey Tailings in Combined Alternative 1. The Shelton Abbey Tailings site will be reclaimed by making the following improvements to the covered and revegetated tailings repository surface:

- Clear work areas along the perimeter of the repository surface, the upgradient side (inside) of the main embankment and low, poor draining areas.

- Regrading will be carried out to establish positive drainage to the north and east. Clean earth will be imported to fill in low areas, and for construction of a wide, mild-sloping buttress against the inside of the main embankment and extending into the tailings site surface.

- Cover regraded and built-up areas with topsoil.

- Surface Water Management – Construct and stabilise cross-drainage and perimeter drainage ditches. Install culverts at road crossings and under berms. Typically direct drainage to the east and north. Construct one or more sedimentation basins, located at or near discharge points.

- Plant the disturbed and bare areas with indigenous vegetation.

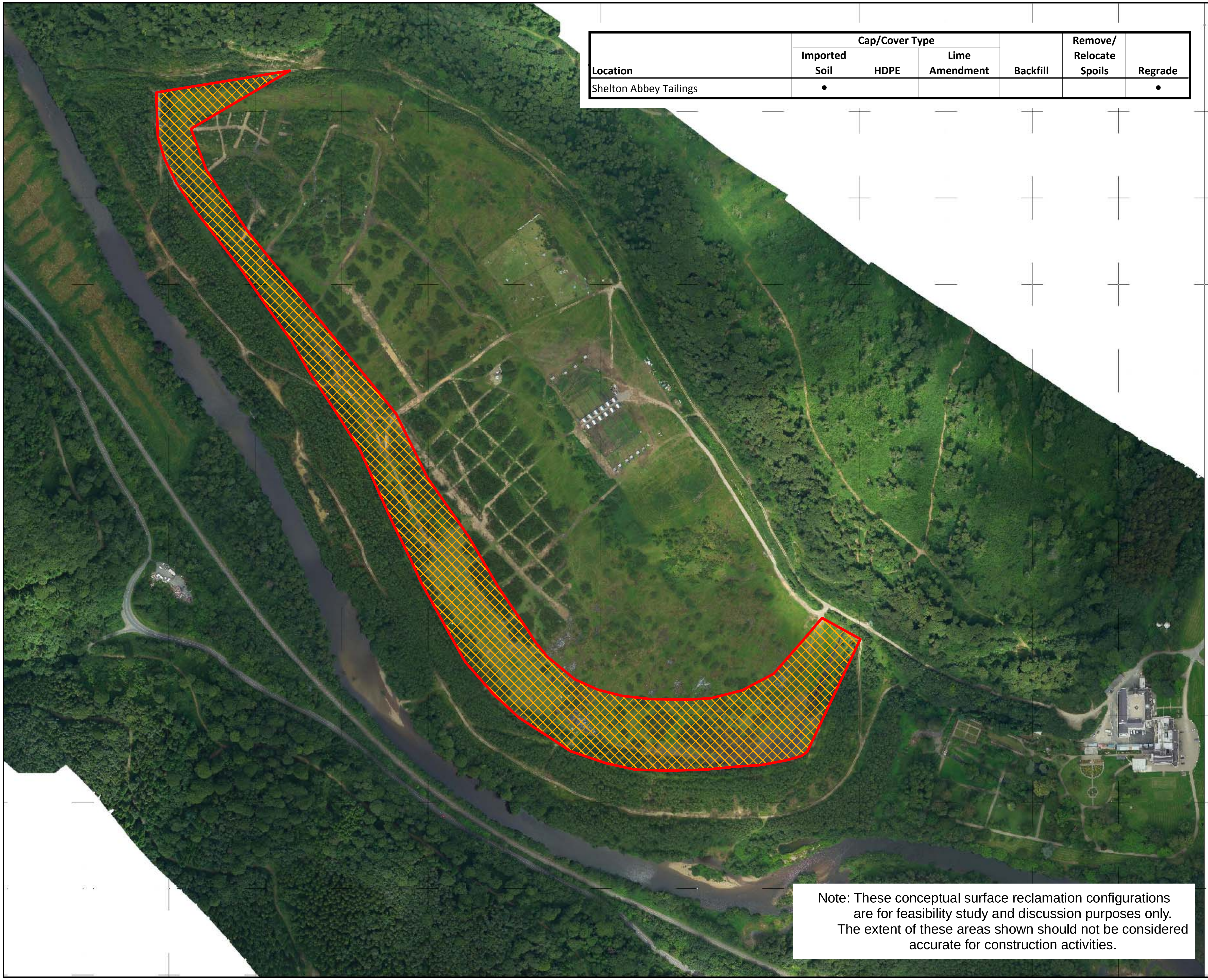
- These actions will reduce infiltration and improve groundwater and river quality. It will also provide long-term effectiveness and sustainability of the site, which has degraded and will continue to do so unless upgraded and maintained.

6.2.2 Water

East/West Avoca Water (Figure 6-9)

The selected remedial technologies and process options for East/West Avoca – Water are those described in East/West Avoca Alternative No. 4 – Water (Section 5.1.2.4). They follow:

- Implement source control/discharge control measures for acid mine water discharges, including shaft sealing and plugging, excavation and backfilling, discharge control (control bulkheads) and shallow, leaky bulkheads. Many of these measures are required in any case to eliminate or substantially reduce the physical hazards associated with dangerous underground mine workings.



Location	Cap/Cover Type			Backfill	Remove/ Relocate Spoils	Regrade
	Imported Soil	HDPE	Lime Amendment			
Shelton Abbey Tailings	•					•

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

Legend

▨ - Imported Soil Cover

— - Reclamation Areas

* - All reclaimed areas will include revegetation, surface water management, and institutional controls.

N
W E
S

Meters
0 50 100 150 200

1 centimeter equals 50 meters

CDM

FIGURE 6-8

Combined Alternative 2 - Solids

Shelton Abbey

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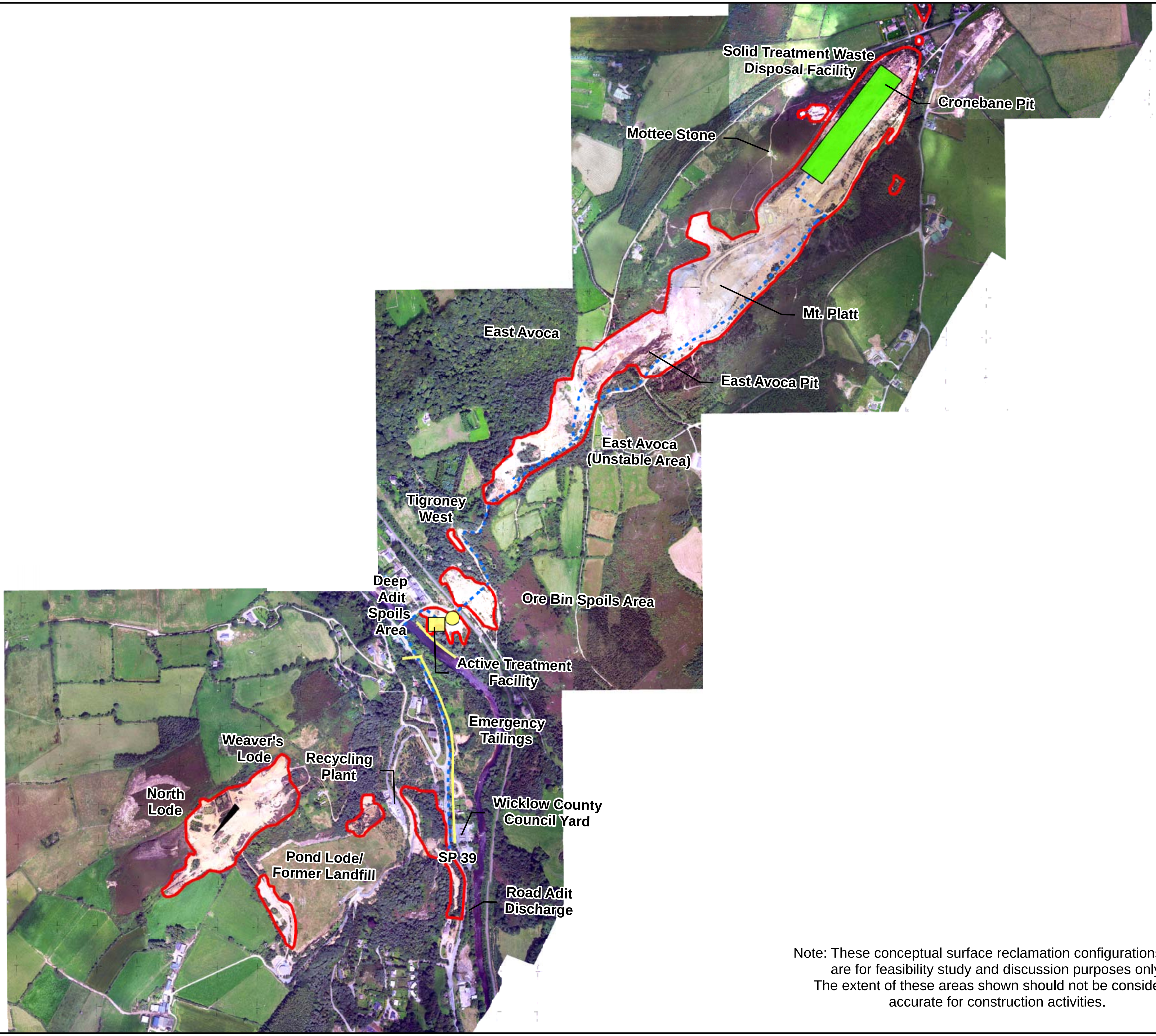


Legend

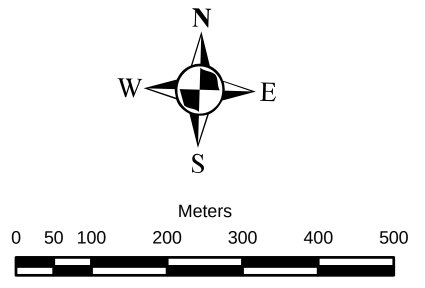
● - Tank

— - Soil-Bentonite Barrier and Pump-Back System

▪▪▪▪▪ - Pipe

— - Reclamation Areas

* - Implement appropriate institutional controls, such as fencing and gates around reclaimed areas, and deed restrictions.



1 centimeter equals 100 meters

Note: These conceptual surface reclamation configurations are for feasibility study and discussion purposes only. The extent of these areas shown should not be considered accurate for construction activities.

CDM

FIGURE 6-9

Combined Alternative 2 - Water

East/West Avoca

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- Implement groundwater containment and extraction at East/West Avoca through soil bentonite walls and extraction wells located in the vicinity of the Deep Adit spoils areas on the east side of the river, and the Emergency Tailings Pond on the west side of the river. This action is intended to intercept zones of contaminated diffuse groundwater flows and transport the flows to treatment.

- Implement surface/mine water control by construction of inlet/outlet structures, ditches and channels, piping and pumping facilities to transport acid mine water discharges to treatment.

- Construct and operate an active water treatment-lime precipitation plant, located in the vicinity of the Deep Adit spoils area, to treat all East/West Avoca acid mine water discharges and extracted groundwater. The plant will provide the most important improvement to the Avoca River water quality.

- Monitor treatment plant discharges. Recycle through the active water treatment plant or discharge to the Avoca River, depending on measured water quality. Storage tanks will be provided for monitoring to minimise the possible release of contaminated water into the Avoca River.

- Construct and operate a solid treatment waste disposal facility at the reclaimed Cronebane/Mt. Platt area. The facility will safely contain the solid wastes generated from water treatment. Under-drainage will be directed to treatment.

- Extend roadways as needed to access both water treatment and solid treatment waste disposal facilities.

Shelton Abbey Water

Avoca River sampling in the vicinity of the Shelton Abbey Tailings facility indicates minimum degradation in the river's water quality. Accordingly, there is no groundwater extraction and treatment, and no containment of solid treatment waste at the Shelton Abbey Tailings site for Combined Alternative 2. However, monitoring including sampling upgradient and downgradient of the Shelton Abbey tailings facility will be conducted (see Section 6.3) to further evaluate the conditions.

6.2.3 Institutional Controls, All Locations

The institutional controls for all locations will generally be as described in Section 5.1.1.1 East/West Avoca Alternative No. 1 – Solids. Implement access controls/restrictions such as gates, barriers, signs, and fencing at and around access points, work areas, and facilities. Utilise legal restrictions and covenants, including signage and legal documents/agreements where appropriate. A berm and fence will be constructed between the Mt. Platt reclaimed area and the East Avoca Pit.

6.3 Monitoring

Various types of monitoring should be conducted including routine water quality and flow monitoring, operational monitoring of treatment facilities, geotechnical monitoring, and routine inspections of remediated features. These actions are presented in the following sections.

6.3.1 Routine Water Quality and Flow Monitoring

Before and during construction and operation of treatment facilities, construction of the groundwater extraction systems, and completion of solids alternatives, an accurate base line of water quality and flow should be established. This was attempted in 2007 but due to weather conditions, it was not possible to obtain low flow data. As a result, we recommend that at a minimum, water quality samples should be collected during both high and low flow conditions. In practice, samples should be collected on a quarterly basis to avoid the problems of mobilising during only high and low flow periods. Water samples should be collected at the following locations:

Avoca River:
- Upgradient locations above Meeting of the Waters (or for convenience to obtain composite, samples at Lions Bridge and Ballinaclash Bridge)
- Upgradient of Whitesbridge
- Downgradient of the confluence with the Deep Adit discharge
- Upgradient and downgradient of the Emergency Tailings Pond area
- Downgradient of the confluence with the Road Adit discharge
- Across from the abandoned Coal Yard
- Upgradient of Shelton Abbey
- Downgradient to Shelton Abbey

Tributaries:
- Vale View
- Red Road
- Sulphur Brook

Adits:
- Deep Adit
- Road Adit
- Intermediate Shallow
- Cronebane Intermediate
- Ballygahan
- Spa Adit

Springs:
- Radio Tower Spring
- Paddy's Spring
- Holy Well

Existing Groundwater Monitoring Wells:

- MWDA1
- MWDA2
- MWET1
- MWET2
- MWPF1
- MWSA2
- GW1/05
- GW2/05
- SG104

New Groundwater Monitoring Wells:

- Two new bedrock monitoring wells should be constructed on each side of the Avoca River in the vicinity of the mine area (four total wells)

- Two new shallow alluvial monitoring wells should be constructed in the vicinity of the northern end of the Emergency Tailings Pond

Homeowner's Wells:

- Five known wells will be sampled
- Potential additional wells will be located

Analyses should be performed for a complete list of both total and dissolved metals, at a minimum including: Al, As, Cd, Ca, Cu, Fe, Pb, Mg, Mn, Ni, and Zn. At least twice a year (high flow and low flow), general water quality parameters should also be analysed including: TDS, TSS, acidity, ammonia, nitrate, nitrite, phosphorus, sulfate, total organic carbon, total alkalinity and total organic nitrogen.

Flow rates should be measured at each of the adits, tributaries, and springs. The recommended permanent Avoca River flow monitoring station (downgradient of the relocated Road Adit discharge) should be installed as soon as possible. In addition, staff gauges should be installed upgradient (e.g., at Whitesbridge) of the permanent monitoring station. Water levels should be measured in each of the groundwater wells. The continuous water level recorders in the recently installed monitoring wells (six "MW" wells above) should be maintained and periodically downloaded. Continuous level recorders should be installed in the proposed new wells.

6.3.2 Operational Monitoring

The above sampling and analyses program should be started as soon as possible and maintained during and after construction of remedial alternatives. Once the active water treatment plant is operational, the discharge should be monitored consistent with regulatory requirements. After initial startup monitoring (daily and then weekly samples), samples, at a minimum, should be collected on a monthly basis of the treated discharge and analysed for the list of metals given above. Quarterly, the general water quality parameters should also be determined. Continuous measurement of specific conductance (or TDS), turbidity, pH, and flow rate should also be carried out. Alarms or notification should be provided to the operator of upset conditions based on these continuous measurements.

The solid materials generated from the treatment facility should also be analysed routinely. After initial startup, analyses should be performed monthly in conjunction with the water quality analyses. Total metals concentrations (same list as above) and leachable concentrations (per BS EN 12457 Part 3 for regulatory classification) should be measured.

Piezometers for measuring groundwater levels and gradients should be installed in conjunction with the soil bentonite wall (two piezometers, one upgradient and one downgradient, for each wall).

6.3.3 Geotechnical Monitoring

Instruments for monitoring rock formation or earth embankment movements, settlement, or subsidence of any remaining spoil piles and backfilled areas or suspected weak ground areas, and groundwater table levels in embankments or pit backfills should be incorporated with the monitoring program.

Vertical borehole inclinometer stations should be strategically located in East Avoca behind highwall faces at the Cronebane Pit (3), East Avoca Pit (3); in West Avoca behind the highwall faces at the Pond Lode Pit (1), North Lode Pit (1) and Weaver's Lode Pit (2); and at Shelton Abbey in the tailings pond embankment (2). An inclinometer can be used at each station to measure and record ground movement (direction and amount of deflection) along the length of each borehole. Measurements at twice per year intervals should be conducted.

Settlement cells should be installed at the locations of known or suspected collapsed shafts, crown holes or filled cave-in areas, and in pit backfills to monitor subsidence or ground settlement. A suggested network of settlement cells includes nine at Connary, seven at Cronebane/Mt. Platt, 10 at East Avoca/Tigroney West and 12 at West Avoca. The settlement cell data readout stations would be located outside of the potential areas of settlement/subsidence. One manual readout data recorder can be used to measure settlements at all stations. Measurements at twice per year intervals should be conducted.

Piezometers should be installed to monitor groundwater table levels in the pit backfills at Cronebane/Mt. Platt (2), East Avoca/Tigroney West (2) and West Avoca (2); and in the Shelton Abbey tailings pond embankment (2). The piezometers should be strategically located to measure groundwater table gradients, as well as levels. A water level meter should be used to make the measurements at a frequency of once per quarter.

6.3.4 Additional Studies

Because the tracer study was only performed one time at conditions of elevated flow, it should be performed again at low flow conditions (at least two more times). In addition, the sediment quality and marcroinvertebrate populations should be monitored yearly after treatment of the discharges starts.

Some predesign studies should be conducted. This includes design studies to determine the depth and length of the soil bentonite walls and extraction well size, depth and pumping rates.

Additional monitoring wells should also be installed in the bedrock near the Avoca River and in the shallow alluvium north of the Emergency Tailings Pond (see Section 6.3.1). These wells are needed to better evaluate metal impacts and loads to the Avoca River.

Site investigation such as geophysical surveys needs to be undertaken to investigate areas where voids are suspected to occur in East Avoca. The surveys may be followed up with drilling to confirm and further evaluate the suspect areas.

6.3.5 Inspections and Maintenance

Besides the routine and operational monitoring discussed above, routine inspection should occur of all remediated features. Specifically, inspections should occur at a minimum of twice a year for the following items:

- Caps and covers including vegetation cover
- Pipelines and other water conveyance/containment structures including ditches, culverts, and sedimentation panels
- Shaft seals, control bulkheads, and leaky bulkheads
- Pumps and mechanical equipment at the treatment plant (filter press, aeration units, etc.)
- Fences, signage, and barriers
- Solid waste and sediment disposal facilities
- Restored heritage structures (e.g., ore bins)
- Tailings impoundments
- Regraded slopes

In some cases, routine maintenance of the above items will be needed. However, inspections will determine if and when maintenance activities are required.

6.4 Construction Schedule Scenarios

Initiation of the Avoca mine site remediation construction would be preceded by completion of the major engineering investigations and designs necessary for issuance of the construction bid documentation, development of the necessary planning and assessment documents including EIS (environmental impact statement) documentation, and the assembly of permissions to proceed that need to be obtained prior to issuance of the major construction contracts. Two to three years may be necessary to accomplish these tasks and investigations. Scenarios for the scheduling of construction can assist in the overall project planning. The objectives of the construction schedule scenarios in planning the build-out of the Avoca Project follow:

- First and foremost, before the onset of the construction program, install the physical institutional controls (fencing and gates) and permanent or temporary barriers, as appropriate, at known mine openings, such as shafts and adits, or other hazards, such as highwalls and unstable structures, in order to safeguard the health and safety of the public and project workforce.
- Obtain the remaining permissions to carry out the work and ensure that the major construction contracts are awarded as soon as possible thereafter.
- At the East Avoca open pit, the unstable highwall that threatens a public road needs to be addressed as a priority.
- Install the permanent water-related monitoring units.
- Order long lead-time equipment and materials as soon as permissions are obtained.
- Organise the work prioritising health and safety issues.
- Organise the work in phases so the most important action for improving water quality, the active water treatment plant, comes on line early in the project build-out.
- Bring the next-most important action for improving water quality, such as the soil-bentonite wall and groundwater extraction action, on line at least one year following the start of active water treatment plant operations, so the impacts of each can be measured and distinguished.
- Organise the work so as to balance, as much as reasonable, the cost of the phases.
- Organise the work so the actions that are less effective on ecosystem recovery come on line in later phases.
- The schedule scenario provides for phasing the cost of the project to be aligned with the project funding.

- Engineering investigations and design will necessarily precede construction. The scheduling scenario thus provides a way to estimate the engineering design costs and schedule the estimated construction management costs.

It is difficult to accomplish all of these objectives because some of them may be conflicting. For example, before treatment plant operations can commence, the solid treatment waste disposal facility has to be operational. This requires that at least a major portion of one of the more major and costly work items, the Cronebane Pit/Mt. Platt remediation, has to occur so construction of the solid treatment waste disposal facility can move forward. Cost balancing among the phases may therefore push construction and operation of the water treatment plant into a second phase. Alternatively a smaller disposal facility may need to be constructed onsite to facilitate the implementation of the water treatment plant as a priority.

6.4.1 Construction Schedule Scenarios for Combined Alternative 1

The work would be in three phases. The physical institutional controls and barriers to other public safety hazards at the East and West Avoca sites would be installed immediately. Work phases are estimated to be on the order of one to two years each. Total construction time can be as short as three years for an optimum schedule, or as long as six or more years for a balanced cost and funding schedule.

6.4.1.1 Optimum Schedule

Work items that begin in one phase may be completed in the following phase. For example, the construction of the active water treatment plant would begin relatively late in Phase 1, allowing for long lead-time deliveries and site preparations, and conclude in Phase 2. It is estimated that the work would begin as soon as the major construction contracts are awarded.

Phase 1

- Install and maintain physical institutional controls, signage, and other temporary or permanent barriers to the sites' physical hazards in order to safeguard the public.

- Order long lead-time equipment and materials. Mobilise.

- Remediate the Deep Adit spoils site.

- Construct the active water treatment plant.

- Remediate the Cronebane/Mt. Platt area.

- Construct the solid treatment waste disposal facility.

- Construct the control bulkheads in the Deep Adit and Road Adit, and the pipe connections to the active water treatment plant.

- Install the permanent water-related monitoring units.

Phase 2

- Install the soil bentonite walls and groundwater extraction system, construct the shaft plugging, shallow bulkheads, and the pipe/channel connections to the active water treatment plant, and implement any additional water institutional controls.

- Remediate the East Avoca/Tigroney West Area (not including the Deep Adit spoils site).

- Remediate the West Avoca area.

Phase 3

- Remediate the Connary Area.

- Construct the experimental passive treatment system and related components in the East Avoca area.

- Remove/contain Avoca River sediments.

- Remediate Shelton Abbey tailings.

- Construct Shelton Abbey groundwater extraction and treatment/disposal system

- Install the permanent geotechnical monitoring units.

- Accept the work, site clean-up, and demobilisation.

6.4.1.2 Balanced Cost and Funding Schedule

An optional schedule for Combined Alternative 1 that better balances the cost per phase can be accomplished by moving the construction of the active water treatment plant to Phase 2, and remediation of the West Avoca area to Phase 3. The schedule for the phasing would be commensurate with the funding, and may be up to two years for each phase. The optional phasing follows:

Optional Phase 1

- Install and maintain physical institutional controls, signage, and other temporary or permanent barriers to the sites' physical hazards in order to safeguard the public.

- Order long lead-time equipment and materials. Mobilise.

- Remediate the Deep Adit spoils site.

- Remediate the Cronebane/Mt. Platt area.

- Construct the solid treatment waste disposal facility.

- Construct the control bulkheads in the Deep Adit and Road Adit, and the pipe connections to the active water treatment plant.

- Install the permanent water-related monitoring units.

Optional Phase 2

- Construct the active water treatment plant.

- Install the soil bentonite walls and groundwater extraction system; construct the shaft plugging, shallow bulkheads, and the pipe/channel connections to the active water treatment plant, and implement any water institutional controls.

- Remediate the East Avoca/Tigroney West area (not including the Deep Adit spoils site).

Optional Phase 3

- Remediate the West Avoca area.

- Remediate the Connary area.

- Construct the experimental passive treatment system and related components in the East Avoca area.

- Remove/contain Avoca River sediments.

- Remediate Shelton Abbey Tailings.

- Construct Shelton Abbey groundwater extraction and treatment/disposal system.

- Install the permanent geotechnical monitoring units.

- Accept the work, site clean-up, and demobilisation.

6.4.2 Construction Schedule Scenarios for Combined Alternative 2

Combined Alternative 2 is less effective than Combined Alternative 1, from the environmental protection perspective because there are no HDPE caps or lime-soil stabilisation; there is no experimental passive treatment system; and there is no groundwater extraction, treatment, and solids disposal at the Shelton Abbey Tailings site. Consequently, the time for project build-out would be somewhat shorter if the same general time frame for the project build-out was established as for Combined Alternative 1. The schedule scenarios are the same as for Combined Alternative 1; however, the costs are lower.

As with Combined Alternative 1, the work would be in three phases. The securing of the East/West Avoca sites' physical hazards would be the first order of business, in order to safeguard the public. Investigations, designs, planning documents, and permissions leading up to the award of the major construction contracts would be the same as for Combined Alternative 1.

6.4.2.1 Optimum Schedule

Work items that begin in one phase may be completed in the following phase. For example, the construction of the active water treatment plant would begin relatively late in Phase 1, allowing for long lead-time deliveries and site preparations, and conclude in Phase 2. It is estimated that the work would begin as soon as the major construction contracts are awarded.

Phase 1

- Install and maintain physical institutional controls, signage, and other temporary or permanent barriers to the sites' physical hazards in order to safeguard the public.
- Order long lead-time equipment and materials. Mobilise.
- Remediate the Deep Adit spoils site.
- Construct the active water treatment plant.
- Remediate the Cronebane/Mt. Platt Area.
- Construct the solid treatment waste disposal facility.
- Construct the control bulkheads in the Deep Adit and Road Adit, and the pipe connections to the active water treatment plant.
- Install the permanent water-related monitoring units.

Phase 2

- Install the soil bentonite walls and the groundwater extraction system; construct the shaft plugging, shallow bulkheads, and the pipe/channel connections to the active water treatment plant, and implement any water institutional controls.
- Remediate the East Avoca/Tigroney West area including the East Avoca open pit (not including the Deep Adit spoils site).
- Remediate the West Avoca Area.

Phase 3

- Remediate the Connary area.
- Remove/contain Avoca River sediments.
- Remediate Shelton Abbey Tailings.

- If not already completed, install the permanent geotechnical monitoring units.
- Accept the work, site clean-up, and demobilisation.

6.4.2.2 Balanced Cost and Funding Schedule

An optional schedule for Combined Alternative 2 that better balances the cost per phase can be accomplished by moving the construction of the active water treatment plant to Phase 2, and remediation of the West Avoca area to Phase 3. The schedule for the phasing would be commensurate with the funding, and may be up to two years for each phase. The optional phasing follows:

Optional Phase 1

- Install and maintain physical institutional controls, signage, and other temporary or permanent barriers to the sites' physical hazards in order to safeguard the public.
- Order long lead-time equipment and materials. Mobilise.
- Remediate the Deep Adit spoils site.
- Remediate the Cronebane/Mt. Platt Area.
- Construct the solid treatment waste disposal facility.
- Construct the control bulkheads in the Deep Adit and Road Adit, and the pipe connections to the active water treatment plant.
- Install the permanent water-related monitoring units.

Optional Phase 2

- Construct the active water treatment plant.
- Install the soil bentonite walls and groundwater extraction system; construct the shaft plugging, shallow bulkheads, and the pipe/channel connections to the active water treatment plant, and implement any water institutional controls.
- Remediate the East Avoca/Tigroney West Area including the East Avoca open pit (not including the Deep Adit spoils site).

Phase 3

- Remediate the West Avoca area.
- Remediate the Connary area.
- Remove/contain Avoca River sediments.
- Remediate Shelton Abbey tailings.

- Install the permanent geotechnical monitoring units.
- Accept the work, site clean-up, and demobilisation.

6.4.3 Alternative Construction Schedules

Many different construction scenarios are possible and depend upon the priorities, procurement methods, and bids received from construction contractors. As discussed in Section 6.3 various types of monitoring will be conducted including water quality and geotechnical monitoring. Results of the monitoring program may reveal some immediate priorities or changed priorities that may affect the schedule. For example, monitoring may indicate that stabilisation of the East Avoca Pit highwall (southwest area near the road) needs to be addressed as soon as possible. The schedule scenarios could be changed so that the East Avoca pit is backfilled during phase 1. This would probably result in addressing the Cronebane Pit during phase 2. A temporary treatment waste disposal facility would then have to be constructed for the treatment waste from the water treatment facility because the Cronebane Pit area would not be available for construction of the disposal area. However, depending upon funding and resources, both the Cronebane and East Avoca Pits could be addressed at the same time.

Section 7
Comparative Analysis of Combined Alternatives

The two combined site-wide alternatives presented in Section 6 are comparatively evaluated in this Section using effectiveness, implementability, relative cost, and site compatibility criteria with a focus on the entire site, rather than a media specific evaluation. This comparative analysis evaluation, performed on each geographic remediation area, is technically driven and assumes appropriate remaining requirements can be completed (e.g., environmental impact assessment, planning documents, and necessary permits). Each comparative criterion is defined below.

7.1 Effectiveness

Effectiveness is the ability of the remedial alternative to achieve remedial action objectives including protection of human health and the environment and addressing health and safety concerns due to physical hazards. In addition, effectiveness in this step of the feasibility study process also includes the long-term permanence, reliability, and continued ability to achieve remediation goals of the completed action. Long-term permanence, reliability, and effectiveness are also considered the same as sustainability. The combined alternative with the maximum probability of achieving remediation goals (e.g., water quality standards in the Avoca River, protecting human health, etc.) over the long term, and addressing physical hazards would be rated high for this criterion.

7.2 Implementability

Implementability used in this step of the feasibility study process relates to both the technical and administrative feasibility of constructing, operating, and maintaining the site-wide combined alternatives given the physical constraints of the site. The availability of needed materials and services is also considered. Technical feasibility considerations include the technical difficulties or steps anticipated in construction of the remedy, the impact of construction on the local community, and ease of operations and maintenance of any part of the completed remedy. Administrative feasibility relates to the ability to complete planning processes; procure treatment if required, storage, and disposal services (onsite or offsite); and procure the needed land, equipment, and expertise. For the alternatives comparison, the assumption is that the planning and permitting process can be completed.

7.3 Cost

Cost in this step of the feasibility study are the same as those used in the screening of process options and technologies. The relative costs were derived for each combined alternative.

7.4 Site Compatibility

Site compatibility is an evaluation of how each alternative fits into or complements the existing heritage and cultural features, landscape, and public access. Site compatibility also evaluates overall long-term site management and potential future uses.

7.5 Comparative Analysis of Combined Alternatives

The comparative analysis of Combined Alternatives 1 and 2 is presented below. A side by side comparison of the overall effectiveness, implementability, relative cost, and site compatibility of the two combined alternatives is also presented graphically in Table 7-1. A solid circle means the highest ranking of effectiveness, implementability, or site compatibility. The white areas in the circle represent a relative reduction in the criterion (effectiveness, implementability, or site compatibility). A completely open circle would represent alternatives that are not effective or implementable. For example, the No Action alternative would not be effective in achieving remediation goals and would have an open circle. As shown, both Alternatives 1 and 2 are relatively effective and implementable. Circles are 75 percent or 100 percent filled. However, this should not be considered as indicating that the criterion is 75 or 100 percent satisfied but simply that a 100 percent filled circle is likely to be more successful than the 75 percent filled for the given outreach. The relative costs are presented using Euro symbols. The more Euro symbols, the higher the relative cost.

7.5.1 Effectiveness - Solids

The solids remedies vary at all site locations in Combined Alternatives 1 and 2 from total and partial relocation and regrading in place to provide stabilisation of spoils piles, pit highwalls, rockfalls, and impoundments as needed. Due to the physical hazards identified, these actions are necessary. Both combined alternatives also contain provisions for shaft and adit plugging that address safety issues. Therefore, both combined alternatives are equally effective in addressing the health and safety concerns due to physical hazards. Regrading coupled with ditch construction as needed also directs surface water to an onsite treatment facility for treatment.

Table 7-1 Comparative Analysis of Combined Alternatives

Site-Wide Combined Alternatives	**Effectiveness**	**Implementability**	**Relative Cost**	**Site Compatibility**
Alternative 1 – Relocation of Mt. Platt, East Avoca, Tigroney West, and West Avoca spoils, regrading of Connary spoils and SP39. Containment of relocated solids material through HDPE cap overlain with soil/ indigenous vegetation. Alternative includes treatment of both East/West Avoca Water and the Shelton Abbey Tailings Water.	●	◕	**€€€**	●
Alternative 2 – Relocation of 80 percent of Mt. Platt; relocation of East Avoca and West Avoca spoils; regrading of Connary, Tigroney West spoils and SP39. Containment of relocated solids material through lime amendment tilled into spoils surface overlain with soil/indigenous vegetation. Alternative includes treatment of only East/West Avoca water.	◕	●	**€€**	●

●	Complies with the criterion
◕	Complies less with the criterion
€	Relative cost, the greater number of **€** symbols, the greater the cost

The surface water control and stabilisation components of each combined alternative are followed with subsequent installation of one of three types of soil cover/cap designs:

- Simple soil and indigenous vegetation
- Lime amendment application to spoils followed with soil and indigenous vegetation
- HDPE followed with soil and indigenous vegetation

Based on data collected from reclaimed mine sites, soil cap/cover designs using lime neutralisation agents tilled into the spoils material or an HDPE cap installation minimising infiltration are effective in reducing acid water generated from infiltration or inflow through mine waste. Both types of caps/soil covers promote growth of indigenous vegetation which prevents erosion of the soil cover, eliminates both dermal and ingestion exposure pathways to the spoils and pit wastes, and reduces infiltration through the covered waste. Flourishing indigenous vegetative growth is evidence of a long-term remedy. Simple soil covers without lime amendment or HDPE liner have not proven to be as effective in supporting growth of indigenous vegetation and may therefore be impacted by erosion over time.

Using lime amendments tilled or disced into spoils or pit material as part of a soil cover/cap design would neutralise the surface of the mine waste and control acid generation, providing a deep root zone for indigenous vegetation to grow and develop over the mine waste. The neutralisation capacity will decrease with time. However, infiltration of water will occur. The lime amendment provides some neutralisation of infiltration passing through the mine waste.

Use of a non-permeable material such as HDPE as part of the cap design would greatly reduce actual infiltration through mine waste from precipitation events. By preventing surface water from infiltrating the spoils and pit waste, acid water generation would be greatly reduced. This action coupled with the surface water management controls would provide a greater level of effectiveness by reducing acid water and metal loading to the treatment plant more than a lime amendment/soil cover with indigenous vegetation or a simple soil cover and indigenous vegetation. The HDPE is more effective, reliable, and sustainable over a long time period than soil covers or covers with lime addition.

A side by side comparison of the effectiveness of Combined Alternative 1 and 2 for solids is presented in Table 7-2 for each site location.

Table 7-2 Solids Effectiveness Screening

Site Location	Combined Alternative 1	Combined Alternative 2
Connary	Since Connary spoils contribute less loading to the Avoca River than other spoils, surface water management coupled with installation of lime-neutralising agents into the soil cover provide an effective remedy for this site location. Regrading of spoils piles provides stability and addresses physical hazard concerns.	Installation of soil cover and indigenous vegetation would provide a less effective remedy at this site location than Combined Alternative 1. Regrading of spoils piles provides stability and addresses physical hazard concerns.
Mt Platt/Cronebane	Relocation of Mt Platt spoils into the Cronebane Pit and cover of remaining spoils with lime-neutralising agents and soil cover coupled with surface water management is effective. Subsequent placement of HDPE cover in Cronebane Pit overlain with soils and indigenous vegetation would be highly effective for a major source of contamination to the Avoca River. Relocation of Mt Platt into Cronebane Pit is highly effective in stabilisation of both the pit highwall and Mt Platt.	Relocation of 80% of Mt Platt spoils into the Cronebane Pit and subsequent cover of remaining surface with soils and indigenous vegetation would be a less effective solution than the Combined Alternative 1. Subsequent placement of only indigenous vegetation in Cronebane Pit over placed spoils would be less effective than Combined Alternative 1. Relocation of 80% of Mt Platt spoils into Cronebane Pit will also be effective in stabilisation of the pit highwall.
East Avoca	Relocation of East Avoca spoils to East Avoca pit is a highly effective and permanent solution. Subsequent placement of HDPE cover in East Avoca Pit overlain with soils and indigenous vegetation would be a highly effective remedy in reducing contamination to the Avoca River and preventing human contact. Relocation of East Avoca spoils into East Avoca Pit is effective in stabilisation of both the pit highwall and spoils piles (with the addition of spoils from Tigroney West and Deep Adit areas).	Relocation of East Avoca spoils to the East Avoca Pit is effective. Subsequent placement of only soils and indigenous vegetation in the East Avoca Pit over placed spoils would be less effective than Combined Alternative 1. Long-term effectiveness and sustainability would also be less. Relocation of East Avoca spoils into East Avoca Pit will also be effective in stabilisation of both the pit highwall and spoils piles but not as effective as Alternative 1 (less spoils backfilled).
Tigroney West and Deep Adit Area	Surface water management coupled with installation of lime-neutralising agents into the soil cover provides an effective remedy for Tigroney West spoils. Relocation of the Deep Adit spoils to the East Avoca Pit would be a highly effective remedy for this site location. Ore bins would be relocated and restored. Relocation of Tigroney West and Deep Adit spoils into East Avoca Pit is highly effective in stabilisation of both pit highwall and spoils piles.	Use of soils and indigenous vegetation would provide a less effective remedy at Tigroney West than Combined Alternative 1. Ore bin relocation and restoration would be identical to Combined Alternative 1. Regrading, soil cover, and vegetation of the Tigroney West spoils would effectively address stability concerns with spoils piles. Deep Adit spoils relocation would be same as Combined Alternative 1.

Table 7-2 Solids Effectiveness Screening

Site Location	Combined Alternative 1	Combined Alternative 2
West Avoca (except SP39)	Relocation of West Avoca spoils (except SP39) and subsequent placement of HDPE cover in the North Lode Pit overlain with soils and indigenous vegetation would be a highly effective, permanent remedy in reducing contamination to the Avoca River and eliminating human contact. Relocation of West Avoca spoils (except SP39) into the North Lode and Weaver's Lode Pit is highly effective in stabilisation of both pit highwalls and spoils piles.	Subsequent use of only soils and indigenous vegetation in the North Lode Pit over placed spoils would be less effective than Combined Alternative 1. Same stabilisation effectiveness for West Avoca spoils, North Lode and Weaver's Lode pits as Combined Alternative 1. Use of HDPE in Alternative 1 is more effective and sustainable over a long time period.
West Avoca SP39	Surface water management coupled with installation of lime amendment soil cover and indigenous vegetation will provide an effective remedy for SP39 in reducing contamination to the Avoca River.	Same remedy, same protectiveness as Combined Alternative 1
Avoca River Sediments	Removal of ferricrete deposits and sediment with subsequent placement in an on-site repository, cover with soil and indigenous vegetation provides an effective remedy for sediments.	Same remedy, same protectiveness as Combined Alternative 1
Shelton Abbey Tailings	Regrading, filling, and other surface water management components coupled with installation of a soil and indigenous vegetation provide an effective remedy for this site location.	Same remedy, same protectiveness as Combined Alternative 1
Summary of Comparative Effectiveness	High	Moderate

7.5.2 Effectiveness - Water

Because the water components of both combined alternatives only differ for the Shelton Abbey Tailings and the construction of a passive pilot plant, the effectiveness comparative analysis of these alternatives does not require a table.

Under Combined Alternatives 1 and 2, East/West Avoca source control and discharge measures for acid mine water discharges will be used for all discharging adits by collection and treatment in an active treatment facility. Collected groundwater will be transferred to an active treatment system for treatment prior to discharge to the Avoca River. This will provide an effective permanent solution for contaminated groundwater at East/West Avoca. Addition of a passive treatment facility will not increase or decrease effectiveness.

Combined Alternative 1 also includes extraction of groundwater from the base of the Shelton Abbey Tailings using a soil bentonite wall and extraction wells. Combined Alternative 2 would provide no extraction or treatment of this groundwater. Therefore, Combined Alternative 1 will provide a more effective remedy than Combined Alternative 2.

Both alternatives contain Shelton Abbey monitoring (see Section 6.3) including upgradient and downgradient monitoring of river water quality. Implementation of monitoring as part of Alternative 2 at an early stage (as soon as possible) would allow collection of additional information concerning the impact on the river. This would allow a more informed decision as to whether the soil bentonite wall and water treatment is necessary. If necessary, the construction could occur in the later phases.

7.5.3 Implementability – Solids

As with the effectiveness comparison, the stability measures such as relocation and regrading of spoils and pit materials use standard construction methods and practices. Therefore, both alternatives provide highly implementable methods for addressing physical hazard concerns. All three types of soil covers/caps will be discussed in general terms in the text, with a specific comparison of the Combined Alternatives at each site location presented in Table 7-3.

Table 7-3 Solids Implementability Screening

Site Location	Combined Alternative 1	Combined Alternative 2
Connary	Regrading of spoils with addition of lime and a soil/vegetation would be a highly implementable remedy.	Regrading with a soil/vegetation cap (no lime amendment) is slightly more implementable compared to Combined Alternative 1.
Mt Platt/Cronebane	Relocation of all Mt Platt spoils is implementable. Installation of the HDPE cap would be less implementable than a soil/cover cap.	Relocation of only 80% of Mt Platt spoils would be as disruptive to the community as removing all spoils. However, less material is moved so the alternative is slightly more implementable compared to Combined Alternative 1. Installation of a simple vegetative cover over the Cronebane Pit would be easier to implement than the HDPE cap in Combined Alternative 1.
East Avoca	Relocation of East Avoca spoils to East Avoca pit is implementable. Installation of the HDPE cap would be less implementable than a soil/cover cap.	Relocation of East Avoca spoils to East Avoca pit is same as Alternative 1. Subsequent placement of only a vegetative cover in the East Avoca Pit over placed spoils would be easier to implement than the HDPE cap in Alternative 1.
Tigroney West	Relocation of Tigroney West and Deep Adit Area spoils to East Avoca pit is implementable. Replacement of Tigroney West spoils with clean soil and vegetation cover is more difficult to implement than Alternative 2.	Same remedy for Deep Adit spoils relocation. Regrading (no relocation) of Tigroney West spoils and installation of a simple soil/vegetative cover over the spoils areas would be easier to implement than Combined Alternative 1 (relocation).
West Avoca (except SP39)	Relocation of West Avoca spoils (except SP39) and subsequent placement of HDPE cover in the North Lode Pit overlain with soils and vegetative cap would be more difficult to implement when compared to Alternative 2.	Relocation of only large spoils piles and cover with soil/vegetation only is easier to implement than Alternative 1.
West Avoca SP39	Regrading with lime amendment and subsequent soil/vegetation cover is implementable.	Regrading with only a soil/vegetation cover is easier to implement than Alternative 1.

Table 7-3 Solids Implementability Screening

Site Location	Combined Alternative 1	Combined Alternative 2
Avoca River Sediments	Removal of ferricrete deposits and sediment, installation of a check dam would all be difficult to implement. Subsequent placement in on-site repository, cover with soil and vegetative cap is implementable.	Same remedy, same implementability as Combined Alternative 1.
Shelton Abbey Tailings	Regrading, filling, and other surface water management components coupled with installation of a soil and vegetative cover is easy to implement.	Same solids remedy as Alternative 1.
Summary of Comparative Implementability	Moderate	High

Installation of all covers will involve regrading of spoils material. Installation of a simple soil/vegetation cover will have the shortest construction seasons and therefore, the lowest impact on the community. The installation of the lime amendments would require transportation of the lime amendment material to each applicable site location, which makes it less easy to implement than a simple soil/ vegetation cover when compared relatively. However, the tilling of the lime amendment into the spoils material could be incorporated into the regrading step, which would not substantially increase the construction time required for implementation of the remedy. The largest impact to construction schedule would result from installation of an HDPE cap. The HDPE material would require transportation to each applicable site location as well as time to install and implement QA/QC procedures.

Implementation of relocation of the spoils piles would require transportation of spoils throughout the Avoca site. This would require flagging and dust control measures particularly along public roads, which will impact the community during construction. Therefore, relocation of spoils would be relatively more difficult to implement than regrading in place.

7.5.4 Implementability – Water

Since the water components of both combined alternatives only differ for the Shelton Abbey Tailings and construction of a passive pilot plant, the implementability comparative analysis of these alternatives does not require a table.

In Combined Alternatives 1 and 2, East/West Avoca source control and discharge measures for acid mine water discharge will be utilised to collect and treat all adit discharges in an active treatment facility. Extracted groundwater will be transferred to an active treatment system for treatment prior to discharge to the Avoca River. Therefore, both combined alternatives would be rated as equal under the implementability criterion. Construction of a passive pilot plant at East Avoca makes Alternative 1 more difficult to implement than Alternative 2. Because Combined Alternative 1 also includes extraction of groundwater from the base of the Shelton

Abbey Tailings using a soil bentonite wall and extraction wells plus construction of a treatment plant, it would be more difficult to implement than Combined Alternative 2 (no action with monitoring).

7.5.5 Costs

Due to installation of HDPE caps, relocation of larger volumes of spoils material, construction of a passive pilot plant, and treatment of water from the base of the Shelton Abbey Tailings Pond, the relative costs for Combined Alternative 2 are lower while the relative costs for Combined Alternative 1 are higher.

7.5.6 Site Compatibility

Both alternatives will preserve historical structures such as engine houses and the tramway arch. Both alternatives also provide for relocation and restoration of the ore bins. Both alternatives remove physical hazards and improve site access. Alternative 2 does provide for the retention of a portion of Mt. Platt, but each combined alternative is rated the same for overall site compatibility.

7.6 Conclusion

While both combined alternatives address physical hazards and protect human health and the environment, Combined Alternative 1 is more effective at reducing acid mine water production through use of an HDPE cap/soil cover and lime amendment in spoils. Combined Alternative 1 is more effective, reliable, and sustainable over long time periods than Combined Alternative 2. Combined Alternative 2, with less relocation of spoils material, shorter construction durations due to ease of soil/vegetation covers, and less transportation of materials within the site during construction is easier to implement than Combined Alternative 1. The relative cost for Combined Alternative 1 is higher than that of Combined Alternative 2.

Section 8
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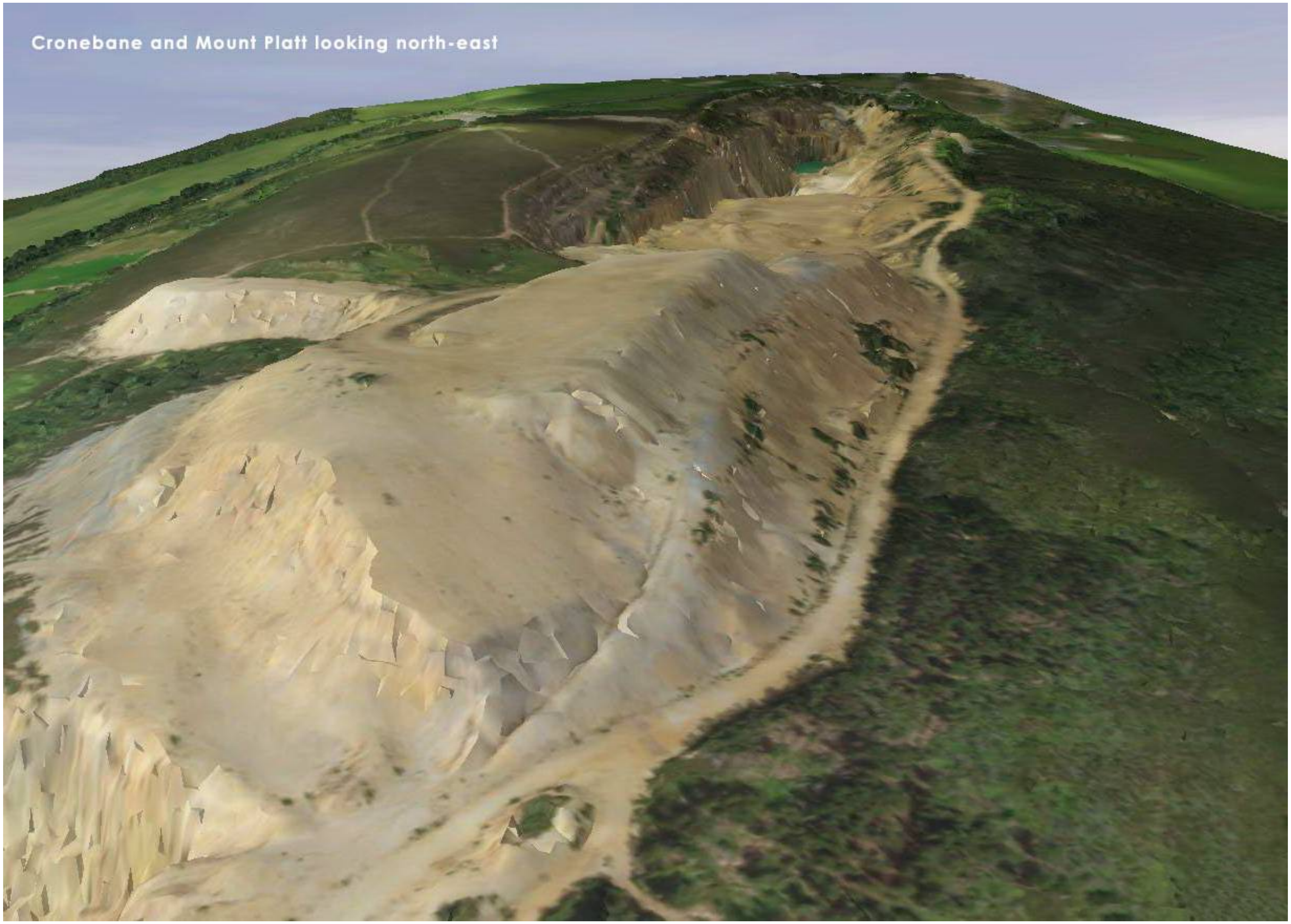
Appendix A
Site 3-D Figures
(Pre- and Post-Remediation)

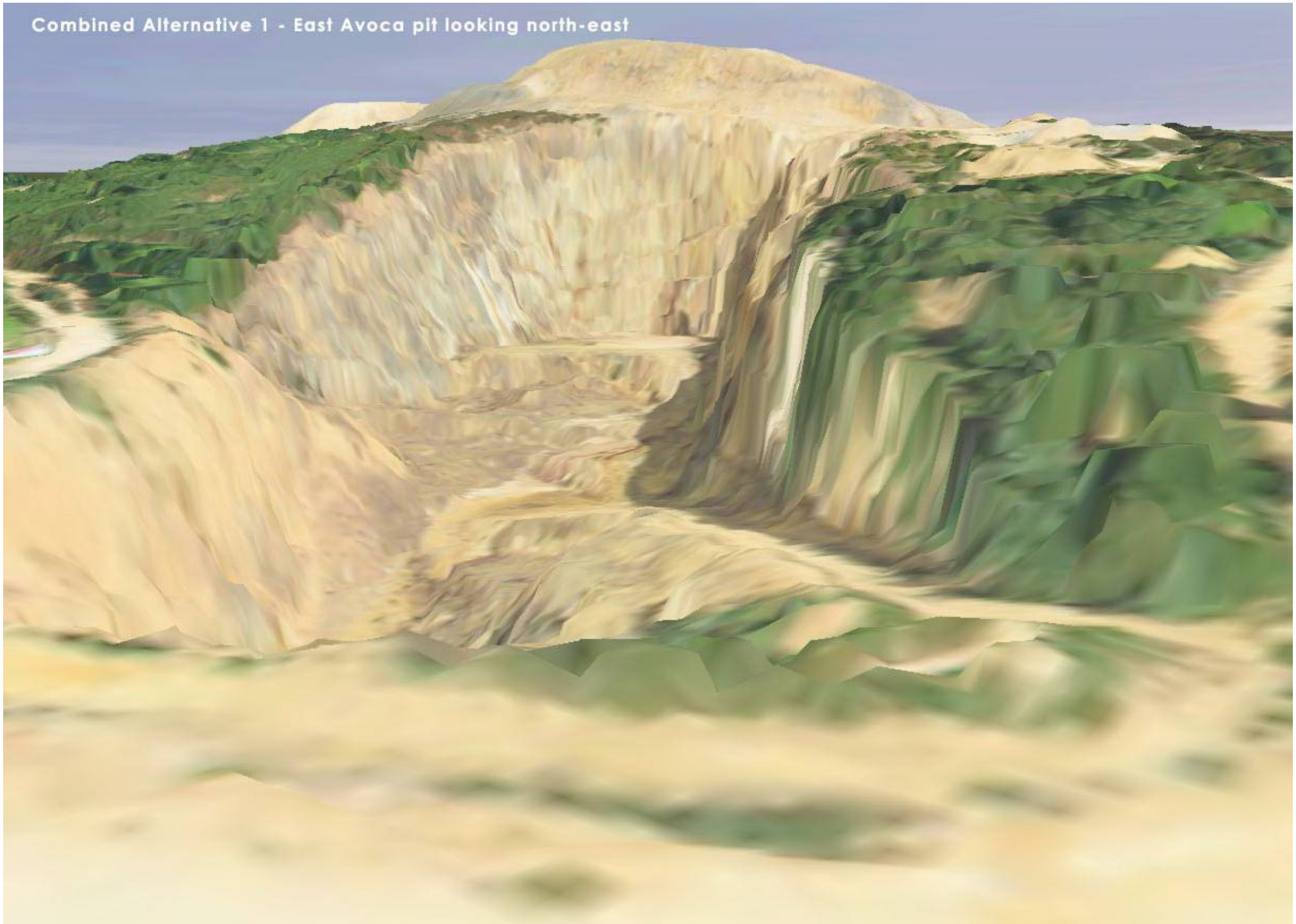
Cronebane and Mount Platt looking south-west

Combined Alternative 1 - Cronebane looking north-east

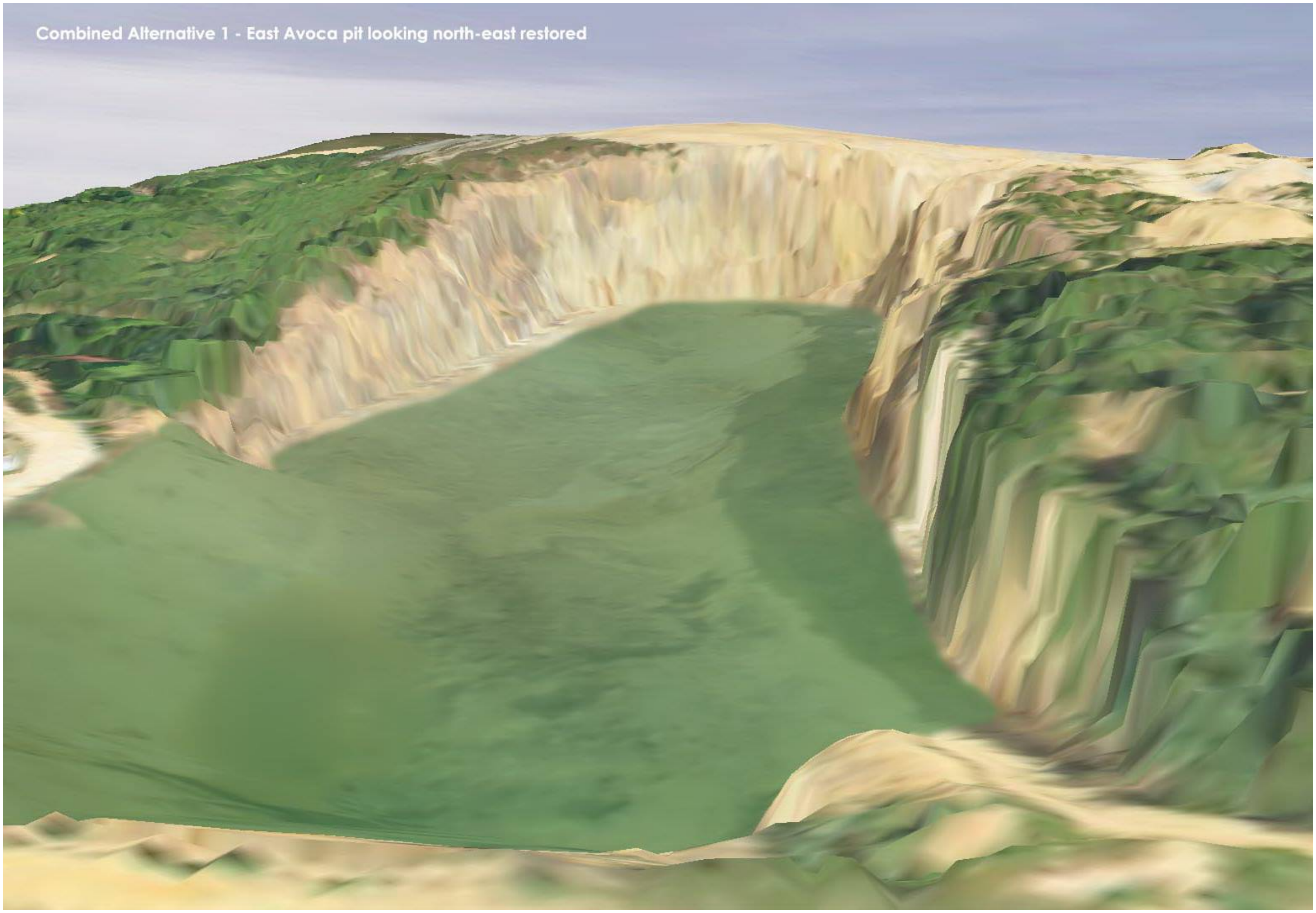


Cronebane and Mount Platt looking north-east

Combined Alternative 1 - Cronebane looking north-east restored



Combined Alternative 1 - East Avoca pit looking north-east



Combined Alternative 1 - East Avoca pit looking north-east restored

Combined Alternative 1 - East Avoca pit looking south-west

Combined Alternative 1 - East Avoca pit looking south-west restored

Combined Alternative 1 - East Avoca from West Avoca

Combined Alternative 1 - East Avoca from West Avoca restored

Combined Alternative 1 - Weaver & North Lode looking south

Combined Alternative 1 - Weaver & North Lode looking south restored

Combined Alternative 1 - West Avoca from Williams Engine House

Combined Alternative 1 - West Avoca from Williams Engine House restored