BEST PRACTICE
ENVIRONMENTAL
MANAGEMENT
IN MINING

Contaminated Sites

Environment Australia

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Cover photo: Ardeer site August 1998. A review by an environmental auditor confirmed that the land was suitable for use as parkland including children's playground and basketball area (see Case Study 3). Credits: Carter Holt Harvey.

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FOREWORD

Environment protection is a significant priority for our society. A major role for government is setting environment standards and ensuring that individuals and organisations meet them. Increasingly, however, government, industry and community organisations are working as partners in protecting our environment for present and future generations.

Representatives of the minerals industry in Australia and Environment Australia, (the environment arm of the Federal Government), are working together to collect and present information on a variety of topics that illustrate and explain best practice environmental management in Australia's minerals industry. This publication is one of a series of booklets aimed at assisting all sectors of the minerals industry—minerals, coal, oil and gas—to protect the environment and to reduce the impacts of minerals production by following the principles of ecologically sustainable development.

These booklets include examples of current best practice in environmental management in mining from some of the recognised leaders in the Australian industry. They are practical, cost-effective approaches to environment protection that exceed the requirements set by regulation.

Australia's better-performing minerals companies have achieved environmental protection of world standard for effectiveness and efficiency—a standard we want to encourage throughout the industry in Australia and internationally.

These best practice booklets integrate environmental issues and community concerns through all phases of mineral production from exploration through construction, operation and eventual closure. The concept of best practice is simply the best way of doing things for a given site.

The case studies included in these booklets demonstrate how best practice can be applied in diverse environments across Australia, while allowing flexibility for specific sites. Each booklet addresses key issues by presenting:

- basic principles, guidance and advice;
- case studies from leading Australian companies; and
- useful references and checklists.

Mine managers and environmental officers are encouraged to take up the challenge to continually improve their performance in achieving environment protection and resource management and to apply the principles outlined in these booklets to their mining operations.

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EXECUTIVE SUMMARY

Land contamination from mining has sometimes threatened human health and damaged Australia's environment. While it may be that the processes of extracting and concentrating minerals will inevitably result in some land being contaminated by mining, this in no way absolves the mining industry from its responsibility to minimise and remediate contamination.

The best way for a mining company to avoid contaminating land is to apply best practice environmental management principles. Best practice means minimising and managing contamination throughout the whole life of a mining operation — from its conception, through its construction, operation and decommissioning phases. By doing this, a company will comply with regulations, minimise the risk of penalties and future liabilities, and improve its image.

Some potentially contaminating processes, for example tailings and in situ leaching are specific to mining. Nevertheless, the experience of other industries can be drawn on to develop best practice management strategies for land contamination in the mining industry. The strategic framework for managing contaminated land published by ANZECC/NHMRC in 1992 is a valuable reference for understanding the key issues of preventing and managing land contamination wherever it occurs. This report has now been supplemented by the 'Assessment to Site Contamination: Draft National Environment Protection Measure and Impact Statement' from the National Environment Protection Council (NEPC).

Mining managers must ask themselves if their company and operations are equipped to apply best practice to managing land contamination. Do they understand relevant Commonwealth and State/Territories legislation? What mining processes can contaminate land? Are effective systems in place to detect and identify land contamination?

The best way to guarantee that effective procedures are being followed is to integrate contamination management into the overall environmental management system (EMS). This will subject contamination management to the same environmental monitoring and auditing that apply to other aspects of mine management.

Effective contamination management depends on effective systems and techniques for detecting the contamination and then assessing its significance. It must be decided if a particular area of a mine will be sampled (targeted sampling) for contamination, or if sampling will be on a broader scale (grid sampling). Managers need to be aware of the Australian Standard that outlines sampling protocols (this reference is provided in the booklet). Only by adequately assessing contamination can the correct remediation decisions be made. A risk-based approach is being increasingly applied to assess the significance of land contamination in Australia.

Assessing the significance of contamination varies with the environmental values assigned to contaminated land or water and with their projected future uses. It is also based on whether, and by how much, a contaminant exceeds the threshold level for a site with a defined environmental value. References for published threshold values are listed in the booklet.

Assessment results will determine if urgent action or a more gradual remediation approach is warranted. An immediate response might include recovering as much of the contaminant as possible, removing people, or placing barriers. Soil remediation may be needed and soil remediation techniques are summarised in the booklet.

If best practice has been followed, contamination on a site will have been kept to a minimum through good management; any contamination will have been remediated progressively throughout the life of the mine and there will be no liability for subsequent cleanup. Failure to clean up a site so it satisfies requirements for 'sign-off' can result in costs and liabilities such as continued lease payments and remedial works. Furthermore, less tangible costs of a damaged public image and reduced accessibility to future sites will also accrue. The question of who is responsible for site remediation also has to be resolved. A valuable resource for this is the ANZECC paper on financial liability for contaminated sites.

Case studies have been chosen to demonstrate how best management principles can be used to minimise the problems of land contamination in Australia's mining industry, even though not all are from mining.

Many of the management topics discussed in this booklet such as environmental management systems, tailings and hazardous substances have been the subject of other booklets in the series. Some relevant material is repeated here but referring to other booklets will often help in appreciating how to apply best practice management to contamination.

The aim of the booklet has been to place the issue of land contamination under the umbrella of best practice environmental management in mining. It will serve as a ready-reference for anyone wanting to minimise land contamination. The approach taken by the mining industry on land contamination must be above reproach. Implementing best practice management of land contamination will benefit not only the environment, community and company shareholders, but the mining industry as a whole.

CONTENTS

Glossary	
ANZECC	Australian and New Zealand Environment and Conservation Council
NHMRC	National Health and Medical Research Council
SOP	Standard Operating Procedures
Institutional Controls	Manage and minimise the possibility of health risks through mechanisms such as groundwater restrictions, limiting the type of land usage and ensuring appropriate protective equipment and behaviours are in place for workers
ISL	In situ leaching
AMD	Acid mine drainage
Putrescible	Liable to rot or become rancid
RBCA	Risk-Based Corrective Action

INTRODUCTION

This booklet aims to show how mining companies and regulatory authorities can apply best practice principles to minimise the potential for land to become contaminated, and to remediate existing contaminated land.

If best practice is applied to managing contaminated land, companies, the community and environment will all benefit. The best practice approach will:

- minimise the risk to human health and the environment;
- satisfy regulatory requirements and therefore minimising the risk of penalties;
- avoid contamination through design and operation, thus reducing future liability;
- allocate remediation resources to maximise environmental benefits and minimise the cost of obtaining an environmentally acceptable outcome; and
- provide general public-good benefits by preventing land contamination and, where required, restore the environment so it is safe for other uses.

Throughout the booklet, best practice environmental management principles are used as a framework for looking at past, current and future attitudes to land contamination, and ways to prevent and combat it.

1.1 PRINCIPLES OF BEST PRACTICE ENVIRONMENTAL MANAGEMENT

Best practice environmental management has been variously defined, but it is not static — it is a process of continuous improvement in what we do and requires a change in an organisation's culture.

Two definitions are:

- the practice of seeking out, emulating and measuring performance against the best standard available; and
- applying 'soft' and 'hard' technologies to environmental issues to achieve maximum, continuous improvement at minimum cost (Australian Manufacturing Council, 1992). 'Soft technologies' include innovative management approaches such as Total Quality Management (TQM), flatter structures, work teams, cross functional cooperation, statistical process control, an open door to community involvement, devolved environmental responsibility, and problem solving. They cause minimal disturbance and do not require significant infrastructure. 'Hard technologies' include automated machine technology, computer aided design and manufacture, robots, leading edge process/production technology and computer-based support systems. They include technologies that require significant infrastructure and/or labour to operate, and may significantly disturb the site.

Many practices that give rise to soil and/or groundwater contamination are unique to the mining industry. However, it is possible to transfer management practices and technologies used to manage contaminated land in other industries to the mining sector. This is illustrated in some of the case studies in this booklet.

The strategic framework for managing contaminated land is set out in the ANZECC/NHMRC (1992). It can be used to assess best practice environmental management of land contaminated through mining (for its key elements, see Box 1).

Box 1: Summary of Key Elements of ANZECC/NHMRC (1992) Framework for Managing Contaminated Land

Prevention

- Preventing site contamination is of paramount importance. Creating new, additional contaminated sites should be minimised and further contamination of already contaminated sites prevented. Contingency plans should be developed to minimise the risk of contamination in the event of an accident.

Management

- Contaminated site management strategies should protect all segments of the environment and avoid transferring contaminants from soil to air or water.
- The potential for contamination to harm the health and well-being of the community and its structures and service conduits must be considered. Some Australian cities and towns rely on groundwater for domestic use and particular care must be taken to protect groundwater.
- The fundamental goal of contaminated site cleanup should be to render the site acceptable and safe for long-term use and to maximise its potential future uses.
- Whenever human health is at risk, either onsite or offsite, or the environment is at risk, a site should be cleaned up to the extent necessary to minimise such risks in both the short and long term.
- If there is no threat to human health or the environment, it may be appropriate to clean up the site less thoroughly, to contain the contaminants onsite or use planning controls to limit site use. Technical feasibility and the net social benefit of cleaning up a site need to be taken into account.

Cleanup should not proceed if it is likely to increase the problem. The preferred hierarchy for cleanup is:

- Treat soil onsite to destroy the contaminant or reduce hazards to acceptable levels.
- Treat excavated soil offsite before either returning soil with acceptable residual contamination levels or removing it to a suitable waste disposal site.

If neither of these options is practicable, then:

- Remove contaminated soil to an approved disposal site and replace with clean fill.
- Isolate the soil by covering it with a properly designed barrier.
- Choose a less sensitive land use to minimise the need for remediation.
- Leave contaminated material in-situ providing there is no immediate danger to the environment or community and the site has appropriate controls in place.

These options may involve penalties under environmental guarantees given to State governments by operators. Every effort should be made to prevent contamination (see Leasing Obligations).

This framework needs to be applied in a practical way so it takes account of a minesite's location, logistics of infrastructure and any cleanup costs. However, polluted soil should be regarded as potentially hazardous waste and it should be subjected to the same controls over its use, storage, transport and ultimate disposal as industrial waste.

1.2 Applying Land Contamination Principles

How do these principles apply to contamination of land through mining? After all, mining aims to extract and concentrate metals, coal or oil, and it could be argued that it will inevitably contaminate land. While it is true that background levels of naturally occurring elements are generally elevated at minesites, these intrinsically high levels are not considered to be land contamination. However, the processes used to extract ore and produce waste can contaminate land and water; these must be governed by standards applied to other industries. Many mines are located in remote areas and the mining industry has often been slow to view contaminated land as a major issue. For industry sectors operating within urban areas there is greater pressure to redevelop land for safe, beneficial use and this highlights the need to reduce risks to human and environmental health. Communities can be deeply concerned about the potential impact of contaminated land on ecosystems of pristine areas that surround many Australian mines.

Contamination at mine sites must be assessed and managed to ensure high standards of occupational health and hygiene for workers and contractors. Also, older mines are often surrounded by townships that developed around them (e.g. Broken Hill, Mt Isa, Mt Morgan, Kalgoorlie) and the mine and town inhabitants must coexist safely.

The aim of this booklet is to highlight, for the mining industry, the importance of minimising contamination and if it occurs effectively cleaning it up. The contents are based on the principle that the mining industry is a temporary user of land — that is, land needs to be left in a condition after mining that does not significantly reduce its potential and options for other types of land use.

This booklet identifies the causes of land and groundwater contamination, and how the risk of contamination may be minimised. It also outlines strategies and tools to detect and remediate contamination, using best practice environmental management principles.

Case studies demonstrate how best practice principles can be applied to minimise risk (use of environmental auditing in Santos case study) and how to cleanup contamination safely and effectively (Ardeer, East Perth, Red Dome and copper smelting case studies).

1.3 What is Land Contamination and Why is it a Problem?

A contaminated site, as defined in the *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites* (ANZECC/NHMRC, 1992), is: *'a site at which hazardous substances occur at concentrations above background* *levels and where assessment shows it poses, or is likely to pose, an immediate or long-term hazard to human health or the environment.'*

There are various sources of contamination. Some, such as sulphidic waste (acid mine drainage) and tailings, are directly associated with mining. Others, such as fuel storage, ore processing or waste disposal, may be associated with support activities.

Land contamination is a problem as it can affect both human health and the environment of a minesite and its vicinity. Contaminated soil, subsoil, groundwater, surface water, particulates in air, and other materials such as waste rock dumps, can all affect the environment beyond the site boundary. Future use of the site may be compromised and this can represent a significant financial liability. For example, regulatory authorities may require that the impacts of earlier mining are rectified as part of the approval conditions for any future mining of a site. The cost of this may significantly change the economic viability of any new mining proposal (see Section 6 for a summary of recommendations on financial liability from the ANZECC/NHMRC, 1994 position paper).

Practical ways to apply best practice principles for contaminated site cleanup are listed in Box 2) using the memory prompt 'Get SMARTER'.

Box 2: Get Smarter

Strategic planning and management commitment to minimise potential for contamination at the time a mine is planned, designed and brought into operation.

Managing using Best Practice principles and staff training to identify processes/activities/materials (minesite infrastructure) that may give rise to contamination.

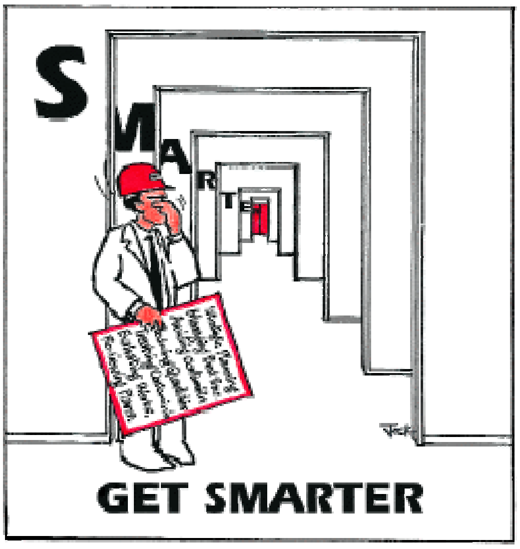
Avoiding contamination through management systems, tools, inventory controls, monitoring, and the thoughtful disposal of used contaminants or containers.

Reducing quantities of contaminants used or produced by: maximising process efficiencies, monitoring sites frequently (including sites of potential fugitive emissions), reusing/recycling, and selective mining and placing of potentially contaminated rock material.

Treating contamination incidents promptly — emergency response plans should be used to deal with immediate risks and then redefine operational procedures to reduce longer term risks.

Evaluating effectiveness of operational procedures, remedial works and the mine plan by auditing contaminant management procedures and comparing their performance against environmental and mine closure objectives.

Reviewing and updating mine operational and closure plans and assessing and remediating any contaminated site to meet subsequent landuse aspirations by the neighbouring community and the government.



1.4 Australian Legislation

Mine Planning

Most new mining projects in Australia are legally bound to undergo a formal Environmental Impact Assessment (EIA) and approval processes. EIA is one of the best ways to identify and manage the potential impacts of land contamination on a minesite during mine planning. It also provides a structured approach to considering environmental aspects during project-planning and decision-making processes.

By identifying issues that may lead to land contamination in a proposed mining operation, appropriate planning, management and operational procedures can be introduced to prevent contamination.

Further information on the requirements for EIA can be found in the booklet *Environmental Impact Assessment* in this series.

Leasing Obligations

Within Australia, mines are leased from the Crown under lease agreements that impose strict conditions on the use and operation of a minesite. Once mining operations have ceased and the mine is closed, the lease is returned to the Crown. Leases are regulated by the Crown and bonds or security deposits are returned at the end of a lease only if the site is returned to an agreed condition. The minesite should be reviewed regularly by environmental auditing. When a breach is shown with land or groundwater contaminated, the bond value may be increased or forfeited on mine closure.

State and Territory Requirements

Waste containment and contaminated sites management are generally the responsibility of the relevant State or Territory Government. Also, requirements for assessing, managing and remediating contaminated land currently vary between jurisdictions. This affects all aspects of contaminated land including liability, cleanup requirements, listing and certification. Policy differences on cleanup standards are particularly marked. As well, jurisdictions vary on whether compliance certificates are issued after completion of remediation work and on the status of such certificates.

Contact the relevant State or Territory environment protection authority or department for requirements and guidelines.

Work on updating national-level guidance on preventing, managing and remediating site contamination is coordinated by ANZECC in consultation with NHMRC. The 1992 ANZECC/NHMRC Guidelines remain a standard reference even though they lack whole-of-government and legislative endorsement.

The National Environment Protection Council (NEPC) is developing a nationally agreed and formally-recognised approach for assessing contaminated sites (scheduled for completion at the end of 1999) — a *National Environment Protection Measure on Assessment of Site Contamination.*

The Measure will be used throughout Australia to assist assessors, environmental auditors, developers and regulators to avoid costly duplication in method development, as well as reducing compliance costs and updating the assessment parts of the 1992 *Guidelines*. It should reduce variations between the jurisdictions, but some variations may remain. The Draft Measure is available at the NEPC website http://www.nepc.gov.au/pdf/nepm_is.pdf or the NEPC Service Corporation can be contacted at the following address:

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More information about contaminated sites is at http://www.erin.gov.au/portfolio/epg/contam.html. The site has links to a range of other sites, including that of NEPC, the States and Territories, and US EPA.

Occupational Health and Safety Requirements

The NEPC draft report includes draft guidelines for protecting the health and safety of site investigation personnel, other personnel on the site, users of adjoining land and passers-by (Schedule B [10]). While primarily aimed at health and safety during site assessment, the draft guidelines are a useful reference for safe practices during all phases of assessing and remediating a contaminated site.

The guideline document covers:

- the duties and responsibilities of the site safety assessor;
- site access;
- signage;
- dust generation from the site;
- contaminant spread both onsite and offsite;
- odour;
- noise and vibration;
- drainage;
- sediment control;
- storing and handling wastes;
- storing dangerous goods;
- appropriate assessment and classification of soils for disposal;
- protecting groundwater;
- contaminated groundwater (including disposal issues);
- earthworks; and
- site-specific conditions requiring variations from generic guidelines.

Risks at contaminated sites should be identified and a site specific safety plan (SSSP) established. All site assessment staff should undergo health and safety training. Consult the National Guidelines for Integrating Occupational Health and Safety competencies into National Industry Competency Standards (NOHSC: 7025, 1995) should be consulted for information on required competencies.

2 How Mining Processes Can Contaminate Land

Contamination may result from either intentional discharge of contaminants to the environment (e.g. waste disposal), or from unintentional discharge (e.g. fuel storage systems failing). A leak may be a slow continuous one (e.g. a leak from an underground fuel tank) or a single, short-term release (failure of a process plant releasing a significant volume of process liquor). To ensure best practice when identifying potential contaminating circumstances:

- have a sound understanding of the composition of all materials used in the mine and processing operations and their contamination potential (see Box 3 for substances that can cause land contamination); and

- systematically review and identify events and routes that could release contaminants.

Principal sources of contamination and activities resulting from various mining stages are discussed below.

2.1 Exploration and Trial Operations

Exploration

The potential for land contamination during exploration is low. Sources include the transport, use and storage of fuels and lubricants, and drilling fluids and additives. Contamination can result from:

- storing and handling fuels and lubricants without adequate containment;
- disposing of wastes onsite; and
- using unlined sumps for drilling fluids and onsite disposal of drilling muds that contain problem contaminants.

Photo: Goldfields (Tasmania) Ltd

Goldfields (Tasmania) Ltd, Mt Julia Prospect, 30km North of Queenstown, Tasmania. Preventing site contamination during exploration is achieved where any leakage from a 500L fuel tank (behind drill rig) drops onto a sheet of corrugated iron, then into a section of roofing gutter, flowing into a white PVC pipe visible in photo. The PVC pipe is routed around main and subsequent sumps, draining into a 1000L water tank shown.

Trial Operations

Trial operations are a part of developing a mine and associated mineral processing facilities. They help identify and resolve technical issues and determine operational viability.

The potential for trial operations to contaminate land varies with their scale and materials used. Potential sources include the accidental release of processing chemicals, fuels and wastes from trial operations.

Because trial operations are often short-term and temporary, the infrastructure for environmental protection, waste management and materials storage and handling is not always developed, or recognised as important. Significant environmental impacts, beyond the scale of the operation, have occurred where best practice has not been implemented.

Through the 1970s to early 1980, a trial uranium mining operation at Yeelirrie, Western Australia resulted in significant land contamination. The site was abandoned with minimal decommissioning, was not fenced and therefore was easily accessed by the public. It was discovered later that people had been swimming in the tailings dam and uranium ore from the site was used to repair roads.

(see http://www.wmc.com.au/envrep96/ page22.htm for more information)

Box 3: Substances from Mining with Land Contamination Potential

- Minerals being mined onsite.
- Metals or other constituents of waste or low grade ore disposed of on site.
- By-products of mineral processing.
- Chemicals used in mineral processing and associated by-products.
- Contaminants from ancillary activities (e.g. workshops and power generation).
- Stored fuels and lubricants.
- Waste materials from processing operations.

While some of these contamination sources can be avoided through appropriate facility design and operation, there may still be a need to dispose of bulk materials such as waste ore that can give rise to land and groundwater contamination.

Issues that need to be considered include:

- What constituents, such as drilling mud additives and processing reagents, are present, even in small quantities, in materials used in the mining operations? Could these cause future contamination needing cleanup if not managed properly?
- What substances are contaminants: for example, will naturally occurring metalliferous rock that is relocated to the surface be considered a contaminant or a source of acid or mobile metal salts?
- What waste materials are (or could form) contaminants? For example, will general or municipal refuse buried onsite be considered, or give rise to, contamination?

2.2 Minesite Construction

Wastes from mine construction and development often differ from those produced by other mining activities. Construction should incorporate appropriate materials waste management practices with proper storage and disposal of soils, fuels and refuse.

2.3 Mine Operations

Mine operations giving rise to contamination include:

- Excavation, which can allow air and water exposure to sulphidic ores leading to generated acid drainage and mobilisation of metals;
- spillage of fuels, materials and wastes in underground workings; and
- backfilling the mine excavations with waste materials that leach contaminants.

2.4 Processing — Surface Operations

Processing ores can lead to land being contaminated through:

- chemical and fuel storage;
- chemical and fuel spillage and leakage during transport, storage and handling. Filling operations can contaminate land and waterways, and have been the source of significant contamination from mining;
- process liquor containing chemicals and metals being lost (e.g. through leaks in process equipment or system failures);
- disposal of waste by-products including tailings, slag, ash, dusts or coke;
- dust and air emissions (e.g. in the past, emissions from the Port Pirie lead smelter contaminated the surrounding areas;
- rapid short-term releases (e.g. spills or major failure in storage or transfer systems), or by slower releases (e.g. leaking underground storage tanks); or
- increased volume and range of chemicals used at minesites with the objective of extracting a wider range of metals from ore bodies.

2.5 Extraction — in Situ Operations

In situ extraction of a metal requires reagents such as acid being injected into the ore body which has reasonable natural permeability or else micro or macrofissures are introduced to allow a reaction. The hydrometallurgy aspects of in situ leaching of copper and gold are discussed by Lawson (1990). In situ leaching typically includes the following steps: pumping a liquor into the ore body, recovering the liquor by pumping to the surface, extracting the mineral in a processing plant on the surface, and reusing the liquor. The surface processing operations associated with in situ mining can cause land contamination if containment is not adequate.

This typically includes the following steps: pumping a liquor into the ore body, recovering the liquor by pumping to the surface, extracting the mineral in a processing plant on the surface, and reusing the liquor. The surface processing operations associated with in situ mining can cause land contamination if containment is not adequate.

This process seeks to convert metals from an insoluble form in the ore body, to a soluble form, which could contaminate surrounding groundwater. However, the extent to which such contaminants migrate is restricted by the extraction activities, by an aquitard below the ore body (if present), and by natural attenuation of the liquor within the aquifer.

Because in situ extraction is subject to formal approval through the EIA process, an in situ operation is not necessarily subject to the same regulations as accidental contamination of soil and groundwater that may be associated with other mine operations.

2.6 Storage of Tailings

The composition of tailings (the waste by-product of mineral processing) varies with the nature of the ore and the refining process used. Concentrations of various unwanted metals are often higher in tailings than in unprocessed ore and inorganic constituents or chemicals used in mineral processing may also be present (e.g. alkaline 'red mud' from bauxite processing).

Examples of land being contaminated from mine tailings include elevated concentrations of arsenic in surface material at old gold mining sites in central Victoria, asbestos contamination of the Wittenoom township (north-west Western Australia) through reuse of tailings in construction materials, and wind-blown dust from dry tailings from metal processing sites in Hobart, Tasmania.

2.7 Handling Waste Chemicals, Consumables and Equipment

Most contamination from mining results from inappropriate handling of materials or waste disposal. Wastes causing concern may include:

- asbestos waste;
- waste oils;
- workshop wastes including oils, solvents and paints;
- discarded electrical equipment; and
- waste pesticides and herbicides (including discarded packaging, equipment and wash water).

Appropriate landfill practices are not always followed. Sometimes they may be driven by convenience (e.g. filling a gully) rather than good environmental practice.

Asbestos has historically been used extensively as a construction and lagging material in the mining industry. Disposal of asbestos wastes during construction, maintenance or decommissioning may not have accorded with current regulatory requirements. Even where asbestos has been disposed of correctly by burial, restrictions may need to be placed on future use of the disposal area.

Stockpiling waste can also contaminate land if contaminants leach or dust control methods have not been applied.

2.8 Management and Human Behaviour

Improper operation of mine systems and mineral processing facilities can result in process liquors and contaminating materials such as fuel being released. An example is failing to manually close a valve at the base of a fuel storage tank after draining accumulated water, releasing fuel into a bunded area.

Good practice is achieved by following Standard Operating Procedures (SOPs) and establishing clear individual responsibilities. Accidental releases of process liquors and other materials can occur when there is a change in personnel and the new personnel are inexperienced or unfamiliar with the facility.

3 Minimising the Risk of Land Contamination

3.1 Overview

Ways to minimise land contamination range from good housekeeping of operational facilities, to identifying (during mine planning) potential contamination sources.

The key principles are to:

- know the composition of all materials used, generated or stored and how they could contaminate land.
- identify likely sources of contamination during planning, design and operation phases;
- provide and maintain containment of areas;
- monitor and audit operations and facilities; and
- validate and document the final condition of land and groundwater after cleanup or closure.

The sections below discuss how to plan mines to minimise contamination during exploration, trial processing, mine operations, and tailings and waste management. A checklist of actions to prevent contamination is shown in Box 4.

Box 4: A Checklist for Avoiding Contamination Problems

Create an inventory of potential contaminants (this may require research e.g. understanding the components of rock materials).

- Assess potential impacts.
- Introduce a monitoring program based on impact assessments.
- Ensure the mine's site policy, operational manuals and procedures and closure plan are current.
- Train staff to prevent and deal with contamination; and

- Review staff performance regularly.

3.2 Mine Planning

An Environmental Impact Assessment should detail strategies to avoid, minimise or manage land and groundwater contamination as part of the mine plan.

An EIA will include a review of the hydrology, hydrogeology and geology of a site, and will identify potential receptors (human and environmental) that may be adversely affected. For example:

- Can chemical storage facilities be located where geological conditions favour containment of spills?
- How can the minesite design minimise transfer of fuels and chemicals across the site?
- How can facilities containing wastes or spillages be made secure?

A number of Australian Standards provide valuable advice on mine planning and design. The Australian Standards include The International Classification for Standards (ICS) which indexes standards according to a number of predetermined fields. Fields that may be used during mine planning and design include:

- Field 13: Environment and Health Protection, Safety;
- Field 73: Mining and Minerals;
- Field 77: Metallurgy; and
- Field 91: Construction Materials and Building.

Other advice (such as Codes of Practice) may provide for design criteria for mining and minerals processing operations, and for support facilities such as fuel storage (e.g. Australian Institute of Petroleum (1998) *CP4:Design, Installation and Operation of Underground Storage Tanks*).

The booklets on *Mine Planning for Environmental Protection by the Environment Protection Agency and Best Practice Environmental Guidelines for Construction* published by The Environment Protection Authority of Victoria (Victoria EPA.) also provide advice on minimising environmental impacts during mine construction.

Photo: Niugini Mining (Australia) Pty Ltd

Exploration Camp, Mungana, Red Dome Gold Mining area, west of Cairns, Queensland. Contamination from the oil rack is avoided by constructing a drip tray made with railway sleepers and a plastic sheet filled with sand.

3.3 Best Practice Exploration and Trial Operations

Best practice environmental management procedures for exploration and trial operations include:

- containing losses of fuel and lubricants from an oil rack using a drip tray made with railway sleepers, overlaid with plastic sheeting filled with sand;
- using biodegradable drilling fluids, using lined sumps for collection of drilling fluids, recovering drilling muds and treating them off-site, and securely storing dried waste mud by burying it in a purpose-built containment area;
- avoiding waste disposal at the site wherever possible, by segregating, trucking out, and recycling waste;
- containing potentially contaminating fluids and other wastes;
- cleaning up areas of spillage of potentially contaminating liquids and solids, and rehabilitating an exploration area after activities have been completed; and
- ensuring formal closure procedures accord with guidelines and licence conditions, including post-closure auditing, and preparing documents to confirm closure follows best practice.

The level of containment and control varies with the type of contaminants present, and whether they will cause future problems. If the operations are large, many of the precautions that apply to full scale mineral processing are applicable. Further information can be found in the *Hazardous Materials* and *Onshore Minerals & Petroleum Exploration* booklets in this series.

3.4 Minerals Processing Facilities

Mineral processing facilities should be designed so that the potential risks of chemicals and process liquor being released to the environment are minimised. The design process should include systematically reviewing land and groundwater contamination risk factors. It is essential that the designer be made aware of the nature and sensitivity of the surrounding environment. The design brief should clearly specify, for example, the environmental values placed on ecological resources. It should also take account of sensitive land usage that requires protection, and the long-term requirement for minesite closure, rehabilitation and subsequent landuse. The guiding principle should be to follow sound engineering design principles that reflect relevant Australian or International Standards.

The design brief should include specifications to ensure:

- The mill layout, and logistics for handling materials, minimises movement of materials over potentially non-contained areas (such as roads).
- Stockpiles of materials are contained and not dispersed by wind and water (e.g. by watering or covering). If ores are potentially contaminating in their

own right (e.g. non-ferrous metal ores, ores containing potentially toxic components such as arsenic, and reactive ores, such as those with a high sulfide content), then grinding and conveying operations designs should provide effective containment to avoid releasing material to the ground or as dust (see *Dust Control*).

- Stockpiles are managed so they do not become contaminated and then need additional handling or disposal.
- A low process or storage inventory is held to reduce the potential volume of material that could be accidentally released.
- Processing areas are contained and systems designed to effectively manage and dispose of contained stormwater, effluent and solids.
- Tanks are above ground, preferably with inspectable bottoms, or with bases designed to minimise corrosion. Above-ground (rather than in-ground) piping systems should be provided. Containment bunds should be sealed to prevent spills contaminating the soil and groundwater.
- Equipment, and vehicle maintenance and washdown areas, are contained and appropriate means provided for treating and disposing of liquids and solids.
- Air pollution control systems avoid release of fines to the ground (such as dust from dust collectors or slurry from scrubbing systems).
- Solids and slurries are disposed of in a manner consistent with the nature of the material and recognises and avoids contamination.
- Effluent and processing liquor drainage systems avoid leakage to ground; cracking at concrete pipe concrete junction boxes/manholes is common and such systems should be avoided where possible by using flexible drainage pipework.
- Design of effluent disposal systems, especially those including ponds, recognises that leaking ponds can contaminate soil and groundwater and that contaminated sediments and salts may accumulate (this is especially so with evaporation ponds).

Cleaner production principles should be applied to reduce waste when mineral processing facilities are being designed or reviewed. For example:

- substitute less toxic materials, where practicable, to reduce impact on the environment should a release occur; and
- reduce waste generation.

3.5 Minimising Acid Mine Drainage

Acid mine drainage is caused by oxidation of sulphidic mine wastes in waste rock dumps, tailings impoundments and coal rejects. The two major hazards from acid drainage are the low pH discharges in run-off or seepage and elevated levels of soluble metals. Both of these can harm human health or the environment.

A comprehensive approach is provided in the booklet *Managing Sulphidic Mine Wastes and Acid Drainage* in this series.

3.6 Tailings Management

Tailings are generally managed by onsite containment, either in a purpose-constructed facility, or through backfill in the mine or pit. While the tailings emplacement may not, in itself, be considered to be contaminated land, it is important that the tailings and leachate be contained. The tailings emplacement will be subject to formal approval through the process of EIA, similarly to in situ mining. Therefore, the operation is not necessarily subject to the same regulations as accidental contamination of soil and groundwater that may be associated with other mine operations.

The storage facility should be planned, designed, operated and eventually closed to restrict movement of tailings.

Designers of containment systems must take into account site characteristics and ensure containment will prevent tailings from being released and contaminating the environment. The use of geomembranes or synthetic liners may be warranted to minimise releases. Controlling leachate is critical to minimising land contamination from tailings. If/when the tailings dry out, windblown dust may contaminate land. Best practice includes using capping technologies and pH adjustment chemicals. See *Tailings Containment*. For gold mining, a useful reference is *Tailings Storage Facilities and Australian Gold Mines* by the Minerals Council of Australia.

Photo: Niugini Mining (Australia) Pty Ltd

Red Dome Gold Mine, Chillagoe, North Queensland. The tailings slurry line is placed blow the crest of an inward cambered dam wall so if the line breaks or leaks, spillage will flow into the dam rather than contaminate the surrounding environment.

3.7 Handling and Storing Materials

Storage and handling of hazardous materials such as fuel and chemicals are common sources of land contamination in the mining industry. Diesel or fuel oil is often used to fire power stations and considerable quantities of hydrocarbon fuels are bulk stored at mining or mineral processing facilities.

The overall facility design should aim to minimise the handling of hazardous materials. Storage facilities should minimise the risk of a release and ensure containment of any release. The Australian Standard AS1940 Storage and Handling of Flammable and Combustible Liquids provides best management guidance on the design of secure storage and handling systems for petroleum hydrocarbons. These principles can be applied to a range of chemicals and hazardous materials used in mining.

While there are various ways to improve facility design to reduce the accidental releases, these must be supported by appropriate operating procedures and training. For further information see the *Hazardous Materials Management, Storage and Disposal* booklet in this series, and AS1940 *Storage and Handling of Flammable and Combustible Liquids*.

For Occupational Health and Safety Issues, National Occupational Health and Safety Commission (NOHSC) publications can be searched at: http://www.worksafe.gov.au/

Publications on treating of scheduled waste can be searched at: http://www.ea.gov.au/industry/search.html.

3.8 How to Safely Manage and Dispose of Waste

It is essential that appropriate waste management facilities are included in the design of mines. Waste management facilities may include appropriately designed landfills to receive municipal refuse (e.g. associated with the mine and township) and solid and inert wastes from the mine or mineral processing facilities.

Best practice waste management practices include:

- segregating wastes by type and level of contamination;
- recycling and reusing wastes whenever practicable;
- reducing volumes (e.g. by evaporation); and avoiding waste dilution (e.g. by using roof-high contamination source areas to exclude rain, and segregate plant drainage);
- ensuring onsite waste disposal facilities (e.g. repositories) are appropriately designed for the wastes, and licensed as necessary; the design should recognise the need to protect groundwater;
- using licensed waste contractors where wastes are to be disposed of to offsite facilities such as landfill, and ensuring offsite facilities are licensed and appropriately designed to accept the wastes (various guidelines released by State environmental authorities provide guidance on the disposal of contaminated wastes to landfill);
- disposal of other wastes according to requirements (e.g. disposal of waste solvents from workshop by an appropriately licensed waste disposal contractor); and
- documenting waste disposal areas so that the history of waste disposal is recorded and wastes can be located if necessary.

While most attention should focus on managing waste chemicals and process by-products, potential contamination from disposal of putrescible materials and water (such as mine water) should not be ignored. The effects of gas generated from such material in landfills can adversely affect the use of land, and domestic waste landfills can fall within the definition of contaminated land.

However, many mining operations are remote from much of the waste disposal infrastructure. Therefore, practical alternatives to the normal waste disposal options may be needed. It may be necessary to dispose of mine water as well as solid and liquid wastes. In remote areas it has been common practice to dispose of such water to the tailings dam or to evaporation ponds. However, the possibility that this could lead to salt or other contaminants entering groundwater should be recognised. How waste disposal facilities including landfills and tailings dams (refer previous section) are designed and operated is critical to minimising land contamination. The facilities should by designed to provide a level of containment consistent with the sensitivity of the surrounding environment and the nature of the waste material. The use of geotextile membranes, leachate collection and secondary containment (for hazardous materials) should be considered. Water management systems should be designed to cope with both normal operation and storms. See *Tailings Containment* and *Hazardous Materials Management, Storage and Disposal* for further information.

3.9 Detecting and Identifying Land Contamination

Land contamination can be minimised only if a mine has effective systems for detecting and identifying land contamination. The ways in which contamination is generally detected are listed in Box 5 and discussed further in Section 5.

Points that assist in focussing a company's environmental objectives include:

- normal mine management procedures must have the capacity to identify contamination and potential liability;
- contamination may be present or discovered by others (such as adjacent property owners, or companies undertaking due diligence for purchase); and
- in applying due diligence, contamination must be identified and defined and shareholders informed of potential liabilities.

To identify and define contamination, questions include:

- How is an investigation designed and how extensive should it be?
- What protocols need to be followed? Can existing onsite environment staff undertake the investigation? Can an onsite laboratory be used, or must samples be sent to a specialist laboratory?

These issues are discussed in detail in Section 5.

4 Management Systems to Limit Contamination Threats

4.1 Environmental Management System

An Environmental Management System (EMS) helps managers apply principles of quality assurance/management to meet both current and future environmental requirements and challenges. An EMS will help a company meet environmental performance indicators and reach its environmental objectives and targets.

An EMS incorporates elements of review, objective setting and implementation. By defining objectives and responsibilities for environmental performance, documenting work procedures that protect the environment, monitoring environmental performance — and auditing to ensure procedures are followed — an EMS provides a level of assurance that environmental impacts are being appropriately managed. A formal assessment of current environmental impacts is part of an EMS.

A EMS identifies risks from contamination. Operating procedures and management strategies to address these risks can then be developed, leading to a Waste Management Plan.

How to manage land already contaminated, and avoid further contamination, are questions an EMS should address. Details of implementing an EMS are provided in the *Environmental Management System* booklet in this series.

4.2 Environmental Monitoring

Environmental monitoring is essential for determining whether land has been, or could be, contaminated. Monitoring may focus on the health of environmental components in the vicinity of the site, such as:

- groundwater quality;
- storage tanks, particularly underground fuel tanks;
- stack and other air emissions; and
- discharges either from tailings containment facilities, or discharges from dumps with AMD potential.

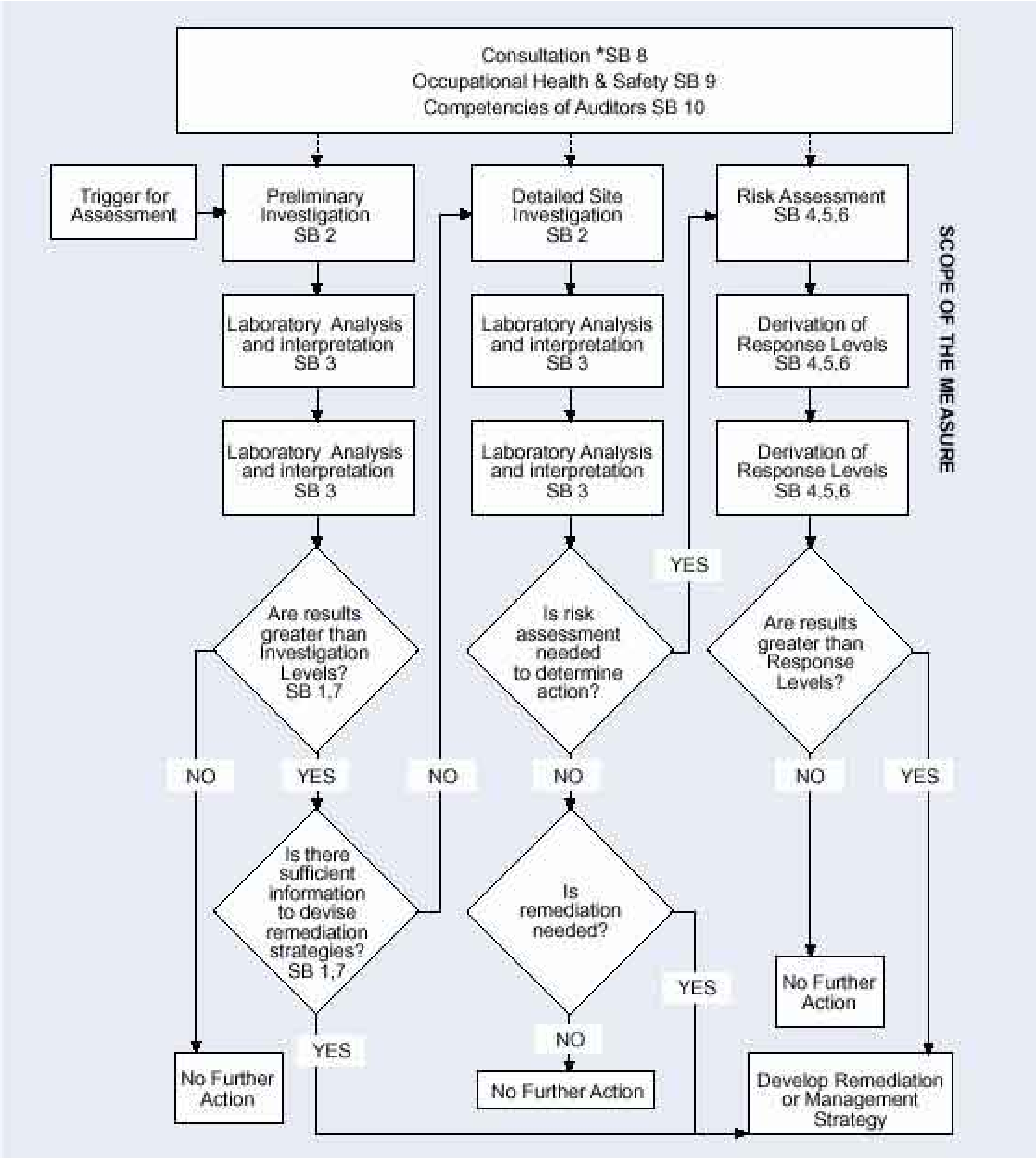
Further information is presented in the booklet *Environmental Monitoring and Performance*. Information on sampling and analysis to determine the presence and extent of contamination is outlined in Section 5.

4.3 Environmental Auditing

Environmental auditing is an important tool for identifying potential impacts on the environment by mining activities, and is an essential component of the EMS.

A key focus of an environmental audit should be to identify current and potential releases that may contaminate land, and to develop options to minimise them. System or hardware failures may cause such releases (e.g. old chemical storage equipment with increased risk of failure) as can failure to comply with SOPs (e.g. inappropriate disposal of waste solvents from workshops).

5 Techniques for Assessing and Remediating Contaminated Land



*SB refers to Schedule B of the draft Measure

Figure 1: General Process for Assessment of Site Contamination

A considerable body of knowledge has developed in Australia on how to assess the significance of contamination, but it focuses on urban land development. However, its application to remote-area mine-site development is still useful.

Questions on how contaminated land at mining sites is assessed include:

- how is the significance of contamination assessed? Can guideline values be used to compare results or is a more detailed analysis required?
- what land and groundwater uses need protection? What is the danger to human health?
- is it necessary to eliminate all sources that could give rise to future groundwater contamination?

- is it necessary to return the land to its original condition, or can some localised contamination remain?
- is residual contamination containment acceptable-and what conditions should be imposed to restrict future activities on the site.

5.1 Identifying and Assessing Contamination

Typical ways that an investigation of contamination may be triggered are listed in Box 5. The flow chart in Figure 1 (from Schedule A, page 19, *Assessment of Site Contamination, Draft National Environment Protection Measure and Impact Statement*, 29 March 1999 (NEPC, 1999)), shows a hierarchy of options for assessing the significance of contamination. SB refers to Guidelines for the Assessment of Site Contamination. These Guidelines are outlined in Schedule B of the Draft Measure. The Draft Measure can be downloaded from http://www.nepc.gov.au/pdf/nepm_is.pdf

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Box 5: Detecting Land Contamination

One or more of the following processes can trigger a contamination investigation:

- an environmental assessment or audit;
- due diligence investigations associated with property transfer;
- reporting a significant release to the environment using say, an incident report (e.g. valve accidentally left open allowing tank to drain into bund);
- excavation or works that encounter material identifiable by odour or visual impact;
- routine environmental monitoring;
- impacts observed by users on adjacent land;
- routine testing of storage and distribution equipment; and
- losses identified through a review of materials inventory records.

When investigating, identifying and assessing contamination, it is usual to separate the process into:

- preliminary exploratory investigations to determine whether there is a problem, the contaminants that are present, and some understanding of their significance; followed by
- more detailed investigations to better define the extent and significance, and clarify areas of uncertainty.

It is usually not cost-effective to undertake detailed investigations without some exploratory work, unless the nature of the problem is well defined (as, for example, with a localised spill of fuel).

The first step in assessing an operating minesite is to review the history of site activities with staff who have worked on the site for a long time. They can help identify potentially contaminating activities and locations where releases of contaminating materials may have occurred. Some sites have been redeveloped several times and records may need careful review. Historic records, including aerial photographs and old company reports lodged with the Mines Department, may be useful for identifying previous sources of contamination.

Land contamination can occur at the surface or at deeper levels. Surface contamination may be indicated by staining or odour. Deeper contamination is more difficult to identify and samples of soil and groundwater may need to be taken and analysed.

The ANZECC Guidelines, associated documents and various State environmental agency publications give guidance on designing sampling programs to detect or identify contamination. In particular, the Australian Standard AS 4482.1-1997 *Guide to the Sampling and Investigation of Potentially Contaminated Soil, Part 1: Non-volatile and Semi-volatile Compounds* constitutes best sampling. Refer to State agency guidelines on sampling design and procedures when work is carried out for statutory purposes.

In most cases, sampling and analysis will include a combination of:

- targeted sampling in areas where contamination could have occurred (such as in fuel storage areas); and
- grid sampling to characterise broader areas of the site to confirm whether contamination is present.

With large areas, careful sampling design is important to maximise information and to control costs. Minimising analytical costs can include selecting a subset of samples for detailed analysis, and focusing on contaminants of concern. Information derived from these analyses can determine cleanup requirements.

Soil samples may be taken by a spoon (in the case of surface samples), by hand auger, or by excavator or drilling rig for deeper samples.

The Australian Standard (above) outlines protocols for taking samples:

- the sampling program should have a detailed written work plan and quality assurance plan prepared in advance;
- an appropriate occupational health and safety program should be implemented; this is particularly important when the contamination could pose a significant hazard to the sampling staff;
- cross contamination by equipment can spread contaminants;
- cross contamination between samples is a particular concern when drilling through areas of high contamination, into clean areas;
- where contaminants are volatile, sampling, storage and analysis methods must be designed to retain the contaminant;
- specified holding times for transport and storage before analysis must be adhered to;
- chain of custody documentation should be maintained;

- samples should be analysed by a laboratory recognised by the appropriate authorities (in Australia the relevant accreditation authority is the National Association of Testing Authorities (NATA); and
- quality control and quality assurance samples must be taken at specified frequencies, with check analyses being undertaken by a secondary independent laboratory (refer to AS4482.1 — 1997).

Attention to these details is particularly important when the results define the extent or significance of contamination for subsequent sale or statutory purposes. When the methods are not followed, the contamination may not be detected, or characterised properly.

Some experienced consultants specialise in soil and groundwater contamination investigations and can be engaged if an extensive investigation is needed. The environmental agencies in some States maintain a list of accredited auditors; these auditors can provide an independent review and advice on investigation methods.

Techniques for detecting contamination are summarised in Box 6.

Box 6: Techniques for Detecting Contamination

Two main types of techniques, sampling and non-sampling (or non-invasive), are available for detecting land contamination:

Sampling techniques:

- targeted or judgemental sampling, designed to identify if contamination exists when the likely sources of contamination are known;
- systematic sampling on a grid or random basis across the site (useful where sources of contamination may be unknown);
- stratified sampling which may incorporate a mixture of judgemental and systematic sampling or systematic sampling at different sampling densities across the site.

Simple observation during sampling can help determine the extent of contamination. For example, the boundary of a contaminated fill layer may be most easily identified by careful observation during sampling.

Non-Sampling/Non-invasive techniques:

Various non-invasive or non-sampling techniques can also help but more detailed investigations may still be needed. Geophysical examples include:

- ground penetrating radar;
- resistivity; and
- conductivity magnetometer surveys.

These techniques can detect changes in density associated with, say, a change from fill to natural soil conditions, the presence of metallic objects such as drums of waste (by density, magnetics or conductivity), or contaminants that change the conductivity of soil or groundwater (e.g. elevated concentrations of dissolved salts in groundwater).

5.2 Assessing the Significance of Contamination

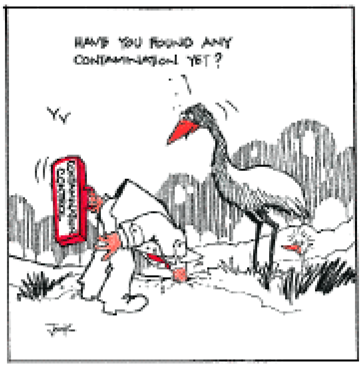
Risk-based Contamination Assessment

The ANZECC Guidelines adopt a risk-based approach to managing contaminated land. This approach recognises that land need only be suitable for the uses to which it will be put, and does not necessarily have to be returned to a pristine state. However, a commitment to best practice demands performance beyond the narrow limits of regulatory requirements. What is deemed 'acceptable land use' now may not be acceptable in the future. While returning the land to pristine condition may be prohibitive at present (with current technology and costs), a 'minimally rehabilitated' site may become a future liability.

A similar system of risk-based site management, referred to as 'Risk-Based Corrective Action (RBCA)' has been gaining support internationally, and in some industries and government sectors in Australia. The principles of RBCA are:

- **m**anage sites based on the risk to human health and the environment;
- **u**se a staged approach, first comparing sampling results with published risk-based guideline values (such as the ANZECC Health and Environmental Investigation Thresholds) to determine whether a site may pose a risk if these guideline values are exceeded; then carrying out a more detailed site-specific assessment of the risk if necessary;
- **m**anage sites to reduce risk, rather than focussing only on reducing the contaminant activities. This allows more flexible site management approaches and can take advantage of approaches such as containment and natural attenuation. These approaches can be of particular relevance to the mining industry in which sites may continue to be used for mining for the foreseeable future.

Guidelines are being prepared for applying RBCA to the Australian downstream petroleum business. A similar approach can be taken for the mining industry. There is further information on the general framework for RBCA in the ASTM (1995) 'Standard Guide for Risk Based Corrective Action Applied at Petroleum Release Sites'.



Protecting Specific Uses of Land and Groundwater

When assessing possible effects of contamination, 'beneficial uses' of the land or groundwater should be considered. The environmental values to be protected are determined by the future use of the land and water. The sensitivity of land and water to contamination usually decreases as follows:

- Ecosystems — protecting plant and native animal life and ecosystems associated with the land and water is the most sensitive requirement.
- Agriculture — protecting plant growth and avoiding residues accumulating in cattle and sheep.
- Human health — protecting humans in a residential setting (especially where garden produce is grown and eaten).
- Human health — protecting humans in a commercial, industrial or mining setting is usually the least sensitive requirement, because in these situations it will usually not be necessary to provide for plant growth or the protection of soil ecosystems.

In making an assessment, it is useful to first consider 'threshold levels' for contaminants in soil and water for their designated environmental values. If contaminant concentrations are higher than these threshold levels, further investigation is required.

Useful published threshold levels are:

- Soil—environmental: ANZECC Guidelines (1992) and the Environmental Quality Objectives in the Netherlands Ministry of Housing, Spatial Planning and the Environment (1994)
- Soil—phytotoxicity: NSW EPA Guidelines for the NSW Site Auditors Scheme (1998)
- Soil—human health for various land uses: National Environmental Health Forum (1996) 'Health-based Soil Investigation Levels'.
- Water—various uses: ANZECC Australian Water Quality Guidelines for Fresh and Marine Water (1992).

Assessing possible effects on ecosystems is a developing science, and preliminary guidance is provided in a draft 'National Framework for Ecological Risk Assessment of Contaminated Sites' released by Environment Australia. The draft report is in three parts: Part A, Framework Description; Part B, Derivation of Ecological Impact Levels; and Part C, Exposure, Toxicological and Chemical Parameters.

When applying threshold levels, it is essential to consider the full range of possible effects. For example, while soil contamination might not threaten human health, it may still contaminate groundwater, or have aesthetic effects such as an unpleasant odour. These latter effects can sometimes result in more stringent constraints than required to protect human health.

Protecting groundwater for future use determines cleanup requirements. These can vary from State to State. However, State environmental policies generally require that future uses of groundwater be protected where possible, and sources of contamination removed. When it is clearly impractical to remove sources, or the future use is highly unlikely, it may be agreed that a source may remain in place.

More Detailed Assessment Quantitative Risk Assessment

If contaminant concentrations exceed threshold levels, a more detailed assessment of the risk to human health and the environment, and whether remediation or other management works are required, may be warranted.

This requires a careful risk assessment of exposure pathways, receptors (such as the mine workers), toxicity of the contaminants in the form found on the site, and actual levels of exposure. The results from the assessment may indicate that published threshold values are too low and remediation is not required.

If risk assessment is used in this way, the agreement of the relevant environment authority or an accredited auditor with the findings should be sought, as appropriate in the particular State or Territory.

Specialist consultants who can help assess human health and environmental risk can generally be identified through the environmental regulatory agencies.

5.3 Remediation and Management Strategies

General Requirements

The strategy for remediation and management should:

- reflect the need to protect all environment segments;
- render a site acceptable and safe for a long-term continuation of its existing use and maximise (to the extent practicable) the future use of the site;
- not proceed if the process is likely to create more harm than leaving the site undisturbed; and
- consider the public and occupational health impacts associated with remediation and assessment works.

For there to be a risk, exposure to the contamination must be possible. Remediation techniques include relocating contaminated materials to a containment area onsite or offsite, full treatment (such as bioremediation or thermal treatment) to destroy the contamination and allow the material to safely remain onsite, or partial treatment (e.g. stabilisation) to reduce the hazardous nature of the material and help contain it.

While onsite treatment is usually preferred, for active mines and industrial facilities, greater use is being made of institutional controls (see glossary) and containment because of the limitations and cost of onsite treatment.

Urgent Remedial Action

When contamination is identified, the urgency of response varies with the level of risk posed by the contamination.

If the risk is not immediate and significant, then a further measured assessment should be undertaken to develop a cost-effective remediation strategy. If the contamination poses a real and immediate risk to human health or the environment, then urgent action may be required. This should aim to reduce the risk as soon as possible by reducing the volume or concentration of bioavailable toxic contaminants and/or excluding access by people and animals. The contamination should also be contained or directed, to minimise environmental effects or potential contamination of surface and groundwater sites.

Some initial responses may include:

- recovering as much of the contaminant as possible (e.g. of free phase fuel from groundwater); applying chemical absorbents or neutralisers as required (e.g. lime to neutralise an acid spill); and using temporary bunding or similar barriers to limit contaminant spread and to help its collection;
- removing people who may be exposed (e.g. by restricting access to the contaminated area); and
- placing barriers to prevent or reduce exposure (e.g. using personal protective equipment, installing a groundwater interception barrier or constructing a fence to limit access to the contaminated area).

Photo: Santos Limited

General view of the Moomba Facility Liquids Recovery Plant. The environmental audit is one part of the management strategy to minimise and mitigate oil losses *outlined in the Santos Australia Environmental Management System (see Santos Case Study).*

Removing contamination sources

The most direct methods are:

- Excavate and remove contaminated soil for disposal at an onsite repository or an offsite landfill (e.g. those provided by local government). This is the most common method, being generally the cheapest in urban environments or mine sites close to towns. For many minesites, their remote location and adjacent land favour the use of onsite repositories.
- Treat the soil or groundwater to destroy the contaminant. Treatment technologies vary greatly with contaminant, media and site characteristics. Soil treatment may include bioremediation, stabilisation, thermal desorption, chemical treatment, solvent extraction or soil washing. If the treatment (such as soil washing) concentrates the contaminant, then further treatment of the resulting concentrate (e.g. by stabilisation) or any one of a range of more novel methods may be used. Methods aimed at destroying the contaminant are generally not applicable to metals, although some extraction methods are available that allow the contaminant to be concentrated and the volume of material reduced for further management. For mining sites, the methods of treatment most likely to be applicable are:
    - hydrocarbon contamination: bioremediation (e.g. land farming); and
    - metals contamination: stabilisation by adding cementing agents (if leachability of the material needs to be reduced);
- Relying on natural attenuation or degradation. This method can apply where significant sources have been removed and only dissolved contamination remains in groundwater. It can also be applicable to shallow hydrocarbon contamination in soils, where natural biodegradation will occur over time. Natural attenuation can be appropriate for the mining industry, for which the time-scale available for remediation is often long and there may be few constraints on the use of land during this period.

When groundwater is contaminated, the contaminant source should be removed.

Ways to remove groundwater contamination sources include excavating, pumping and treating, air sparging and vacuum extracting volatile contaminants; and onsite bioremediation.

Remediation techniques and the advantages and disadvantages of applying them to various contaminants are summarised in Table 6.1.

Placing barriers between contamination and personnel or the environment

Capping and containment systems can provide a physical barrier between contamination and persons or the environment. Options for contaminated soils include clay or geomembrane capping systems, or excavating the soil and placing it in a secure repository constructed of compacted clay or geomembrane liners. A structure such as a building or waste rock dump may also provide a containment barrier.

It is essential that future activities on a capped site are controlled, to maintain system integrity. If coverage greater than 3 or 4 m is provided, and the contamination is not at a dangerous level, site redevelopment may be appropriate.

Regulatory authorities differ in approving construction of onsite repositories for contaminated soil, and should be consulted if this option is proposed.

If groundwater is likely to be contaminated, physical systems to contain the waste may be used (e.g. membrane, clay or bentonite slurry cutoff walls). Alternatively, a hydraulic system could be used to pump groundwater from the contaminated zone to reverse flow, thus minimising contaminated groundwater flowing towards users.

Protective clothing should not be worn as a substitute for best practice. It should generally only be needed by personnel such as maintenance workers who may need to access services deep in contaminated soil.

Constraints on Future Site Use

A range of institutional controls are available to manage contaminated land and avoid risking health. Examples include restricting groundwater use, not using the land for buildings with basements (e.g. if volatiles are present at depth), restricting worker activities (e.g. no sub-surface works without appropriate personal protective equipment), or limiting the range of usage (e.g. not allowing land to be used for agricultural or residential use).

Planning authority approval is required where a constraints option is proposed. This approach can be a legitimate way to manage sites. However, it is reasonable to expect that such controls and restrictions will be maintained in perpetuityor reviewed if another use of the site is proposed.

Table 6-1: Summary of soil remediation techniques

Technique	Contaminant applicable	Advantages	Disadvantages
Bioremediation (landfarming, biopiles, bioventing)	Organics	Low cost Natural process Onsite or offsite depending on the site conditions and contaminants	Ineffective on inorganics Inhibited by metals & low pH Time Uncertain performance in some cases
Containment/Capping	All types	Beneficial where landfill access is limited	Long-term liability Long-term management plan

		Reduces recharge to groundwater Reduces exposure to surface contaminants Low cost In many cases it is the only practical alternative (e.g. tailings management)	and maintenance required Ongoing monitoring Restrictions on activities in capped area Perception
Incineration	Inorganics & organics	High effectiveness	Large energy requirements Air discharges Disposal of ash required Cost Public perception
Onsite vitrification	Organics, heavy metals & radionuclides	Treatment of various wastes simultaneously 25—50% volume reduction Applicable to highly hazardous material Effectively encapsulates metals and radionuclides	Large energy requirements Requires removal/puncture of sealed containers to prevent hood overheating High cost Limited Availability
Offsite disposal	Inorganics & organics	Removes contaminants from site Availability and cost in urban areas Time	Landfill access and volume restrictions Restrictions on disposed material
Onsite repository	All types	Highly effective Reduces area requiring management	Long-term liability Long-term management plan required Leachate management required
Soil Washing	Inorganics & organics	Reduce volume to be treated	Only suitable for soils with a low percentage of fines Cost Residual material (fines or sludge) may

			still require treatment or disposal
Stabilisation & solidification	Metals	Effective for metals May be cost effective alternative to offsite disposal (with some restrictions)	Other contaminants affect stabilisation process Material can be left onsite Ongoing monitoring may be required
Stabilisation & solidification (offsite)	Metals	Effective for metals Allows landfill disposal of material otherwise unacceptable	Other contaminants affect stabilisation process Cost
Thermal desorption	Organics	No ash produced Minimises soil damage Time	Requires air emission controls Low pH may corrode system Cost Ineffective for metails

Table 6-2: Summary of groundwater remediation techniques

Technique	**Contaminant applicable**	**Advantages**	**Disadvantages**
Groundwater pump and treat	All	Reliable design can contain and treat groundwater Offsite treatment systems options (e.g. precipitation, biodegradation, chemical treatment) including wastedischarge to other liquid waste treatment facilities onsite	Disposal of treated groundwater Time Pumping can migrate contaminants and smear separate phase hydrocarbons
Air sparging	Organics (particularly volatiles)	Onsite Relatively low cost	Treatment effectiveness can vary with on site conditions Time (duration)
Separate Phase Recovery	Light organic liquids (e.g. fuels)	Reduce source of groundwater contamination Potential to reuse the recovered organic liquid	Time Disposal of liquid if not able to reuse or recycle

		(e.g. fuel)	
Pump and offsite disposal	Inorganics and organics	Low cost Uses existing treatment facilites	Impact on offsite wastewater facilities. Pumping can result in migration of contaminants or smearing of separate phase hydrocarbons Time
Containment (including cut-off barrier, groundwater diversion, hydraulic containment)	All	Low cost Applicable where many other techniques not practical Time	Ongoing monitoring Liability retained Disposal of water if hydraulic containment employed Ongoing maintenance
Natural attenuation	Organics	Low cost Takes advantage of natural processes Minimal intervention	Ongoing monitoring requirement

6 Who is Liable for Contaminated Sites?

Liability for contaminant cleanup at a minesite varies, and depends on the magnitude of the contamination and the risk to human health and the environment. The liability can be allocated to those associated with on-going operations of a mine, and those responsible for potential contamination after mine closure.

Mine management is responsible for ensuring that any contamination is dealt with immediately, and all relevant regulators/authorities are notified. The cost of cleaning up will vary with the type and extent of contamination. More importantly, failure to respond to contamination may delay progressive rehabilitation of the mine. This, in turn, could delay closure and returning the site to the Crown (see Section 1.4). To relinquish the lease to the Crown, the site must be 'signed-off', according to the lease conditions. If best practice has been implemented, progressive remediation and rehabilitation works (including environmental monitoring) will have been conducted throughout the life of the mine. Post-operation remedial and rehabilitation works and mine closure usually take 25 years.

If the environmental requirements have not been met (e.g. offsite contamination) 'sign-off' will not proceed. Potential costs and liabilities of this include:

- continued lease payments and delay of bond payment;
- potential for significant remedial works, for which it may be necessary to bring some infrastructure (ie heavy machinery) back to the site to complete these works;
- significant remediation costs; and
- potential for a poor public image with the stakeholders, especially the immediate community and reduced accessibility to future sites.

Minimising contamination and cleaning it up properly should avoid these problems. Quality control that should also be implemented. This is especially so when infrastructure such as tailings dams and stormwater drains are being designed, built and maintained.

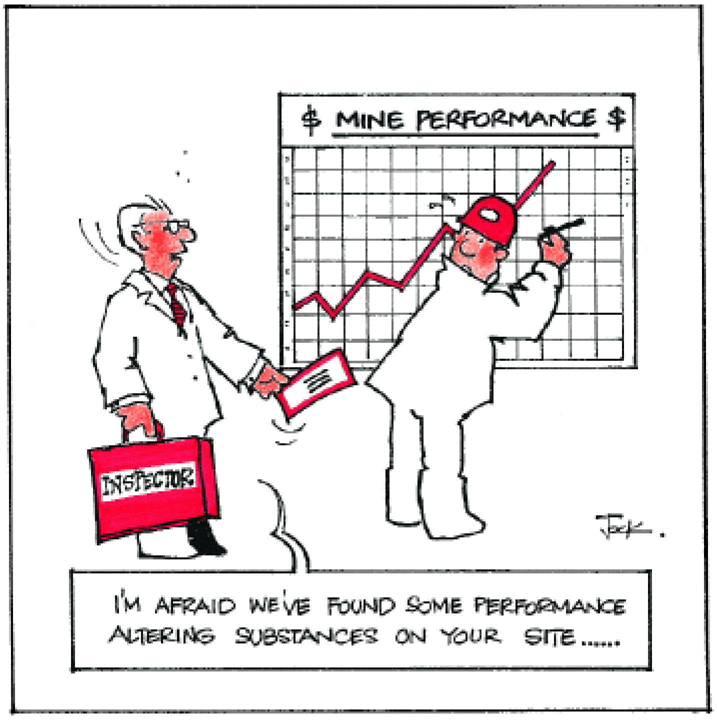
ANZECC released 'Financial Liability for Contaminated Site Remediation, A Position Paper' in April, 1994. This discussion paper proposes a basis for allocating financial liability for contaminated sites, and the general principles have been adopted by each of the Australian State and Territory environmental agencies.

The paper distinguishes sites on the basis of whether the current landuse for a site poses a risk to human health and/or the environment. The key recommendations of the ANZECC paper are:

- Governments should ensure that the polluter, when solvent and identifiable, ultimately bears the cost of any necessary remediation.
- When the polluter is insolvent or unidentifiable, the person(s) in control of the site, irrespective of whether that person is the owner or the current occupier, should be liable, as a general rule, for any necessary remediation costs.

- If a site is a risk to human health and/or the environment, governments should be empowered to intervene to direct remedial action to minimise risk (and to recover costs as above).
- The polluter is responsible for bearing the cost of any offsite remedial works, as a result of contamination from their site.
- When ownership of a non-risk site is transferred, the level of cleanup prior to transfer is a matter for commercial agreement between the parties. This would apply to most land transfers in the mining industry in the form of a mining lease.

In some states, there are legal penalties available to governments to prevent polluters trading or, if necessary, jail them.



I'M AFRAID WE'VE FOUND SOME PERFORMANCE ALTERING SUBSTANCES ON YOUR SITE......

7 Conclusions

The approaches and strategies developed for managing contaminated land in other industries provide the essentials for best practice environmental management of land contamination from mining. However, specific management strategies are needed for contaminated land resulting from, for example, tailings and in situ leaching which are specific to the mining industry.

Best practice environmental management starts with minimising the potential for contamination of land by designing systems to reduce the potential for releases to the environment. This includes implementing appropriate waste management strategies and operating procedures. In the mining sector, waste management (including disposal of by-products from mineral processing) and preventing land contamination are very closely linked. The management of contaminated land needs to a part of the integrated management that covers all environmental issues and is provided by environmental management systems and auditing procedures.

Assessing and managing contaminated land should necessarily be based on the risk posed to human health and the environment, rather than the concentration of any specific contaminant. This facilitates the use of innovative and cost-effective strategies in managing contaminated land.

The ability to manage contaminated sites is vital to best practice management of mining sites. While overall mine and mine systems design should minimise the potential for contamination, and provide adequate safeguards in the event of failure, mine operators must be able to act confidently, competently and swiftly to deal with any contamination — preferably as an immediate, integral response to issues as they arise.

Achieving best practice in this field is not just a case of 'cleaning up an error', but of continuing to demonstrate the operation's responsible and thoroughgoing approach to best practice as a whole. In doing so, the mining operation continues to aspire to be at the leading edge of best practice in the eyes of the community, regulators and its own staff and shareholders.

Photo: Woodward Clyde

Goldfields (Tasmania) Ltd, Henty Gold Mine, 30km North of Queenstown, Tasmania. Because of high rainfall at the site contamination is prevented by an innovative bund system where rainwater is allowed to drain away while retaining any spilt material. As water is always in the bund, absorbent material can be left floating to immediately soak up any spillage.

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Case Study 1

Santos Limitd (QLD, NT AND SA) - Environmental Auditing and Management Systems

Introduction

SANTOS Limited explores for and extracts natural gas and oil in Queensland, Northern Territory and South Australia. Loss of oil is recognised as one cause of potential land contamination. Preventing loss has been a major focus at the business and Santos has a long-term objective of achieving zero oil loss. An 'Oil Stream Process' audit, covering a number of operations (from well sites to point of sale), has been used to identify:

- potential areas of oil loss (high, medium and low risk); and
- approaches to planning, design, handling and management of oil operations to minimise oil loss.

The audit is one part of the management strategy to minimise and mitigate oil losses outlined in the Santos Australia Environmental Management System.

The audit identified procedural and technical areas for potential oil loss. Legislation and other regulatory and non regulatory requirements (e.g. design codes) requiring Company compliance were identified, and existing Santos documentation was reviewed.

Sources of potential oil loss include deficiencies and failures in design and operation. The losses are generally minor and of little environmental significance, but can be numerous. Oil loss through system failures is less common, but if they occur the oil loss may be significant.

Management Systems

The Company has developed a Santos Australian Environmental Management System (SAEMS). An aim of SAEMS is to minimise and mitigate oil losses and resulting effects on land. Strategies developed to achieve this include:

— monitoring, analysing and reporting (to the Environmental Committee of the Board) environmental incidents. By reporting these events, Santos has determined the significance of oil losses, and the consequent environmental and legal implications. In addition, the reporting process provides valuable data for future planning;

— environmental auditing (including the 'Oil Stream Process Audit');

— Environmental Compliance Manuals which outline the legal obligations of Santos, list legislation relevant to the operations in each State and provide an interpretation of the legislation as it may be applied to Santos' operations;

— Codes of Environmental Practice and Procedures. SAEMS also provides for the review of equipment and operational and maintenance procedures; and

— education on oil loss minimisation and other environmental issues, including Environmental Inductions for field staff.

Oil Stream Process Audit

Several aspects of Santos' operations were reviewed as part of the Oil Stream Process Audit, from the well head to the oil storage and processing facilities. The results from the audit were used in two ways: to identify and prevent potential oil loss, and to identify and minimise the impact from existing oil losses.

Potential losses

Potential losses from pipelines, trunklines and flowlines have been identified in the audit as a high priority for action. Although losses are rare, the potential exists for significant oil releases. Lines are located both above and below ground, and detecting oil loss using metering systems can be difficult. The audit identified steps that Santos can take to minimise risk of oil loss through line failure. These include recording the condition and life expectancy of the various lines, with information on the pipe and environmental conditions to which it is exposed (e.g. soil acidity), and developing a subsequent maintenance program.

Photo: Santoas Limited

Feed to Tirrawarra line, Meranjin Field, South Australia.

Minimising land contamination

The audit was also used to identify changes as required to minimise land contamination arising from oil loss. The review of oily waste generation and disposal at a number of facilities is an example. The audit identified areas of potential soil contamination from past disposal of oily sludge from storage tanks, process sumps and drains. Wastes had been placed in slop pits, which were identified as potential contaminated sites. A decommissioning and rehabilitation program for these pits is now underway, including the remediation of several sites by landfarming.

Photo: Santoas Limited

Moomba facility, South Australia. A new oil interceptor pond to collect stormwater from floating roof hydrocarbon tanks.

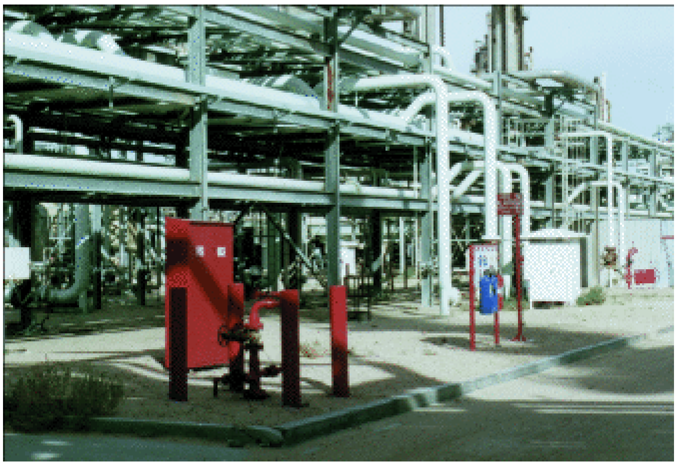

Photo: Santoas Limited

Santos is committed to maintaining emergency and safety equipment such as this fire alarm and extinguisher in top condition at all their facilities.

Education

Santos' oil spill risk minimisation program has created an internal climate that places high priority on zero oil loss. Santos has achieved a high level of environmental awareness in its employees, recognising the need to adhere to the relevant guidelines and legislation in each State. It is expected that the awareness of environmental issues will assist in reducing operational oil loss incidents.

Conclusion

The Santos audit and the oil spill risk minimisation program is part of a continuing program of environmental improvement being undertaken by the Company, involving:

- identifying potential oil spill sources and reducing the volume of oil lost;
- identifying areas of contaminated land to implement management or remediation; and
- responding to regulatory change.

The program exemplifies a best practice approach to the management of contaminated land. These strategies include reviewing processes and systems to identify and reduce potential sources, identifying and managing existing contamination, and education to assist in avoiding future losses. These strategies are incorporated in the overall environmental management system under which Santos operates, ensuring the appropriate allocation of responsibilities and actions.

Photo: Santoas Limited

Jackson Tintaburra facility. Note bunding around storage tanks to contain any accidental spills and minimise contamination.

Case Study 2

Red Dome Gold Mine, Queensland - Incentives to Avoid Site Contamination

The Red Dome Mine was an operational gold and copper mine until 1998 and is near Chillagoe, 135km west of Cairns in far north Queensland. Part of its operations to avoid contamination included washing and neutralising drums used on the site. An incentive scheme to promote this cleanup demonstrates a proactive commitment by the company to encourage workers to adopt an environmentally-responsible mindset.

All empty drums on site were pressure washed. Reagent drums were washed within the plant, and lubricant drums cleaned on a workshop washdown pad fitted with an oil-water separator. Fuel and heat exchanger fluid drums were returned to the supplier or sent offsite for disposal.

All washed drums were then stored in a compacted soil (60cm) area, surrounded by a clay bund, until being collected by a local drum reconditioning company.

The incentive for staff was the transfer of proceeds from the sale of cleaned drums to the social club and local charities. Meeting the company's environment targets directly benefited the environment, the company, the workers and needy local groups. The scheme emphasised company training to help staff understand the importance of environmental systems. This included the need to protect clean water sources and the environment and minimise effluent streams as 'part of the overall job', rather than as an afterthought.

Benefits

- Cleanup and closure costs were reduced by staff adopting a proactive approach during mining.

- The number and extent of environmental incidents fell noticeably after staff had been trained in environmental awareness. Training also reduced environmental damage and operational costs.
- Staff focussed on avoiding clean-up incidents during production, with consequent boosts to worker morale and demonstrated environmental performance.
- Because of the new outlook adopted by workers labour resources were more cost-effectively used in mining as processing activity wound down. Workers were fully occupied until their last days on the job, as they understood the project was not complete until the cleanup was finalised.
- Closure was easier as known problem areas were cleaned up *during* processing operations and the impact of dirty water minimised. The location of incidents, and their nature, were well remembered — not left until long after the incident and the departure of workers.

Photo: Niugini Mining (Australasia) Pty Limited

A used drum storage compound for containing drums prior to recycling or reconditioning.

Case Study 3

ardeer Lead Smelter, Victoria - Lead Contamination of Residential Properties

Introduction

A property at Forrest Street, Ardeer was used for lead smelting and battery recycling, from the 1950s to 1983. Activities at the smelter included breaking old car batteries and re-smelting their lead plates. After decommissioning, the site was redeveloped for low density housing. In 1989, after houses were built on part of the site, contaminants were detected. The primary contaminant was lead but arsenic, cadmium and zinc were also identified.

Various companies who had been involved with the site formed a Joint Management Committee (JMC) to deal with the contamination. The JMC worked with the

Environment Protection Authority of Victoria (EPA Vic) and Brimbank City Council to develop a strategy for managing the site.

Investigations

During 1989 EPA Vic investigated the degree of contamination by taking 100 targeted samples across the 1.6 ha site. This investigation showed high lead concentrations. Because of this contamination, families living on the site were relocated, new houses on the site demolished, and adjacent houses affected by the contamination cleaned.

By installing groundwater wells it was shown that contamination was restricted to the surface soils, and groundwater was not contaminated.

Samples were initially taken using hand augers and a drilling rig. Subsequently, more detailed investigations for the JMC used test pits. The contamination was found to be associated with fill, and this enabled suspect material to be identified visually. More contamination was identified during remediation, when structures such as concrete footings and pipes were discovered. After remediation, residual soil was sampled and analysed to prove that the clean-up had been complete.

Photo: Carter Holt Harvey

Remediation underway (March 1997) at the Ardeer site which was used for lead smelting and battery recycling during the 1950s to 1983.

Remediation Options

A review of site history and additional fieldwork for the JMC confirmed the preliminary findings by the EPA Vic and helped develop a suitable remediation strategy. Remediation options included excavation and disposal at an off-site landfill, excavation and transportation of the soils to a smelter to recover the lead, and containment onsite. Options for future landuse included residential and parkland.

In developing the remedial strategy, the JMC engaged a remediation consultant. The consultant worked with an environmental auditor appointed by the JMC to determine the most appropriate clean-up criteria for the landuse options.

The removal of contaminated soils—with pretreatment as necessary—to landfill was selected as the best remediation option for developing the site as parkland. A conceptual statistical model was used to estimate the volume of soil to be excavated and treated. Lead and the other metals identified in the preliminary assessment were considered in the model. The output from the model indicated an average excavation depth of 0.5 m would be required to meet the nominated remediation criteria.

The remediation criteria for the site was derived from a semi-quantitative risk assessment, based on the site being used as parkland by the local council. A 95% upper confidence limit (UCL) of 2100 mg/kg for lead was proposed to avoid possible effects on the health of people using the site. To minimise risk from remaining contaminants, and effects on plants, a clay cap of 0.5 m was also proposed.

Remediation included sampling soil using a grid program. This determined the depth of excavation, and which soils would need to be treated before being removed. Soils that required pretreatment were stabilised using various additives, and then tested to confirm those requirements for leachability were met.

The contamination was found to be generally restricted to a shallow surface layer of fill (about 0.5m), and removing the fill resulted in the bulk of the contamination being eliminated. After remediation, validation testing showed that most of the site complied with residential use criteria, with the 95% UCL for the mean lead concentration being less than 300 mg/kg. After validation, a plastic warning barrier was placed at the base of the excavation and covered with clean fill and top soil. A site management plan was prepared to assist the city council with its future management of the site.

The auditor compiled an audit report confirming the land was suitable for its proposed use as a community park, and issued a Statement of Environmental Audit to this effect.

Photo: Carter Holt Harvey

Ardeer site March 1989. The EPAVic investigation showed high lead concentrations at the site. Note the need for fencing and signage to restrict public access and warn of danger.

Stakeholders

There were various stakeholders associated with the remediation of the site, including: the former owners/operators of the site, the Victorian government, regulatory agencies, the local council, residents (onsite and offsite) and the local community. Liaison with these groups began before remediation work started, and continued throughout the process.

Conclusion

Past activities at the Ardeer site had resulted in significant lead contamination, which was only identified after the site had been developed for residential use. The contamination was found to be largely restricted to the surface soils, and remediation required excavating, pretreating where necessary, and disposing of contaminated material to a landfill. The site was then capped to minimise residual risk to future users of the site. A high level of cleanup was achieved. The cleanup was subject to review by an auditor, who confirmed that the land was suitable to be used as parkland.

Photo: Carter Holt Harvey

Contamination at the site was generally restricted to a shallow surface layer and removal of this layer eliminated the bulk of the contamination.

Case Study 4

East Perth Gasworks, Western Australia - Innovative Site management Strategy

The former East Perth Gasworks manufactured gas from 1922 until 1971 and was heavily contaminated by gasworks waste. The 4.6ha site includes 300m of Swan River foreshore, part of Perth's main river (see photos). Remediation, started in late 1994 and finished in early 1996, cost $15 million.

The gasworks site is owned by the City of Perth and was part of a major urban renewal program by the East Perth Redevelopment Authority. It was one of the first large-scale remediation projects at a gasworks site in Australia.

The project included:

- investigating site soils and groundwater;
- preparing an environmental impact statement;
- consulting the public;
- a risk assessment study; and

- implementing a multicomponent remediation strategy.

The project shows how a risk-based remediation approach can achieve a cost-effective solution to a significant contaminated site problem. It demonstrates:

- the innovative use of bioremediation for treating contaminated soils;
- conventional excavation; and
- offsite disposal of contaminated material (river sediments) for safe onsite containment of more highly contaminated material at depth on the site.
- offsite disposal of contaminated river sediments so these are safely contained at depth on a new site.

All these strategies can apply to contaminated mine sites.

Contaminants onsite

Leaks and inadequate disposal of by-products from the gasworks had contaminated the site. By-products included ammoniacal liquors, coal tars and both phenolic compounds and spent oxides.

Significant concentrations of polycyclic aromatic hydrocarbons (PAHs) from coal tars were found in the soil. Other contaminants were also detected in the soils, and, where significant, coincided with high PAHs concentrations. The cheapest way to clean up was to target the PAHs. Elevated PAH concentrations, petroleum hydrocarbons, ammonia and phenolic compounds were detected in groundwater. Sediments in the adjacent Swan River were also contaminated.

Risk Assessment

A risk assessment helped determine the acceptance criteria. The five sets of criteria in the following table were developed (in some cases these varied with the depth of the contamination):

TABLE 1: Soil Categories

Soil Class	Designated Use	Criteria
Class A	suitable for any use	background levels
Class B	suitable for residential land-use	residential criteria
Class D	suitable for public open space	public open space
Class E	to local, secure landfill	200 mg/kg total PAHs
Class F	to distant, hazardous landfill	Greater than 200 mg/kg total PAHs

Note: Class C was rubble

These criteria then helped determine which soils required treatment, disposal or safe containment at depth.

Remedial Works

Using a 25 by 25m sample grid, soils were classified at 1m depth intervals. Based on preliminary investigation results, the soils were classified against the acceptance criteria above by using visual evidence (staining) and some confirmatory analyses.

Remediation options

Various remediation options were considered, including:

- containment;
- excavation and landfill disposal;
- bioremediation;
- soil washing;
- thermal desorption; and
- processing in a cement kiln.

Strategy adopted

The adopted remediation strategy included:

- installing a groundwater drain above the site to intercept and divert groundwater, sending it around the site to the Swan River. This reduced water flow through the site and therefore reduced the discharge of contaminated groundwater to the Swan River;
- dredging contaminated sediments from the Swan River and, after dewatering them, placing them onsite (criteria for river sediments much lower than for soils);
- excavating all contaminated soil from elevated site areas planned for high value residential use, and contaminated soil down to the groundwater table from areas planned as parkland;
- placing some low level contaminated soils on the lower area of the site and capping it using dredged sediments and some fresh soil. The capping (containment) was designed to prevent contact with the underlying contaminated soil and minimise groundwater recharge;
- disposal of low to moderate level contaminated soil to a nearby secure landfill; and
- bioremediation (landfarming) of highly contaminated soil (1500mg/kg total PAH) to make it suitable for landfill disposal (200mg/kg total PAH).

Thermal desorption was assessed as uneconomic. Treating wastes in a cement kiln was also evaluated, but dropped following community concern.

Site remediation under a stringent quality control program ensured all soil was handled correctly. The system tracked soil movements to ensure they were disposed at the intended destination, either at landfill or at depth onsite.

Photo: EGIS Consulting Australia

A silt curtain is used to contain suspended sediments when dredging contaminated sediments.

Bioremediation (landfarming) process

As part of the 25 x 25m grid pattern described above, soils were divided into $525m^3$ blocks and five categories. Class E soils (200mg/kg total PAHs) and Class F soils (greater than 200mg/kg total PAHs) would require secure/hazardous landfill.

Disposing of 8000cu.m of class F soils in an isolated intractable waste disposal facility (600km east of Perth) was then $160 / tonne, so alternatives were investigated, including bioremediation. Bioremediation was trialled using 1500 tonnes of Class E soil. Tests reported that bacterial populations did degrade PAHs in the soil.

Tests checked the performance of three soil batches which used nutrient addition and turning of the soils, and nutrient addition only. Over three weeks, average total PAH concentrations dropped from 900mg/kg to well under 200mg/kg. Soils were kept moist (daytime temperatures regularly exceeded 30šC).

Consequently, Class F soils were treated using bioremediation/landfarming. Tests showed marked falls in PAH levels with frequent turning and nutrient addition. Turning soils had an even greater effect upon degradation than nutrient addition. The conclusion was that bioremediation was viable and its impact could be maximised.

The remaining soil was bioremediated in three batches. Class E soils had average total PAH levels of 900mg/kg and these concentrations fell to well below the landfill criteria of 200mg/kg within three weeks. Bacterial population checks showed these bacteria had increased during the bioremediation, suggesting bacteria helped reduce total PAH concentrations. The treated Class F soils were disposed of in a nearby landfill ($65/tonne), instead of being transported long distances at significant cost and placed in a specialised intractable waste disposal facility.

Photo: EGIS Consulting Australia

Trucks leaving the site have a tarpaulin cover to prevent contaminated soils becoming airborne and are subject to wheel washing.

Photo: EGIS Consulting Australia

Extensive excavation of contaminated soils at the East Perth Gasworks site included 300 metres of the Swan River foreshore.

Photo: EGIS Consulting Australia

Excavating contaminated sediments from the Swan River with sediment curtain in the background.

Stakeholders and Approvals

Key stakeholders in this project include:

- East Perth Redevelopment Authority and the City of Perth (responsible for site edevelopment);
- Environment Protection Authority and other government departments;
- the local community; and
- Cement Kiln operators and the surrounding community (local community objections meant the option of treating soil in a cement kiln was not pursued).

As the project was formally assessed under the Environmental Protection Act 1986, an environmental impact statement (EIS) was prepared and sent to the stakeholders, in this case the public and relevant government authorities. The EIS was prepared in conjunction with environmental management plans to remediate the Swan River, the site and determine the proposed containment strategy for residual contamination.

Conclusion

The East Perth Gasworks Remediation Project was one of the largest of its kind in Australia, and demonstrates a range of cost-effective remedial approaches to protect human health and the environment. A risk assessment, environmental impact statement and environmental management plans have contributed to the success of this remediation project.

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Case Study 5

Comalco Aluminium Limited, Bell Bay Smelter, Tasmania - Containment of Wastes

Background

The Comalco Aluminium smelter at Bell Bay in Northern Tasmania has operated for more than 30 years, with waste from the smelting process stockpiled on company land east of the smelter. This led to an unacceptable environmental impact, by today's standards, through leachate and dust generation. In response to these potential problems, the stockpiles have been relocated and, as an interim measure, encapsulated in a polyethylene membrane. New technologies to treat the wastes over the long term are being developed.

The Waste

The waste contained cyanide, fluorides and a number of metal compounds. Four types of waste (spent cell liners, dross, cryolite sludge and material from the sludge pond) and contaminated soil were stockpiled and encapsulated on site. Three thousand tonnes a year of spent cell liners (SCL) (lining material which has broken down) are produced (i.e. two liners are replaced each week). 140 000 m^3 of SCL was stockpiled at the site. The SCL are the most heavily contaminated waste and consist of carbon and refractory fluoride and cyanide salts. The salts are of concern as an alkaline leachate containing fluoride and cyanide can be produced.

Other wastes stockpiled on the site include dross, cryolite sludge and waste from a sludge pond on the site. Dross is waste from the top of the molten aluminium and contains fluoride and aluminium compounds. Historically, dross was stored on site; now it is sold to a local company for further recovery. Cryolite sludge is a combination of two wastes: solids from the SCL leachate moat and sludge from the cryolite recovery plant. Cleaning of the cryolite plant, treatment plant and fume towers produced waste which was stockpiled in the sludge pond. After dry scrubbing technology was installed at the smelter, these areas were decommissioned in September 1997.

Overall Strategy

Comalco sought a medium term solution for containing existing waste, while a suitable technology to treat these wastes was being developed. It is also researching new process methods/treatments to reduce the volume of waste being produced.

The issue of waste treatment is not unique to Comalco, it faces every producer of aluminium. The waste contains substantial quantities of aluminium and steel with some salvage value. Previous attempts to minimise leachate and dust generation included sealing the SCL and dross stockpiles with bitumen. This approach was only partially effective and not consistent with current best practice for managing waste.

The preferred option was to construct a secure containment system for the existing stockpiles and dry storage of new SCL in a building while identifying and implementing a suitable treatment process. The containment system design life is 50 years. This will provide dry storage for the wastes and eliminate dust generation and minimise leachate production.

Containment System Design

Best practice design of the containment system resulted in unobtrusive mounds with batter slope angles able to minimise the volume of infiltration. The batter angle (16°) also allowed for the revegetation of the soil cover and ensured the stability of the SCL material (stable at angles $< 27°$). A composite of high density, 1 mm thick polyethylene (HDPE) and clay was used for the cap and base. The HDPE liner alone is an effective barrier to the leachate but may be penetrated by sharp objects. A quality assurance and quality control program was implemented to ensure it was correctly installed and risk of puncture minimised.

The containment system includes base and cap, leachate collection system and gas venting. The base of the containment system is slightly below the natural surface providing further storage capacity and clean fill for the construction of the bunds. The total cap thickness is 1200 mm, consisting of six layers, including a 1 mm HDPE liner and a geotextile and geonet (used to filter material that may block the drainage system).

A gas venting system was installed to prevent damage to the geomembrane, using PVC slotted pipes placed in the sand layer of the cap. The vent pipes are equipped with spark arresters to prevent flashback from ignition sources.

The base is approximately 800 mm thick, and incorporates a clay layer and a layer of coarse sand which provided the leachate collection system. The drainage pipes collect leachate which flows into the leachate collection tank, located at the lowest point of the base. A stormwater management strategy and vehicle decontamination procedures were implemented to minimise transporting contaminants offsite during waste relocation.

Photo: Comalco Aluminium Limited

Officer inspects one of the revegetated mounds to the centre right. Batter angle 16 degrees assists revegetation and stability.

Stakeholders

Comalco contacted the Tasmanian Department of Environment and Land Management for approval of the relocation concept and stockpile encapsulation.

Also involved in the project were various stakeholders, potentially affected by the construction of the encapsulation mounds. These included:

- local council;
- utility companies (ie. electricity, telecommunications);
- road authority;
- local community; and
- interest groups.

Comalco is now looking forward to developing processes to eliminate the need to stockpile the wastes and remove cyanide and fluorides from the SCLs. In the meantime, any SCL resulting from existing operations is placed in dry storage in a modified building which has the capacity to hold approximately five years of SCL use.

Another incentive was the salvage of steel and aluminium from the waste. This has resulted in savings and reduced the total volume of waste contained.

Conclusion

Comalco has benefited from the project by protecting the surrounding environment from further contamination and reducing the liability to the company. The encapsulation of existing waste has minimised the potential for further contamination of the site, while changing past practices means less waste is being produced and stored.

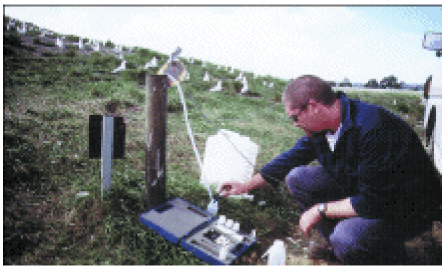


Photo: Comalco Aluminium Limited

Monitoring groundwater adjacent to mounds is routinely carried out by environmental staff. Note plentiful bird life in background.

Photo: Comalco Aluminium Limited

Ryecorn vegetation growth on spent cell liners (SCL) Encapsulation No #1 Vegetation early Feb 1996 with stockpiles 3 & 4 at centre rear. New vegetation requires irrigation.

Case Study 6

Copper Smelter and Refinery, South East Australia - Closure and Remediation Strategy

Introduction

An Australian copper smelting and refinery site, which ceased operations in 1995 after 87 years, needed to be investigated for contamination before it could be sold or decommissioned. Closure and remediation planning for the site was managed by Rio Tinto from 19951997. At the time of closure, it was expected that the site be to be decommissioned and remediated. However, the site was sold to new investors and it is expected to reopen in the latter half of 1999.

The stakeholders potentially affected by site contamination included the current owners, the buyers, the regulator, and the community. Contamination surveys of the site showed which areas needed to be cleaned-up and monitored and this was taken into account in discussions about the sale of the plant. They also showed which areas, both onsite and offsite, needed to be cleaned-up and monitored.

Investigations

The site area is 18.6 ha and was divided into 17 zones according to the site history and processing plant layout. Investigations focussed on soil (onsite) and groundwater contamination (both onsite and offsite). Particular attention was paid to areas known to contain fill material (slag and ash). Ninety-four soil samples were taken from the fill and from top layers of natural soils in each of the 17 zones.

The results of soil sampling indicated elevated total metal concentrations above ANZECC B guidelines in 220,000m^3 of the fill materials. Approximately one-third of this material was considered to have significant levels of leachable heavy metals under neutral or weak acid conditions.

The study of groundwater revealed two aquifer systems separated by a clay layer, both of which had been contaminated by various metals including copper. It was also shown that the contaminants in part of the deeper aquifer had spread to 300m north of the site boundary under an adjacent industrial property.

Remediation Options

Best practice methods were adopted as part of the remediation strategy, with health and ecological risk assessments conducted both onsite and offsite. These showed that risks to people and the environment were very low and that natural attenuation and removal of the contaminant source would prevent the further spread of contaminated groundwater. However, consideration of a range of factors including community perception led Rio Tinto to propose active remediation of the groundwater. The groundwater contamination in the deeper aquifer is being managed by maintaining a pump and treat system. Contaminated groundwater in the shallow aquifer is intercepted by a boundary drain, which directs water to the treatment plant.

Conclusion

This site provides an example of how historical contamination can result in significant remediation costs and potentially affect the community's perception of the mining industry. Best practice methods, which were adopted as part of the site assessment, indicated that the risks posed by the contamination of the deeper aquifer were very low. However, because of the need to recover offsite contamination, where this can be effectively done, Rio Tinto selected pump and treat methods to remediate the groundwater. Information gathered during the assessment and remediation planning phases proved adequate confidence for all the stakeholders that site contamination could be appropriately managed.

Photo: Rio Tinto Limited

Part of the dewatering system for the deep aquifer showing typical well head layout, with pump controls on the left and sampling port on the right. The contaminated groundwater can be pumped from 12 such wells to the water treatment plant to remove dissolved metals.

Photo: Rio Tinto Limited

The interception pit is part of the system used to intercept and collect contaminated surface water and groundwater from the shallow aquifer. The system collects drainage from parts of the site, which has been contaminated by heavy metals. The collected water is pumped to the water treatment plant to remove metals.

Case Study 7

Goldfields (Tasmania) Limited, Henty Gold Mine, Tasmania - Bioremediation

The Henty Gold Mine is in a world-renowned, sensitive environment and was the first gold mine to open in Tasmania since late last century. Its operating procedures have been designed to accommodate the site's high rainfall (3.6 m annually) and limited sunlight (average of 4.8 hr/day).

During development of the mine in 1996, peat and subsoil were stockpiled on a site previously employed during hydroelectric facility construction. The Newton Works Area was employed for hydroelectric program workshops, storage and transport yards from 1985 to 1991. It was decommissioned and rehabilitated in 1991.

Later, in 1996 during site preparation by Henty, two concrete sumps of hydrocarbon-contaminated material were uncovered at the former workshop site. These were then decontaminated and backfilled. In consultation with Hydro and the Department of Environment and Land Management it was decided to remediate the contaminated material by developing a "Landfarm" on a nearby compacted area.

The contaminated soil was turned and windrowed to allow for maximum aeration and was then fertilised to increase microbial activity and surrounded by a peat bund. Oil absorbent materials were strategically placed to collect runoff from the stockpile.

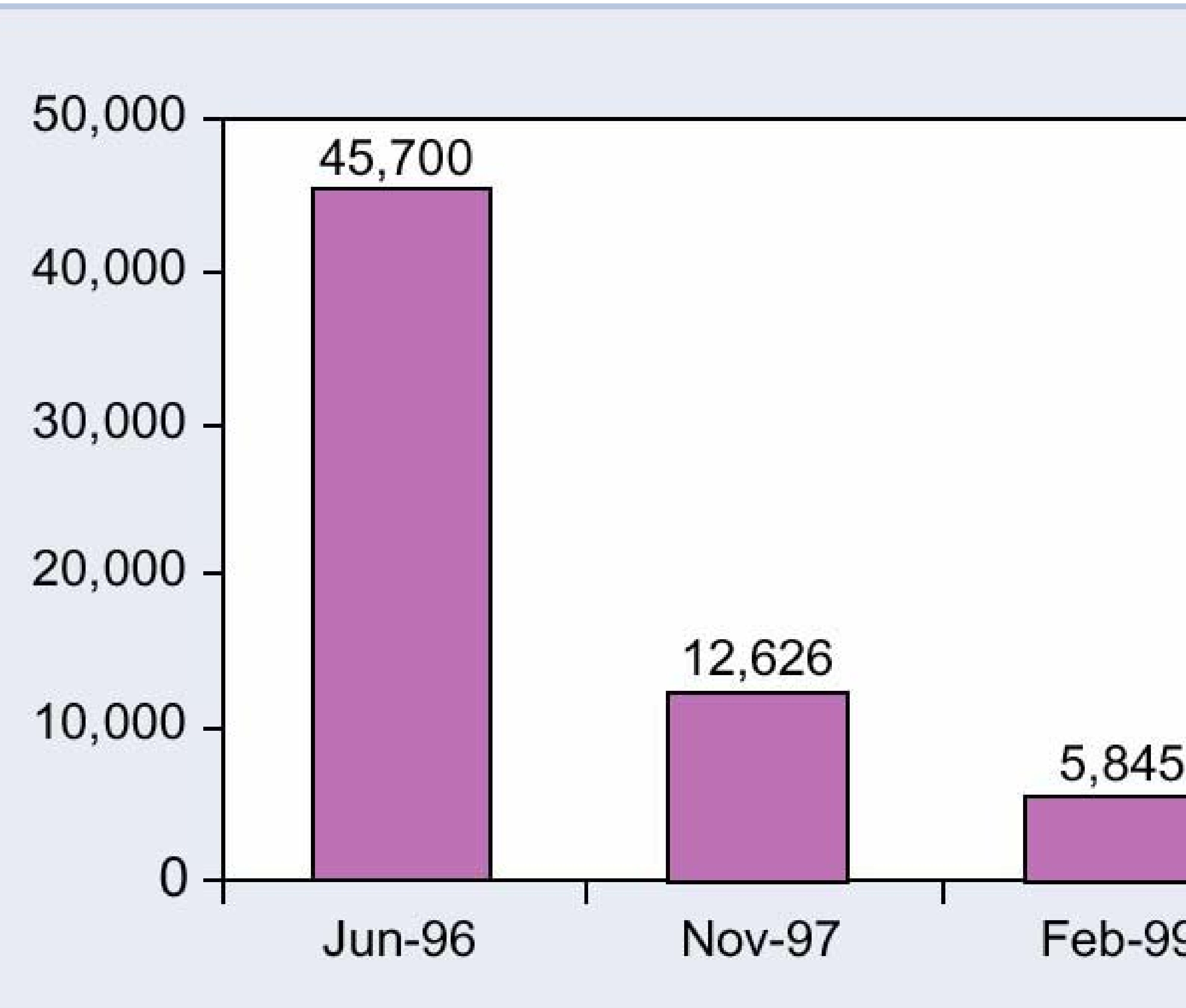
The area was regularly fertilised to encourage biological activity and turned to facilitate oxygenation. Since the landfarm was established, there has been noticeable growth of native button grass and other sedgeland species, which have germinated from the peat seed bank.

A groundwater monitoring bore was installed downstream of the contaminated site in early 1997 to see if nearby groundwater was being contaminated. Results indicated that hydrocarbon levels are below, or at, detection limits. Surface water sampling of Newton Creek (approximately 300m downstream) began early in 1995 as a part of Henty's water monitoring regime. No hydrocarbons were detected in Newton Creek either before or after the 1996 disturbance of the contaminated site.

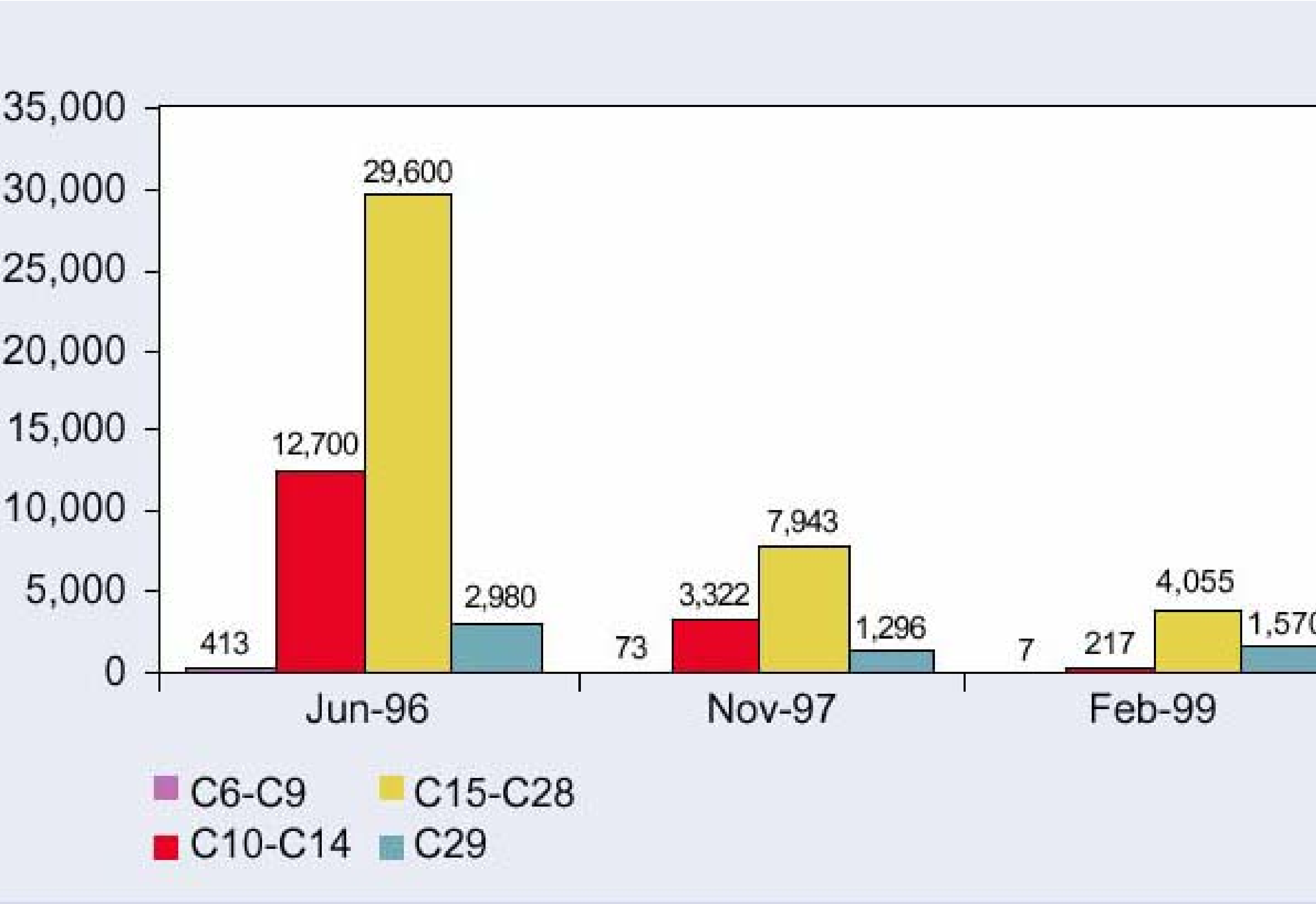
Photo: Goldfields (Tasmania) Ltd

Native sedgeland species have successfully regenerated within the landfarm area, either directly from the seedbank within the contaminated peat, or from windblown seed. The predominant species featured is Juncus pauciflorus*, commonly known as loose-flower rush.*


Photo: Goldfields (Tasmania) Ltd



Creek Landform Total Petroleum Hydrocarbons



Creek Landform Short and Long Chain Hydrocarbons

Surface soil has been sampled since the land farm was first developed. Soils were originally analysed for total petroleum hydrocarbons (TPH), short and long chain hydrocarbons and aromatics (benzene, ethyl benzene, methyl-benzene and xylene). Total petroleum hydrocarbons were tested every 12-18 months thereafter. Results for TPH and chain hydrocarbons are shown at left.

Results indicate an initial 72% decrease in TPH levels from June 96 to November 97 (18 months). A further 13% decrease in TPH levels occurred from November 97 to February 99.

Government regulators have indicated the landfarm material currently meets requirements for clean landfill purposes. Although no further amelioration or treatment of the landfarm material is planned, the site will not be decommissioned immediately. Instead, the material will either be incorporated into waste rock material used for construction in the leach residue pond precinct, or it will be further remediated to a quality suitable for rehabilitation and revegetation.

Photo: Goldfields (Tasmania) Ltd

When the landfarm was established, the combined contaminated soil and peat was windrowed, fertilised and regularly turned to facilitate oxygenation and microbial activity. The landfarm is partially inundated with water for several months of the year. This photograph was taken in mid-winter, making it difficult to identify the windrowed material.

Photo: Goldfields (Tasmania) Ltd

The landfarm area (foreground) is about 80 square metres and is located within the Newton peat storage works area. The Tyndall Ranges in the distance are south of the Henty Lease.