Guidelines for Assessing and Managing Coal Tar Contamination in Roading

Waste Management Institute New Zealand (WasteMINZ)

December 2023

Document Version Control

Version	Date finalised	Written/updated by	Description of changes
Draft 0.1	May 2022	WasteMINZ	Draft document for key stakeholder consultation
Version 1.0	December 2023	WasteMINZ	Draft document updated based on key stakeholder feedback

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Acknowledgements

These guidelines were developed in consultation with the following individuals, and would not have been possible without their time and expertise:

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- Graham Corban, Hill Laboratories
- Rowan Freeman, Pattle Delamore Partners Ltd
- Stephen Gardner, Waka Kotahi / New Zealand Transport Agency
- Chris Hillman, Tonkin + Taylor Ltd
- Simon Hunt, EHS Support New Zealand Ltd
- Reagan Knapp, HAIL Environmental Ltd
- Michael Massey, Environment Canterbury
- Christopher Mongillo, Sephira Environmental Ltd

We would like to thank the various contributors, including environmental consultants, local authority staff and industry representatives, who provided feedback during the respective consultation periods. In particular, the following individuals have made substantial comments that have enhanced this document:

- Helen Davies, Contaminated Land Solutions
- Tim Dee, Fulton Hogan
- Stacy Goldsworthy, Civil Contractors New Zealand
- Stephanie Koviessen, Environment Canterbury
- James Mitchell, Ministry for the Environment
- Carole Smith, WSP
- Fiona Smith, Smith Environmental
- Mark Tipper, Christchurch City Council

About WasteMINZ

WasteMINZ is the largest representative body of Aotearoa new Zealand's waste, resource recovery and contaminated land sectors. We work towards ongoing and positive development of our industry through strengthening relationships, collaboration, knowledge sharing and championing the implementation of good practice standards.

Disclaimer

Every effort has been made to ensure that these guidelines are as comprehensive and accurate as practicable; however, WasteMINZ will not be held responsible for any action arising out of their use.

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Abbreviations

ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Governments
AT	Auckland Transport
BaP	Benzo(a)pyrene
CCC	Christchurch City Council
CSM	Conceptual site model
GCMS	Gas chromatography and mass spectrometry
HAIL	Hazardous Activities and Industries List
MfE	Ministry for the Environment
NESCS	Resource Management (National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health) Regulations 2011
PAHs	Polycyclic aromatic hydrocarbons
PEF	Potency equivalency factor
PPE	Personal protective equipment
RAMM	Road Assessment and Maintenance Management
RMS	Roads and Maritime Services
SPLP	Synthetic Precipitation Leaching Procedure
SQEP	Suitably qualified and experienced practitioner
TCLP	Toxicity Characteristic Leaching Procedure
TEQ	Toxic equivalency
TPH	Total petroleum hydrocarbons
US EPA	United States Environmental Protection Agency
UV	Ultraviolet

Definitions

Asphalt: a mixture of solid aggregate and a liquid binder (such as coal tar or bitumen) used to construct roads, paths, car parks, or other paved surfaces.

Benzo(a)pyrene (BaP) toxic equivalency (TEQ) concentration: as defined in the NESCS, the sum of each of the detected concentrations of nine carcinogenic polycyclic aromatic hydrocarbons (PAHs) (benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, BaP, chrysene, dibenz(a,h)anthracene, fluoranthene and indeno(1,2,3-cd) pyrene), multiplied by their respective potency equivalency factors (PEFs) (World Health Organisation & International Programme on Chemical Safety, 1998).

Bitumen: a petroleum-based liquid used as a binder or sealant for asphalt in roading. Bitumen typically contains lower concentrations of polycyclic aromatic hydrocarbons (PAHs), compared to coal tar, and may also contain a different mixture of PAHs. Bitumen is therefore considered to be less toxic, less mutagenic, and less ecotoxic than coal tar.

Bitumen roading material: any portion or layer of a road or path that was mixed with bitumen as a binder, or sprayed with bitumen as a sealant, and typically includes low concentrations of PAHs, as described in Table 1.

Chip seal: a surface layer of binder (bitumen or coal tar) into which fine-grained aggregate was pressed. Coal tar-containing surface layers might have subsequently been buried when a road was resurfaced.

Coal tar: a dark, sticky, liquid by-product of coal gasification by high-temperature decomposition of coal in the absence of oxygen (pyrolysis). Coal tar contains a wide variety of chemicals, including PAHs. Some PAHs such as BaP are considered carcinogenic and/or mutagenic and can be toxic in aquatic ecosystems as well as cause human health impacts.

Coal tar asphalt: a subset of coal tar roading material, consisting of coal tar-containing binder mixed with aggregate to make asphalt. In this guidance, the more general term “coal tar roading material” is used, unless specifically referring to “coal tar asphalt.”

Coal tar roading material: any portion or layer of a paved area (e.g. base course, sub-base, emulsion layer, surface layer, or any other layer) in which coal tar was used, or which was mixed with coal tar, or which was sprayed with coal tar as a sealant or suppressant. This guidance defines roading material with a total PAH concentration of greater than or equal to 20 mg/kg, and BaP TEQ concentrations of greater than or equal to 1 mg/kg should be considered as coal tar roading material.

Conceptual Site Model (CSM): a system diagram identifying contaminant sources, routes of exposure (pathways), and the receptors that are affected by contaminants moving along those pathways.

Emulsion layer: a layer consisting of a mixture of water and liquid binder (bitumen or coal tar) that is applied between pavement layers to help bond the pavement layers together. Emulsion layers may also be applied to road surfaces as a sealer. Coal tar-containing surface layers might have subsequently been buried when a road was resurfaced.

Hazardous Activities and Industries List (HAIL): The HAIL is a compilation of activities and industries that are considered likely to cause land contamination resulting from hazardous substance use, storage, or disposal. The HAIL is intended to identify most situations in New Zealand where hazardous substances could cause, and in many cases have caused, land contamination. The fact that an activity or industry appears on the list does not mean that hazardous substances were used or stored on all sites occupied by that activity or industry, nor that a site of this sort will have hazardous substances present in the land. Conversely, an activity or industry that does not appear on the list does not guarantee such a site will not be contaminated.

PAH fingerprinting: a weight of evidence approach using a combination of qualitative and quantitative methods to differentiate the likely source of PAHs in base course in the road corridor.

Pathway: according to *Contaminated land management guidelines No 5: Site investigation and analysis of soils* (MfE 2021), in a CSM, a pathway is an actual or potential route of exposure by which a receptor is exposed to a contaminant. "Pathways include inhalation of vapours and dust, direct contact with the contaminant or contaminated media (dermal adsorption), ingestion (dust that covers food or enters the mouth, or directly from hand-to-mouth contact)."

Receptor: according to *Contaminated land management guidelines No 5: Site investigation and analysis of soils* (MfE 2021), in a CSM, a receptor "can be any organism, population or ecosystem that could be affected by the contaminant, including humans." Of particular relevance to this document are receptors including road workers, groundwater users, and freshwater or marine ecosystems that could be affected by exposure to PAH-contaminated water or particles. Both acute and chronic exposure scenarios must be considered, as well as the sensitivity of different receptors.

Rehabilitation: the existing road surface and underlying road structure (pavement) is removed and replaced with new materials. This is also known as pavement rehabilitation and can involve the recycling of existing material.

Solvent: a substance (usually liquid) that can dissolve other materials and form a solution. Some solvents can cause adverse health effects in humans and can be flammable (e.g., white spirits, turpentine, acetone).

Source: according to *Contaminated land management guidelines No 5: Site investigation and analysis of soils* (MfE 2021), in a CSM, the source of potential contaminants of concern that could affect a receptor. Characteristics of contaminant sources include the specific chemical forms present and their concentrations, as well as physical factors such as spatial location, distribution, and particle size. For the purposes of this document, the source is PAH-contaminated, coal tar-containing roading material, and the most common contaminants of concern are PAHs.

Suitably qualified and experienced practitioner (SQEP): practitioners with the specific skill, experience and technical expertise to conduct contaminated land assessment and investigation work. *Contaminated land management guidelines No 5: Site investigation and analysis of soils* (MfE 2021) lists following three ways to check if a practitioner is a SQEP:

1) Practitioners who hold a current Certified Environmental Practitioner (Site Contamination Specialist) accreditation.
2) Practitioners whose experience and qualifications are aligned with the guidance in the NESCS Users' Guide (MfE 2012).
3) Practitioners considered by the local councils to be SQEPs.

Synthetic Precipitation Leaching Procedure (SPLP): A procedure whereby the solid sample is shaken with an extraction fluid for 18 hours (+/- 2 hours) to simulate the leachability of compounds from the solid during rainfall.

Toxicity Characteristic Leaching Procedure (TCLP): A procedure whereby the solid sample is shaken with an extraction fluid for 18 hours (+/- 2 hours) to stimulate the leachability of toxic compounds from the solid. This test is mainly used on samples taken from materials that are destined for landfills.

Well graded: geologic material (e.g. gravel) that contains particles of a mixture of a variety of different sizes (for example, a mixture containing some silt particles, some sand particles, some small pieces of gravel, and some larger pieces of gravel). In contrast, “poorly graded” material has only a narrow range of particle sizes (i.e. only larger pieces of gravel). See Figure 1 for examples.

Figure 1. Example of road surface containing coal tar

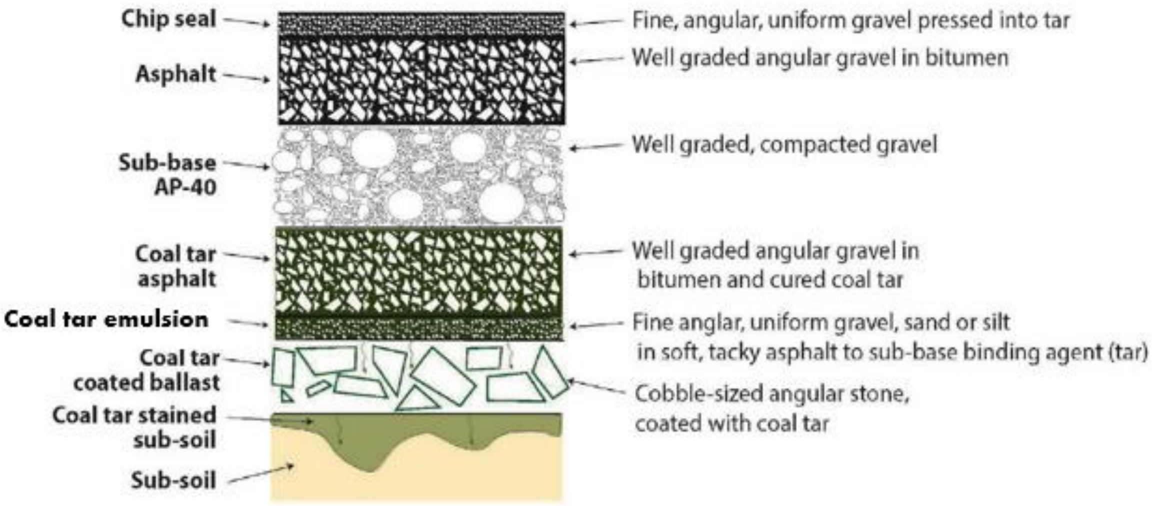

Figure used courtesy of Helen Hudson Mongillo, Sephira Environmental.

1. INTRODUCTION

This guidance has been produced in response to requests to WasteMINZ from practitioners seeking greater certainty on how to identify coal tar in roading; and if present, what may be the best way to manage the contaminated material and assess the risk to human health and the environment.

WasteMINZ is aware of internal guidance developed for Christchurch City Council (CCC) and Waka Kotahi New Zealand Transport Agency. However, there is no New Zealand-wide guidance regarding the investigation or management of coal tar roading material. This document aims to fill that gap by providing both general discussion of coal tar roading material investigation and management, and specific recommendations, all within the New Zealand context. WorkSafe and WasteMINZ members have been consulted on initial drafts. However, the contents of this guidance should not be taken as the opinion of WorkSafe or any one WasteMINZ member, including the authors.

1.1. APPLICABILITY OF THESE GUIDELINES

These guidelines have been developed principally for contaminated land experts and competent practitioners with some experience in dealing with coal tar roading material. The guidance is also usable by people or organisations responsible for, or dealing with coal tar roading material, such as road controlling authorities, regulatory bodies, and professional service suppliers such as consultants and contractors.

1.2. SCOPE OF THESE GUIDELINES

1.2.1. What's in scope

- The history of coal tar use in New Zealand and where it may be found within roading material,
- Determining when roads should be characterised for presence of coal tar roading material,
- Definition, characteristics, and identification of coal tar roading material, including sampling advice, field screening techniques and lab-based testing options,
- The importance of developing a conceptual site model (CSM), especially regarding possible receptors such as road workers and ecosystems, and
- Recommendations on reuse and disposal options for contaminated roading material.

1.2.2. What's out of scope

- Health and safety controls for handling and disturbance of coal tar roading material,
- Air quality concerns relating to handling and disturbance of coal tar material, and
- Coal tar contamination in soil (including roadside berms), where the requirements of the *National environmental standard for assessing and managing contaminants in soil 2011* (NESCS) to protect human health would apply.

1.3. HAZARDOUS ACTIVITIES AND INDUSTRIES (HAIL) STATUS OF ROADS

For the purposes of this document roading material is not considered to be soil and is therefore not subject to the NESCS. Soil under or adjacent to roads may have been impacted by contaminants, in which case the NESCS may potentially apply. It is important that practitioners consider this potential risk as part of their assessment of contaminant risks.

1.4. COAL TAR IN ROADING DEFINITION

Any roading material layer with a total PAH concentration of greater than or equal to 20mg/kg, and Benzo(a)pyrene (BaP) toxic equivalency (TEQ) concentrations of greater than or equal to 1mg/kg should be considered as coal tar roading material.[1] This definition should be used in conjunction with the "weight of evidence" approach and other indicators of coal tar outlined in Table 1.

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[1] The coal tar and roading definition applies to any paved area such as a road, carpark, runway, footpath etc.

2. HISTORY OF COAL TAR IN NEW ZEALAND

2.1. HISTORY

Records suggest that from the late 1800s through to 1988, approximately 54 gasworks sites operated across New Zealand. Syngas, a mixture of carbon monoxide and hydrogen, was produced by heating coal in an oxygen-deficient atmosphere. A variety of by-products were produced during the gas manufacturing process, with many of these by-products being refined and used in other industrial operations/processes. Coal tar was a key by-product from the gas manufacturing process, with coal tar composition varying between the individual gasworks sites. The source coal and specifics of the gas production process (such as temperature) influenced the coal tar composition at different sites.

Coal tar was a valuable by-product, and most plant operators sought out opportunities to increase revenue from by-products. Most coal tar was typically sold as produced, refined on-site to yield saleable by-products, or used as a fuel. The size of the gasworks influenced how the coal tar was reused; the sale or refining of coal tar was un-economic at smaller gasworks so it would be disposed of as a waste.

Over the decades of coal tar production, coal tar was primarily used as a binder in road pavements, either sourced from the local gasworks or imported from elsewhere in New Zealand or from the United Kingdom (some gasworks produced higher quality coal tars than others, making importation viable).

At the start of the 20th Century, road-grade bitumen was produced in the United States. Bitumen is much less toxic, more durable and easier to handle than coal tar and was used in New Zealand road construction starting in 1914.

By the mid-1950s, the number of gasworks producing coal tar was dwindling, as was importation of coal tar from the United Kingdom. However, coal tar was still used extensively in or on New Zealand roads until construction of the natural gas reticulation system caused progressive closure of gasworks during the 1970s and 1980s. The latest recorded use of coal tar in roading was in some areas of Christchurch in 1985 (Environment Canterbury, 2015).

2.2. LOCATIONS OF HISTORICAL GASWORKS

During preparation of the Ministry for the Environment’s (MfE) Guidelines for the Assessing and Managing Gasworks in New Zealand (MfE 1997), information was collated on the location of gasworks sites within New Zealand and their dates of operation. A list of the known gasworks sites operating in New Zealand is given in Appendix A. It should be stressed that the presence or absence of a gasworks site in a particular area is not a reliable indicator of the presence or absence of coal tar roading material within that area. Examples of this are included in Appendix B.

2.3. CHARACTERISTICS OF COAL TAR VERSUS BITUMEN

It is important that coal tar is distinguished from bitumen, as bitumen is derived from crude oil and contains a much lower proportion of polycyclic aromatic hydrocarbons (PAHs) in comparison to coal tar. As such, bitumen is considered to present a far lesser risk to the environment and human health. Table 1 below summarises the key differences between coal tar and bitumen.

Table 1. Characteristics of coal tar versus bitumen

Characteristic	Coal tar	Bitumen
Appearance and odour		
	Typically, more odorous, can be stickier, browner.	Typically, less odorous, can be more solid, blacker.
Field testing (should be undertaken by a competent person with relevant experience)		
<u>'Coffee / Tea' test</u> Mixing a small, crushed sample of the roading material with petroleum distillate solvent (such as white spirits) and leaving it for 30 seconds.	Solvent is light amber to red or green in colour and translucent ("tea"). Where the product is a mixture of coal tar and bitumen, the bitumen may mask the presence of coal tar. The application of ultraviolet (UV) light can improve the interpretation of the results avoiding false negatives. The coal tar contaminants fluoresce under UV light.	Solvent becomes very dark to black in colour and opaque ("coffee").
<u>'White paint' test</u> Application of a layer of white paint manufactured with petroleum distillate solvent.	Paint turns yellow due to the bleeding through of dissolved PAHs. The application of UV light can improve the interpretation of the data as coal tar contaminants will fluoresce.	Paint remains white.
Collection of samples and laboratory testing. Collection of representative samples of current or buried former surfaces and testing at an accredited laboratory (See appendix E – PAH Fingerprinting methodology).		
<u>Relative PAH concentrations</u>	Typically, in the order of 100s to 1000s of mg/kg. High proportion of heavy mass PAHs, represented by BaP TEQ. Naphthalene typically present in unrefined coal tar.	Total PAH content less than 20 mg/kg and BaP TEQ concentrations less than 1 mg/kg. Naphthalene typically absent.
	Note: If total PAH and B(a)P TEQ concentrations fall between the two indicative scenarios above, further assessment or interpretation may be required. The pavement may be a mix of bitumen and coal tar. Further testing may be required to determine whether the pavement is bitumen or coal tar based.	
<u>Comparison of total petroleum hydrocarbon (TPH) gas chromatograms</u>[2] Gas chromatograms provide a visual fingerprint of hydrocarbons in the samples, and these can be compared to chromatograms for reference materials.	Coal tar samples typically contain large, resolved PAH peaks.	Bitumen samples typically contain resolved PAH peaks on top of a large unresolved complex mixture of aliphatic hydrocarbons. Note: Weathering or degradation of the hydrocarbons in the pavement/basecourse over many years can alter these profiles.
Note: A combination of the above lines of evidence shall be used to make an assessment of the potential for a material to contain coal tar. A SQEP should be consulted if there is any doubt when sampling or interpreting results.		

Table used courtesy of Waka Kotahi / Tonkin + Taylor: *Managing historical coal tar in the Waka Kotahi network.*

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[2] While the analysis of TPH is not recommended for coal tar in roading material because there are no guideline values to compare the results to, the comparison of TPH chromatograms may be useful when interpreting historical TPH data. Example TPH chromatograms of bitumen and coal tar asphalt are presented in Appendix D.

3. WHEN ROADS SHOULD BE CHARACTERISED FOR THE PRESENCE OF COAL TAR ROADING MATERIAL

3.1. INTRODUCTION

It is suggested that roads should be characterised for the presence of coal tar roading material when the following four conditions are met:

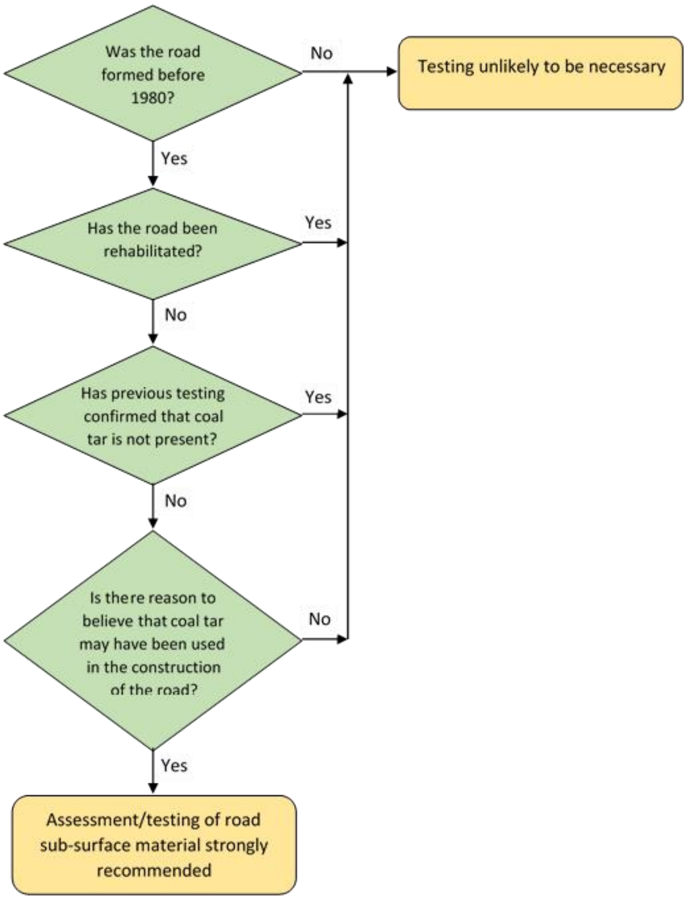
- The original road was formed before 1980, AND
- The road has not been rehabilitated, AND
- No testing has been carried out to confirm that coal tar in roading material is not present, AND
- If coal tar has been found in nearby roads constructed at a similar time (please contact the local regional council or territorial authority as they may have further information).

Note that resurfacing of roads does not require characterisation unless previous investigations have confirmed the presence of coal tar at the road surface.

3.2. DECISION MAKING FLOW-CHART

The following flow chart may be helpful in the decision-making process:

Figure 2. Flow Chart for determining when road characterisation may be required



Some councils have tested widely and have coal tar in roading results data in their Road Assessment and Maintenance Management (RAMM) system or other databases. Any new data for a particular road corridor should be documented for future reference.

3.3. ROAD CHARACTERISATION

Characterisation of roads can occur via Field testing (section 5) or Lab testing (section 6), however if Field testing is employed as a first step and positive results are returned, Lab testing should be carried out to confirm whether the material meets the definition of coal tar roading material contained in this document.

If the initial conclusion regarding road characterisation is that testing is not necessary, but then during the road rehabilitation project coal tar is encountered through its distinctive odour, it is strongly recommended that testing is carried out at that stage.

4. COAL TAR ROADING MATERIAL SAMPLING PROCEDURES

Once it has been established via the decision tree in section 3.2 that roading characterisation is required, then the following sampling procedures should be employed.

The method used to properly collect samples of roading materials for identification of coal tar related contaminants will depend on the nature and scale of the impending roading project. Large scale projects, such as those involving the complete rehabilitation of a road, generate large quantities of waste. Those projects can therefore benefit financially from detailed sampling procedures and a greater number of samples to avoid non contaminated roading material being sent to landfill. Whereas smaller projects, such as the installation or repair of short lengths of in-ground utilities or patchwork repair of the road surface, generally do not warrant large scale sampling. Sampling should only be required where there is a known or anticipated history of coal tar use (see section 3). The sections below provide guidance for projects with different scales.

4.1. GENERAL SAMPLING ADVICE

Wherever possible, sampling locations should be selected within the footprint of the pending infrastructure project. Sampling locations should also avoid any obvious recent resurfacing of the road. For example, often an old road in need of resurfacing will have been subjected to numerous disturbances to repair or install utilities or to fill in potholes. It is also common that widening of the road or installation of new in-ground utilities will have caused the resurfacing of one entire side of the road or resurfacing over a wide utility installation trench. These areas may not represent the conditions in the wider carriageway and could lead the investigator to think no coal tar contamination is present in a road. Therefore, they should be avoided when sampling for coal tar roading material.

Project planners may resist sampling in an active carriageway, electing instead to sample in easily accessible areas (e.g. along the edge of the road) to avoid the cost and effort of closing part of the road to facilitate sampling. However, it is often the case that road widening or re-kerbing results in the removal of coal tar-contaminated roading material along the edge of the road, while the wider carriage way remains contaminated. Therefore, it is convenient to coordinate environmental sampling with other investigation activities (e.g. sub-surface utility locating, geotechnical testing, etc.) to minimise disruption of traffic in the area and costs associated with road closure.

Coal tar-contaminated material is often present in basecourse and sub-base layers of the road that may be unexpectedly discovered during the roading project, causing unplanned delays and increased waste disposal costs. Liquid coal tar or coal tar emulsion was often applied to basecourse gravel and ballast to improve asphalt adhesion. This can be present at depths of 0.1 m or more below the bottom of the asphalt. Stained sub-asphalt layers should be tested, as necessary, for waste disposal characterisation. Additionally, abandoned coal tar contaminated asphalt road surfaces or fragments of coal tar-contaminated asphalt may be present in sub-base soil and gravel. Therefore, test holes should be excavated to the full depth of the future project excavation depths to ensure that all contamination is identified. Basecourse and sub-base materials are very difficult to excavate using hand tools, so sub-asphalt sampling will require the use of an excavator, drill rig or hydro-excavation to access lower layers.

Samples of asphalt must be granulated before submitting them to a laboratory for analysis. This can be accomplished by placing the asphalt into a clean new snap-lock bag and crushing it with a hammer until material that is less than 1cm in diameter is obtained for sampling. Once the sample has been granulated it should be homogenised by shaking the bag. Any large chunks of asphalt or aggregate should be avoided when transferring the crushed asphalt from the bag into a sample jar.

Sampling coal tar roading material for testing is a dirty job, and coal tar is highly toxic and is difficult to clean off sampling tools. Field testing involves the use of aerosol paint and solvents (see section 5). Appropriate health and safety controls should be applied.

All used personal protective equipment (PPE) and field-testing waste must be disposed of as hazardous waste. Solvent waste from field testing and decontamination of equipment should be collected and disposed of at an appropriate recycling or disposal facility.

4.2. LARGE SCALE PROJECTS

Wherever the entire thickness of a paved area will be removed from a road, or if the pending infrastructure repair project extends over a long distance (200 m or more), it is recommended that full-thickness samples of roading material be collected, at a minimum sampling density of 1 per 50 m of road length.

Additionally, for large-scale projects, consideration should be given to any asphalt paved elements on the sides of the road being repaired, such as driveway entrances and walkways. Frequently these areas are paved separately from the adjacent road, using different paving materials.

Ideally, samples should be collected by saw cutting panels or cores through the full thickness of the material. This allows the investigator to inventory the number of layers and the thickness of each layer of material making up the road. This can be very important from a cost saving perspective, since paving can be comprised of many layers of non-coal tar asphalt with only thin layers of coal tar sandwiched in between the non-coal tar asphalt. Frequently, sufficient thickness of non-coal tar asphalt will be present in the upper portion of the roading that significant waste disposal cost savings can be achieved by mapping out the width and depth of non-coal tar-containing upper layers. This information can be used to mill off uncontaminated asphalt for disposal, recycling, or reuse, separately from the underlying coal tar-contaminated layers.

Wherever field tests indicate a mix of coal tar and non-coal tar-contaminated layers, it is recommended that the layers are separated and sampled individually for laboratory analysis. Layers usually can be cleanly separated from each other with a masonry chisel and hammer. Care should be taken to avoid cross-contamination of the materials when separating. For example, disposable gloves should be changed between handling each layer. Project managers will have to assess the potential waste disposal savings against the logistical and economic costs of milling to determine if milling is viable when sampling.

4.3. SMALL SCALE PROJECTS

Pre-construction sampling generally will not be convenient for small scale projects owing to the cost and difficulty of setting up road closure and traffic management to allow for sampling activities. Therefore, it is recommended that project planning allows for the temporary stockpiling of potential coal tar roading material for testing after it has been removed from the project area. Use of an off-site triage area is most convenient, since laboratory analysis of samples may take up to two weeks to complete. In these cases, the material should be stockpiled on paved areas or surfaces protected by a layer of impervious material to prevent contaminating the storage area. Stockpiles should be covered with impervious material and surrounded by bunding to reduce the risk of coal tar contaminants becoming entrained in stormwater or runoff.

Since stockpiling is environmentally risky and inconvenient in general, project management might consider allowing the identification of coal tar contaminated roading material based on field testing alone. However, field testing is not considered sensitive enough to confidently characterise asphalt that is not contaminated with coal tar. Therefore, any material producing no coal tar or trace coal tar field test results should be stockpiled and sampled for laboratory testing, otherwise it should be treated as coal tar-contaminated for disposal purposes. Material producing definite positive coal tar field test results do not need to be characterised by laboratory testing and should be treated as coal tar-contaminated for disposal purposes.

If stockpiling is logistically impossible, then field testing and sampling for laboratory analysis can be undertaken *in situ* at the beginning of the project. For short duration projects (< 1 week), where no information is held about the presence or absence of coal tar contamination and no stockpiling is possible, all asphalt may need to be treated as coal tar-contaminated for disposal purposes, depending on the information available about the road construction.

The principles of sampling small projects for coal tar are similar to those discussed above for large projects. However, samples should represent the full thickness of the roading material and any oil/emulsion layer, since separation of coal tar roading from non-coal tar roading is unlikely to be practicable on small projects. The number of samples collected will depend on the nature and volume of roading material that must be disposed. Care should be taken to collect representative samples of all types/ages of roading material that will be disturbed. It is recommended that a minimum of 1 sample per 100 tonnes of waste material be collected, however more frequent sampling may be necessary depending on the requirements of the receiving waste disposal facility.

Two case studies, one from Auckland and the other from Christchurch, are included in Appendix B and illustrate how these jurisdictions have investigated and are managing their respective issues with regards to coal tar in roading.

5. FIELD SCREENING TECHNIQUES TO IDENTIFY COAL TAR CONTAMINATION IN ASPHALT

There are two field testing techniques available to identify the presence of coal tar contamination in asphalt: the “coffee/tea test” and the “white paint test”. Both tests take advantage of the varying chemistries of coal tar and bitumen to distinguish between the two. These tests are best undertaken by someone experienced in coal tar sampling and chemistry, or under the supervision/guidance of someone who is. The sections below describe the two tests and their advantages and disadvantages.

5.1. COFFEE/TEA FIELD SCREENING METHOD

The “coffee/tea” field screening test is performed by crushing a sample of asphalt or other roading material into a granular state using a hammer, then placing it into a clean, unused clear glass jar with sufficient petroleum distillate solvent (“white spirits”) to cover the asphalt or tar sample. The jar lid is replaced, and the sample is shaken for approximately 30 seconds, and then the sample is allowed to stand. After a minimum of 5 minutes of standing time, the sample jar is then shaken a second time and examined.

Typically, samples where the solvent is observed to be very dark to black in colour and opaque (“coffee”) are interpreted as not exhibiting the presence of coal tar. Samples where the solvent is observed to be light amber to red or green in colour and translucent (“tea”) are interpreted as exhibiting the presence of coal tar.

In some cases, where road material is comprised of a blend of coal tar and bitumen-based binders, examination of a coffee/tea test sample solely in daylight may result in a false negative result. This is because the bitumen in the blended road material will mask the presence of coal tar in the sample. However, the application of UV light enhances the coffee/tea test results for blended samples since coal tar contaminants diluted in petroleum solvents fluoresce under UV light. Inexpensive battery-operated UV torches are readily available at electronics stores and can be used to check for sample fluorescence. Where blended asphalt is being tested, it is convenient to prepare a non-coal tar “standard” from known modern bitumen asphalt to compare with field samples. Side-by-side comparison of the standard with samples under UV light can help identify samples with low levels of coal tar contamination.

It is very important to only use petroleum distillates (white spirits) to perform the coffee/tea test. This is because coal tar has a very low solubility in this solvent, while bitumen has a high solubility in it. So, asphalt made with coal tar will only dissolve a small amount, causing the “tea” response, and asphalt made with bitumen will nearly completely dissolve, causing the “coffee” response. Coal tar and bitumen will behave differently in other readily available solvents like methanol, acetone, toluene, or xylene. In some cases, these solvents can dissolve both coal tar and bitumen, which could lead to false negative results. Some of these other solvents can produce the reverse response, with coal tar looking like coffee and bitumen looking like tea. Petroleum distillates are less flammable than the other solvents mentioned above, however, fire is a risk when working with any solvent.

The primary advantage of the coffee/tea test over the white paint test is that it is more sensitive. Once a field worker becomes familiar with the field test results relative to laboratory test results, even trace levels of coal tar can be identified in a sample. However, the test uses a flammable solvent, which has safety and waste disposal complications that must be considered when planning an investigation.

Examples of positive, negative and trace coal tar test results from the coffee/tea test are presented in Figures 3 and 4.

Figure 3. Coffee/tea test examples

Non-coal tar material is in the left vial, coal tar-containing material is in the right vial, and trace coal tar-containing material is in the centre two vials. See UV enhanced detection, below.

Figure 4. UV enhanced coffee/tea test

Non-coal tar-containing material is in the far-left vial, trace-level to high-level coal tar is in the vials from the centre to the right.

5.2. WHITE PAINT TEST

When white spray paint manufactured with petroleum distillate is sprayed onto cross sections of roading material that contains coal tar, the contamination bleeds through the paint and turns the white paint yellow or brown. The sprayed sample should be allowed to "develop" for at least 1 minute before assessing the result, since lower levels of contamination will take more time to turn the paint yellow. Again, UV light can be applied to the painted samples since the discoloured paint will fluoresce under UV light in a similar manner to the coffee/tea test. White paint sprayed on bitumen-based asphalt will remain white or will only turn slightly beige and will not fluoresce under UV light.

It is important to spray the paint onto a clean asphalt surface since soil or rock dust created when cutting the sample out of the road will block the paint from contacting the asphalt. Water on the asphalt (dust suppression or groundwater) can also block the paint from contacting the asphalt appropriately. This can be avoided by breaking the sample to expose a fresh surface or brushing the test location with a wire brush before spraying with paint.

Field workers should be careful when purchasing white paint for this test, since many are manufactured with acetone, toluene or xylene solvents, and can produce incorrect test results. They should take time to read the paint ingredient labels and look for "petroleum solvent" or "petroleum distillates". Avoid any paint that lists acetone, toluene, or xylene in the ingredient list.

The white paint test is a convenient and useful test to differentiate between specific layers of material without having to break them apart or fragment the material for testing. This is especially helpful in circumstances where multiple layers of road materials are present, and the layers are not easily separated. Full-thickness samples of road material can be sprayed with white paint, and then layers within the sample exhibiting positive results can be measured for their thickness and depth below the road surface. The white paint test has the advantage of not producing flammable hazardous waste, and it does not require a supply of solvent and test vessels. However, the white paint test is not as sensitive as the coffee/tea test. So, negative tests still need to be verified with laboratory analysis.

Photographs showing examples of white paint tests are presented in Figures 5 and 6.

Figure 5. White paint test results

Sample #4 does not contain coal tar, but all of the other samples contain coal tar.

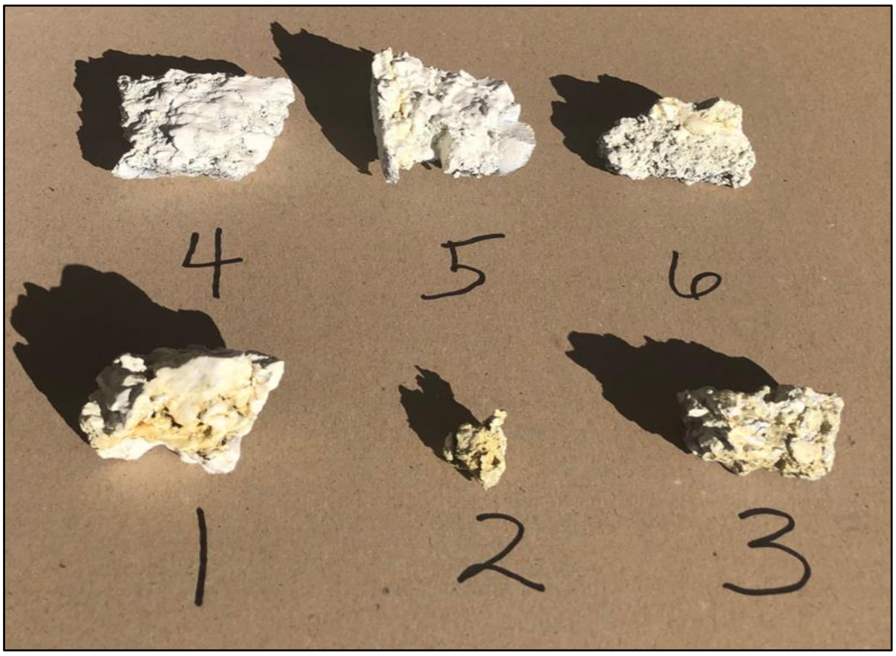
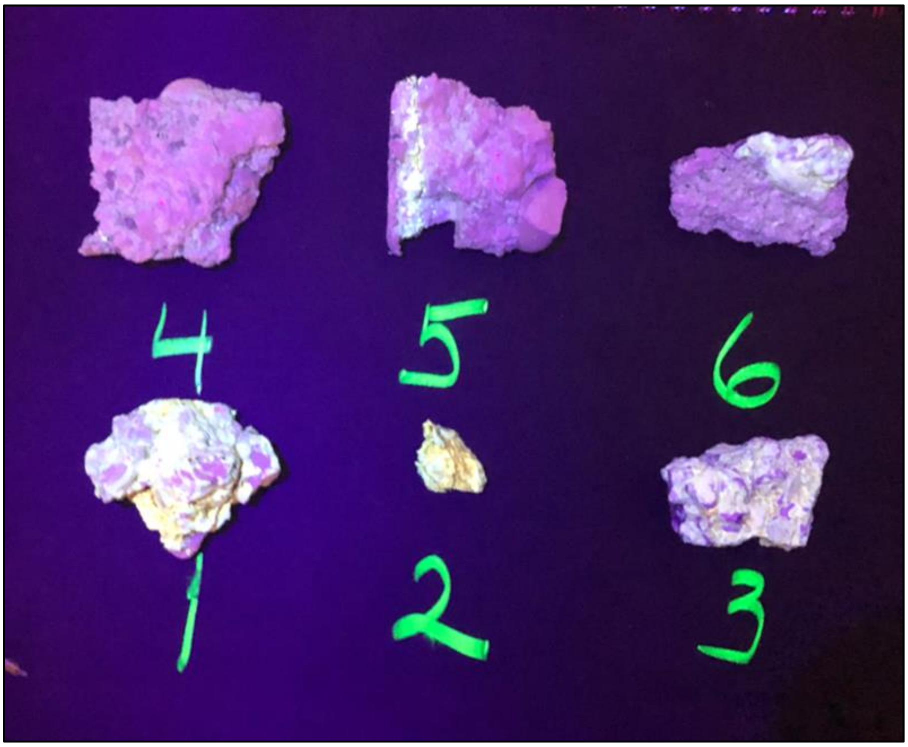


Figure 6. UV enhanced white paint test

Note the layering in samples #5 and 6.



6. LAB-BASED ANALYTICAL TESTING METHODS

6.1. INTRODUCTION

Coal tar itself contains several contaminants of concern. It can contain organic contaminants in the form of PAHs, benzene, toluene, ethylbenzene, xylene, and phenolic compounds (phenol and cresol). Coal tar can also contain inorganic contaminants, including cyanide, sulphate, ammonia, and trace elements. However, the most significant contributor to human health risk is PAHs, many of which are carcinogenic.

This is especially true for coal tar roading, much of which has not only been refined to remove the more volatile organic components and phenolic compounds but has also been weathered over many years such that only the heavier PAHs remain.

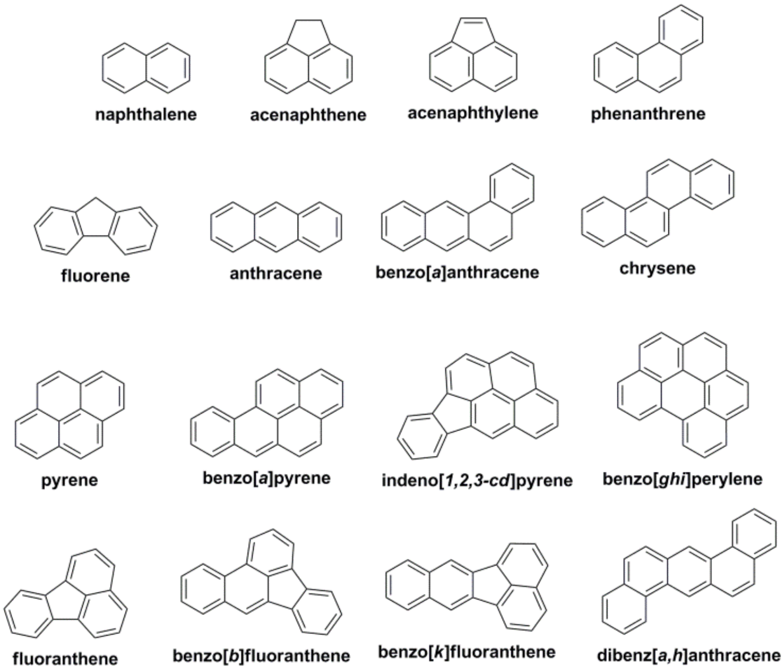
Moreover, this guideline document has adopted both a total PAH concentration of 20 mg/kg dry weight, and a BaP TEQ of 1 mg/kg dry weight, as limits to be indicative of the presence of coal tar in roading, which requires quantitative analysis of individual PAH compounds.

For these reasons, only one laboratory-based analytical method for determination of the presence of coal tar roading is recommended – analysis of PAHs by gas chromatography and mass spectrometry (GCMS).

6.2. POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Of the hundreds of known PAHs in the environment, sixteen have been designated High Priority Pollutants by the United States Environmental Protection Agency (US EPA). These compounds and their chemical structures are presented in Figure 7. These compounds are of primary environmental concern because of their potential toxicity in humans and other organisms.

Figure 7. Names and structures of the 16 US EPA priority pollutant PAHs.



Not all of these compounds have the same toxicity. For example, naphthalene, the simplest PAH with only two aromatic rings, is only listed as a possible human carcinogen whereas BaP is a confirmed carcinogen, based on strong and consistent evidence in animals and humans.

For this reason, each compound has been assigned a potency equivalency factor (PEF). BaP and its equally toxic relative dibenz[a,h]anthracene have been given PEFs of 1, which means that the concentration found in the coal tar roading is multiplied by 1 and consequently will have the highest contributions to the total calculated toxicity. The other compounds have equivalency factors that are orders of magnitude lower (0.1 or 0.01), and therefore when their concentrations are determined and multiplied by their respective PEFs, their contribution to the total calculated BaP toxic equivalency (TEQ) can be much lower than that of BaP or dibenz[a,h]anthracene.

The PEFs for 9 of the carcinogenic priority PAHs are listed in Table 2 below:

Table 2. PEFs for the 9 US EPA priority PAHs.

PAH	**PEF**
Benz(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(j)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Benzo(a)pyrene	1.0
Chrysene	0.01
Dibenz(a,h)anthracene	1.0
Fluoranthene	0.01
Indeno(1,2,3-c,d)pyrene	0.1

Source: https://environment.govt.nz/assets/Publications/Files/methodology-for-deriving-standards-for-contaminants-in-soil.pdf accessed 1/08/2022.

An example of calculating TEQ using the PEFs can be found in Appendix C.

Because of this, the analytical method employed to determine the concentration of PAHs needs to be able to separate and quantify each of these compounds accurately. Fortunately, GCMS can complete both tasks (separation and quantification) relatively easily.

6.3. SUBMISSION OF SAMPLES TO A LABORATORY

A modern commercial environmental laboratory receives hundreds, if not thousands of samples a day. Samples arriving without paperwork (request form/chain-of-custody) can cause significant disruption to processes, and result in substantial delays. Confusion with contact details of the job, such as who took the sample and who submitted it, who the report needs to be sent to, what formats the report are required in, and who will be paying the invoice, also cause delays.

In addition, the roading material being submitted for analysis needs to be in a suitable form prior to analysis. A core sample from a road must be crushed (ideally into sub-10 mm fragments), before it can undergo chemical extraction and analysis. Crushing or grinding will usually entail additional charges, therefore these details should be organised before samples are sent off.

Because some of the lighter PAHs are volatile, samples (especially if they are pre-crushed) should be submitted in glass containers with a screw cap lid that can be sealed in order to avoid loss of volatile target compounds. Sample containers should be filled to the top, leaving as little void space as possible. Samples should be stored in a chilly bin with freezer packs and submitted chilled. Containers are usually provided at no charge by the lab. However, time will need to be allowed for these to be shipped if necessary. It is helpful for the laboratory if samples that are potentially high in PAH be identified on the chain-of-custody, as the lab can then make proactive decisions on pre-dilution steps to protect their analytical process.

Finally, the turn-around-time requirements of the job should be established up front. If results are required urgently, additional charges for expediting are usually applied by the lab.

In summary, it is always advisable to contact the lab prior to submitting samples.

6.4. ANALYSIS OF PAHS BY GCMS

In this method, an organic solvent is used to extract the PAHs from the coal tar roading sample matrix using either shaking, sonication or other means (e.g. US EPA method 3540 or 3550). The solvent extract is cleaned up, usually with silica (US EPA method 3630), and then injected into a GCMS (e.g. US EPA method 8270). The acquired GCMS data is examined for the individual priority PAH compounds, and accurately quantified by peak area comparison against calibrating standards.

Default reporting is usually in the form of a PDF document, which will be the official version of the report. However, data can be delivered in a multitude of other formats, such as XML, CSV, and spreadsheet versions.

Total PAHs (sum of the 16 priority pollutant PAHs) and BaP TEQ data is typically provided as part of the service.

The GCMS has a limit below which analytes cannot be reliably detected. This is called the limit of detection and varies depending on the analyte. There are different ways of treating the limit of detection in calculations. Examples of the different methods of treating the limit of detection when calculating BaP TEQ are provided in Appendix C.

6.5. PAH FINGERPRINTING METHODOLOGY

Auckland Transport has developed a methodology for identifying the likely source of PAHs in roading samples which uses a “threads or weight of evidence” approach. While determining the source of PAHs in roading material may be appropriate or useful in some cases, the specific source of PAH contamination is often irrelevant with respect to ensuring that the appropriate environmental and health and safety approaches/measures are employed when working with and disposing of contaminated roading material. A discussion of the methodology is included in Appendix D.

7. CONCEPTUAL SITE MODELS (CSMS)

7.1. INTRODUCTION

Once Field and Lab testing have confirmed the presence of coal tar roading material, a conceptual site model will be required to help protect potential receptors from being contaminated with PAH when the road is disturbed.

A conceptual site model is a system diagram identifying contaminant sources, routes of exposure (pathways), and the receptors that are affected by contaminants moving along those pathways. It describes the potential or actual behaviour of contaminants at a site. The CSM consists of contaminant "sources" and potential "receptors" that might be affected by contaminants, and "pathways" of transport or exposure that might link sources and receptors and cause adverse effects. The "source-pathway-receptor" framework aids in understanding the potential environmental and health risks associated with contaminants at a particular site. Additional information on CSMs can be found in *Contaminated land management guidelines No. 5: Site Investigation and analysis of soil* (MfE 2021).

7.2. CSM FOR COAL TAR IN ROADING MATERIAL

Coal tar roading material can be a significant source of PAHs, which can in turn be hazardous for receptors such as humans and freshwater or marine ecosystems. PAHs (both dissolved and bound to sediment) can cause water pollution. Higher concentrations of PAHs can be more hazardous to receptors, so the concentration of PAHs in coal tar roading material is of primary concern when considering the contaminant source. The physical form of the PAH-contaminated material (e.g. binder, emulsion layer, fragments, or particles) can also influence potential migration pathways.

The inclusion of different receptors in a CSM helps to answer the question, "What are we trying to protect?" For example, to protect the health of road workers, who could have significant occupational exposure to PAH contamination over the course of their career, workers should be considered in any CSM. Or, if stormwater from a site is discharged to a stream or river (whether directly or through a network), the stream or river and associated ecosystem are receptors to consider in the CSM. Groundwater should also be considered, especially if the groundwater is relied upon for use by humans or livestock, or if it discharges to nearby surface water. Similarly, water users are potential receptors since contaminated water might cause adverse effects for those users. Consideration should be given to aesthetic values of water such as smell and taste, in addition to potential health risks or ecological risks.

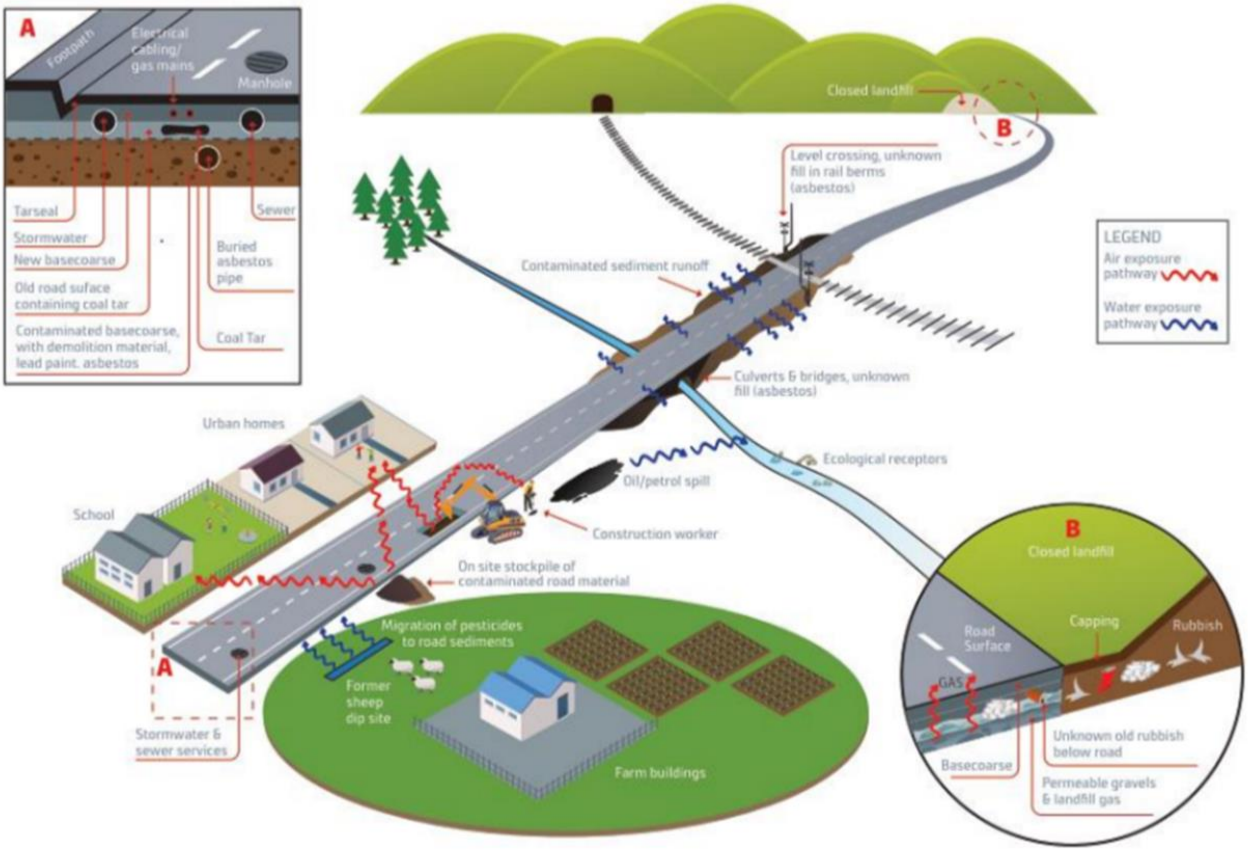
Pathways linking the contaminant source (coal tar roading material) to potential receptors will vary based on a variety of factors such as: site location, distance to surface water, depth to groundwater, topography, the physical characteristics of the contaminant source, the concentration and chemical composition of PAHs in the material, the location of the PAH-contaminated material within the road, etc. Potential pathways linking contaminant sources to potential receptors include direct contact, sediment transport, leaching, ingestion, or inhalation. For example, PAH-contaminated particles from the road surface or from construction might become entrained in runoff and be transported to water bodies. The contaminated sediment would then pose risks to aquatic and marine life, as well as recreational users and those who might consume contaminated fish or shellfish. Road workers will come into direct contact with PAHs through dermal contact, ingestion, or inhalation of PAH-contaminated dust. A single exposure might not cause acute health issues but continued chronic occupational exposure over years or decades could increase cumulative health risks.

For any site where coal tar roading material is a potential contaminant, a CSM will be greatly aided by thorough characterisation of the contaminant source material, as well as consideration of potential receptors and the pathways by which the contaminant might affect those receptors. The CSM should be updated regularly as new information becomes available. Environmental management and safety plans based on the CSM should also be updated as the CSM changes. See the case study in Appendix B for an example of how these updates could be incorporated.

The CSM can help to clarify appropriate guidelines, standards, or regulatory values to use for the protection of human health and the environment and can also inform mitigation strategies and measures to help limit exposure and risk.

The following generic CSM (reproduced with permission from Waka Kotahi NZ Transport Agency) can be used for most roading projects.

Figure 8. Generic Conceptual Site Model for Coal Tar in Roading Projects



8. MANAGEMENT OPTIONS FOR COAL TAR CONTAMINATED ROADING MATERIAL

In most circumstances where coal tar roading material is known to exist or suspected of being present, provided the roading material is in a stable and non-degraded state then the most practical management option is to leave the materials in situ rather than removing them. Should it prove necessary to remove the coal tar roading materials, because of upgrade/routine maintenance work or because the materials are degraded and pose a risk, several options are currently available in New Zealand to manage these materials using either in situ or ex situ (through reuse or disposal) methods.

The following section outlines the main in situ and ex situ management options available to deal with coal tar roading materials. Where in situ stabilisation methods are being considered they must be able to meet the engineering demands/requirements of the road.

An overview of alternative options, that have been considered or are being developed overseas for managing these materials, is also presented.

8.1. LEAVING IN SITU

Leaving materials in situ is a management approach that is similar to other hazardous construction materials which allows for in situ management with appropriate long-term monitoring. Some agencies may elect to take a more proactive approach in managing the liability/risks posed by coal tar roading materials and adopt proactive removal programmes.

The decision to leave contaminated material in situ should consider the following issues:

- Nature and characteristics of the coal tar roading material present (e.g. PAH and phenol concentrations),
- Estimate of likely volume of coal tar roading material (i.e. contaminant mass), roads structural integrity etc,
- Estimate of the likely concentration of PAHs and phenols that could be eluted from the road material as a leachate and/or sediment/dust bound contamination concentrations,
- Contaminant transport mechanisms and attenuation processes, and
- Sensitivity and nature of the receiving environment (depth to groundwater and proximity to surface water receptors etc.) and an estimate of risk.

The risk assessment process must be supported by development of a robust CSM, and the risk assessment endorsed by a SQEP.

It is recommended that larger stakeholders (such as highway/roading agencies, contractors etc.) develop asset databases and consistent assessment methodologies to enable these materials to be appropriately assessed and managed over a large spatial area.

As with any management approach where the liability is left in situ it is advisable to have a long-term monitoring programme that ensures adverse effects are not arising, particularly where sensitive receptors are present.

8.2. DISPOSAL OPTIONS

If leaving in situ is not an option, excavated coal tar material must either be taken to a disposal facility authorised to accept material of this kind or encapsulated on site with appropriate long-term management and regulatory approval.

8.2.1. On-site Disposal

Disposal of coal tar roading material at or near roading project sites (e.g. within the road corridor) has the potential to reduce vehicle movements (i.e. required for waste haulage for off-site disposal), disposal costs and improve sustainability outcomes. However, site-specific risks of on-site disposal should be assessed by development of a robust CSM, by a SQEP, that is informed by a comprehensive understanding of:

- The volume of contaminated material requiring disposal,
- Coal tar roading material waste contaminant characteristics (total concentrations, leachability potential,[3] requirements for amendments before disposal, etc.),
- Sensitivity and characteristics of the physical environment (i.e. separation from groundwater and surface water, ecological receptors, etc.),
- Feasibility of long-term management (e.g. ability to track the location of disposal, ability to manage disposal locations as necessary through perpetuity, the durability of physical barriers installed to contain the waste, etc.), and
- Implications for future road corridor modifications that could disturb materials disposed of on-site.

If the CSM indicates that the risks to human health and the environment from on-site disposal are acceptably low, this guidance recommends that social, economic, and environmental outcomes are evaluated by a SQEP as part of a remedial options assessment. On-site disposal should also consider the relevant council resource consent requirements and long-term administration (e.g. under a management plan, showing the location of the materials and the requirements for upkeep of the containment).

8.2.2. Off-site Disposal

Any coal tar roading material taken off-site for disposal must be shown to meet the receiving facility's waste acceptance criteria, as set out in their current resource consent.

Based on typical properties for coal tar roading material, the WasteMINZ's Technical Guidelines for Disposal to Land (2023) indicate that:

- Coal tar roading material may meet the Class 1 and 2 landfill Waste Acceptance Criteria (WAC);
- Class 3 Landfills (Managed Fills) have a waste acceptance criterion for BaP equivalents of 125 mg/kg. This criterion is designed to be protective of groundwater use and aquatic environment leaching pathways and is based on published organic carbon partition coefficients (K_{oc}). Based on this waste acceptance criterion, some coal tar roading material disposal may be acceptable at Class 3 landfills;

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[3] Noting that Appendix E of this document states "TCLP and SPLP are not appropriate for evaluating the environmental risks from long-term leaching of PAH contamination, other than to inform disposal to Class I and Class II landfills, for which the tests were originally designed." Therefore, leachability potential would require analytical methods that are not currently available in NZ at present. An alternative would be to restrict leachability potential by wrapping the contaminated material in an impermeable membrane.

- Coal tar roading material is very unlikely to meet WAC for a Class 4 Landfill; and
- Coal tar roading material will not meet WAC for a Class 5 Landfill.

It should be noted that, irrespective of which class of landfill, site specific WAC will need to be referenced before a suitable disposal site is identified.

8.3. RE-USE AND TREATMENT OPTIONS

There are no readily applicable treatment or re-use options for coal tar roading material in New Zealand at the time of writing. Regulatory constraints, cost constraints and pilot testing would all likely be required to progress the feasibility of these options. Future potential treatment and re-use options for coal tar roading material include, but are not limited to the following techniques:

- In situ stabilisation and re-use,
- Ex situ re-use,
- Bioremediation,
- Incineration,
- Solvent extraction/washing, and
- Mechano-chemical destruction.

Additional information about these potential treatment and re-use options can be found in Appendix F.

9. CONCLUSION

This document provides guidance for those professional and regulatory bodies involved in managing coal tar in roading material by:

- Defining coal tar roading material as being roading material with a total PAH concentration of greater than or equal to 20mg/kg, and BaP TEQ concentrations of greater than or equal to 1 mg/kg,
- Providing a history of coal tar in New Zealand and identifying locations of historical gasworks,
- Clarifying the key differences between coal tar and bitumen,
- Providing guidance as to when roads should be characterised for the presence of coal tar,
- Offering sampling and analysis advice for road characterisation,
- Detailing the steps involved in carrying out field screening procedures,
- Explaining when and how lab testing should be undertaken,
- Specifying when a Conceptual Site Model should be employed, and
- Outlining current and potential future management options.

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APPENDICES

Appendix A LIST OF KNOWN GASWORKS SITES IN NEW ZEALAND

Gasworks	Opened	Closed
Ashburton Gas Coal & Coke Co	1879	1973
Auckland Gas Co Ltd	1865	unknown
Balclutha Gas Works Co	1893	1927
Birkenhead and Northcote Gas Co Ltd	1902	1955
Blenheim Borough Council Gas Department	1880s	unknown
Cambridge Gas Department	unknown	unknown
Carterton Corporation Gas Department	1907	1966
Caversham	1881	unknown
Christchurch Gas Coal and Coke Co	1864	1982
Dargaville Corporation Gas Department	unknown	unknown
Dannevirke Borough Council Gas Department	unknown	1969
Devonport Gas Works	1825	1960
Dunedin Gaslight and Coke Co	1863	1990 to LPG
Eltham Borough Council Municipal Gasworks	1912	1960
Fielding Gas Co	1897	unknown
Foxton Gas Works Proprietary	unknown	unknown
Gisborne Gas Co Ltd	1883	unknown
Greymouth Borough Council Gas Department	unknown	1980
Greytown Gas Department	unknown	unknown
Hamilton City Council Gas Department	1897	unknown
Hastings Gas Co Ltd	1890	1988
Hawera Gas Co Ltd	1897	unknown
Hokitika Gas Co Ltd	1874	unknown
Invercargill Corporation Gas Department	1874	1986 to LPG
Levin Corporation Gas Department	unknown	unknown
Lyttleton Borough Council Gas Department	unknown	1966
Marton Gas Department	unknown	1954
Masterton Corporation Gas Department	unknown	1977
Mosgiel	unknown	unknown
Napier Gas Co Ltd	1876	unknown
Nelson City Council Gas Department	`1882	1985
New Plymouth Gas Company Ltd	1879	unknown
Oamaru Corporation Gas Department	1876	1980
Ohinemuri Light and Power Co Ltd (also known as Paeroa Gas Syndicate Co)	1888	1897
Palmerston North Gas Co Ltd	1889 or 1891	unknown
Pahiatua Gas Company Ltd	1906	unknown
Port Chalmers Gas Co Ltd	1871 or 1888	1951
Petone and Lower Hutt (Lighting) Board	1900	unknown

Gasworks	Opened	Closed
Rangiora Gas Department	unknown	1966
Sumner Gas Department	unknown	1960
Temuka Gas Co Ltd	unknown	1951
Thames Gas Co Ltd	1872	unknown
Tauranga Gas Works Proprietary	unknown	unknown
Timaru Gas Coal and Coke Co	1875	1978
Waihi Gas Co Ltd	unknown	1978
Waipawa Corporation Gas Department	unknown	1951
Waimate Gas and Coal Co Ltd	1906	1966
Wanganui Municipal Gas Department	1878	unknown
Westport Borough Gas Department	unknown	1974
Wellington Gas Company Ltd	1871	unknown
Whangarei Lighting and Manufacturing Co	1899	1960
Woodville Gasworks	unknown	1951

Note: the presence or absence of a gasworks site which operated in a particular area is not a reliable indicator of the presence or absence of coal tar roading materials within that area. The dates in the table are the best estimates available for when these facilities operated. The data provided courtesy of Simon Hunt (EHS Support).

Appendix B CASE STUDIES

These two case studies demonstrate the endmember of the spectrum in terms of the prevalence of coal tar roading material across Aotearoa New Zealand.

Auckland

Since 2015 Auckland Transport (AT) has pre-tested the road corridor sub-base materials for PAHs when seeking to undertake road rehabilitation works within the previous “Auckland City” boundary in the Tāmaki Makaurau Auckland region. Historical testing had identified approximately 13 locations (sections of road) in which coal tar was likely to have been used, mostly as a dust suppressant. Testing prior to undertaking the road rehabilitation works allowed AT to have certainty over the time and costs associated with the earthworks and disposal (or reuse) of material excavated. It also provided time to seek appropriate NESCS and Auckland Unitary Plan consents where required, rather than holding up the physical works through accidental discovery rules.

A review of historic laboratory results through 2005-2015 identified no instances of coal tar-related PAHs within the road corridor, outside of the previous Auckland City boundary. Since 2015, an additional dozen road locations have been confirmed to contain small sections of coal tar - all of which lie within the old city boundary. While AT continues to monitor and retain laboratory testing results, all the discovered material has been disposed of to landfill and no longer remains within the road corridor.

When pre-testing, samples are collected approximately 50-100 m apart within the road pavement (depending on the length of road to be rehabilitated). If a test result identifies elevated PAH levels, the boundary of the contaminated area is extended to the adjacent “clean” results on either side. While this increases the volume of material to be disposed of to landfill, it provides a trade-off against further delays associated with trying to identify the extent of the contaminated area accurately through further testing. The source of the elevated PAHs in samples is not assessed, as this provides no benefit in altering the disposal option – all contaminated material goes to a licensed landfill.

Christchurch

Selecting a single real-life case study that would reasonably represent the historical use of coal tar in roading in Christchurch is difficult since its use varied widely throughout the city over time. Following the 2010/2011 earthquake sequence, Christchurch City Council (CCC) was tasked with repairing approximately 2,000 kilometres of road and likely a greater length of in-ground utilities located under roadways. Consequently, CCC has had to characterise tens of thousands of tonnes of waste roading material for disposal.

CCC has included provisions for waste roading material testing in roading project contracts since 2011. Larger projects involving the complete reconstruction of a section of road surface, or a long segment of under-road utility require pre-construction testing so that budgeting for waste disposal can be more accurate. Sampling generally occurs at a density of 1 sample per 50 linear meters of carriageway that will be disturbed. However, the density of sampling may increase or decrease depending on how patchy the roading material is, and the amount of previous testing that has occurred in the project area. If the project involves the full width of the carriageway, sample locations often alternate from one side to the other side of the road, to assess if historical road repair or widening projects have resulted in the complete removal of coal tar roading material from one side of the road.

Since sampling for large-scale projects requires staging of construction equipment (e.g., excavator, drill rig, support truck, sampling supply vehicle, etc.) in the active carriageway, formal CCC-approved Traffic Management Plans and Corridor Access Agreements must be in place to facilitate the work. The council usually requires high-traffic areas to be sampled during off-peak hours including at night or on weekends. These administrative procedures are time consuming, expensive and risk disturbing the public peace. So, to avoid multiple road closures for a single project, CCC prefers that roading material sampling be undertaken concurrently with other project related activities such as potholing to identify utility depths and pre-design geotechnical testing. Smaller projects often have allowance in their contracts for testing of waste roading material after the infrastructure work has been completed. However, this requires that an appropriate space is available to stage the waste material until sampling and analysis can be completed.

The hundreds of sampling events conducted to complete post-earthquake infrastructure repairs have found that coal tar was used to construct roadways throughout the Christchurch Central Business District and in most outlying industrial, commercial, and residential areas, including in Lyttelton township and the Lyttelton Port area. Environmental investigations for those projects frequently found coal tar contaminants in asphaltic material on carriageway surfaces, embedded in layers of asphalt within the roads, and in isolated sub-surface layers of roading material where more recent road building buried the coal tar asphalt under paving, basecourse, and sub-base materials. In some instances, historic coal tar-contaminated asphalt was found to have been excavated, crushed, and then redeposited into basecourse and sub-base layers of more modern roads. Coal tar-containing material was also used to construct and/or maintain walkways along roads and in park reserves, for driveway skirting on private and commercial lots, in car parks, and in private and public recreational areas such as basketball and tennis courts. In short, anywhere pre-1980s pavement or roading is found in Christchurch, there is a reasonable chance that coal tar was used to construct or maintain that surface.

Appendix C Limits of Detection (LOD) and BaP TEQ Example Calculations

The limit of detection (LOD) is the quantity or concentration of an analyte which corresponds to the lowest signal generated by the GCMS (or other analytical instrument), that can be observed with a sufficient degree of confidence or statistical significance. It is the lowest analyte concentration that can be reliably distinguished from the background noise of the signal. Any concentration of the analyte below the LOD cannot be reliably determined by the laboratory. However, the analyte may be present in the sample at a concentration below the LOD.

If you are expecting high concentrations of PAHs, it is recommended that you contact the laboratory so that appropriate dilutions can be made.

Laboratories may report concentrations below the LOD as less than the LOD (<LOD) or zero, depending on the laboratory's reporting procedures, while other laboratories will report both. How a laboratory calculates the BaP TEQ will depend on how they report any concentrations below the LOD.

Tables 3 and 4 demonstrate how to calculate BaP TEQ using both ways of accounting for concentrations below the LOD. Note that this method of calculating BaP TEQ uses the method with 9 PAH compounds defined in New Zealand, rather than the 16 priority PAHs defined by US EPA.

Table 3. Example BaP TEQ calculation with BaP concentrations less than the LOD being reported as zero

Analyte	**LOD**	**Concentration (mg/kg)**	**PEF**	**BaP TEQ**
Acenaphthene	0.03	1.74	-	-
Acenaphthylene	0.03	0.18	-	-
Anthracene	0.03	2.5	-	-
Benzo(a)anthracene	0.03	3.3	0.1	0.33
Benzo(a)pyrene	0.03	2.4	1	2.40
Benzo(b) and (j) fluoranthene	0.03	2.9	0.1	0.29
Benzo(g,h,i)perylene	0.03	1.36	-	-
Benzo(k)fluoranthene	0.03	<0.03	0.1	0.00
Chrysene	0.03	2.4	0.01	0.02
Dibenz(a,h)anthracene	0.03	<0.03	1	0.00
Fluoranthene	0.03	9.4	0.01	0.09
Fluorene	0.03	1.63	-	-
Indeno[1,2,3-c,d]pyrene	0.03	1.74	0.1	0.17
Naphthalene	0.1	0.64	-	-
Phenanthrene	0.03	9	-	-
Pyrene	0.03	8	-	-
Total concentration		**47.24**	**-**	**-**
TEQ		**-**	**-**	**3.31**

Table 4. Example BaP TEQ calculation with BaP concentrations less than the LOD being reported as the LOD

Analyte	LOD	Concentration (mg/kg)	PEF	BaP TEQ
Acenaphthene	0.03	1.74	-	-
Acenaphthylene	0.03	0.18	-	-
Anthracene	0.03	2.5	-	-
Benzo(a)anthracene	0.03	3.3	0.1	0.33
Benzo(a)pyrene	0.03	2.4	1	2.40
Benzo(b) and (j) fluoranthene	0.03	2.9	0.1	0.29
Benzo(g,h,i)perylene	0.03	1.36	-	-
Benzo(k)fluoranthene	0.03	<0.03	0.1	0.003
Chrysene	0.03	2.4	0.01	0.02
Dibenz(a,h)anthracene	0.03	<0.03	1	0.03
Fluoranthene	0.03	9.4	0.01	0.09
Fluorene	0.03	1.63	-	-
Indeno[1,2,3-c,d]pyrene	0.03	1.74	0.1	0.17
Naphthalene	0.1	0.64	-	-
Phenanthrene	0.03	9	-	-
Pyrene	0.03	8	-	-
Total concentration		**47.24**	**-**	**-**
TEQ		**-**	**-**	**3.343**

Appendix D PAH FINGERPRINTING METHODOLOGY

A weight of evidence approach using a combination of both quantitative and qualitative techniques can be used to differentiate the likely source of PAHs in base course in the road corridor.

Lines of evidence that can be used to help establish whether roading material is likely to contain coal tar include:

- The absolute concentration of PAH and BaP TEQ,
- The presence or absence of naphthalene,
- The similarity of gas chromatograms with reference samples,
- The ratios of specific PAH compounds, and
- The relative concentrations (percentage of total) each PAH compound.

Absolute Concentrations: Typically, lower concentrations of total PAH and BaP TEQ are detected in bitumen samples relative to coal tar. Coal tar often contains PAH concentrations in the order of 100s to 1000s of mg/kg, whereas bitumen contains less than 20 mg/kg total PAH. If total PAH and B(a)P TEQ concentrations fall between these values, the pavement may be a mix of bitumen and coal tar. This guidance defines roading material with a total PAH concentration of greater than or equal to 20mg/kg, and BaP TEQ concentrations of greater than or equal to 1 mg/kg as coal tar roading material.

Naphthalene: Naphthalene is absent in bitumen, and its presence is an indicator of coal tar. However, the absence of naphthalene in extremely weathered coal tar is not uncommon, and its absence does not conclusively indicate that the roading material is bitumen based.

Reference Chromatograms: Gas chromatograms provide a visual fingerprint of hydrocarbons in the samples, and these can be compared to gas chromatograms for reference samples of coal tar and bitumen based roading material. Coal tar reference samples typically contain large, resolved PAH peaks while the bitumen samples contain resolved PAH peaks on top of a large, unresolved complex mixture of aliphatic hydrocarbons. However, weathering or degradation of the hydrocarbons in the pavement/base course over many years can alter these profiles. Examples of gas chromatograms for coal tar and bitumen roading materials are shown in Figure 9 and Figure 10 below.

Figure 9. Example gas chromatogram of bitumen asphalt

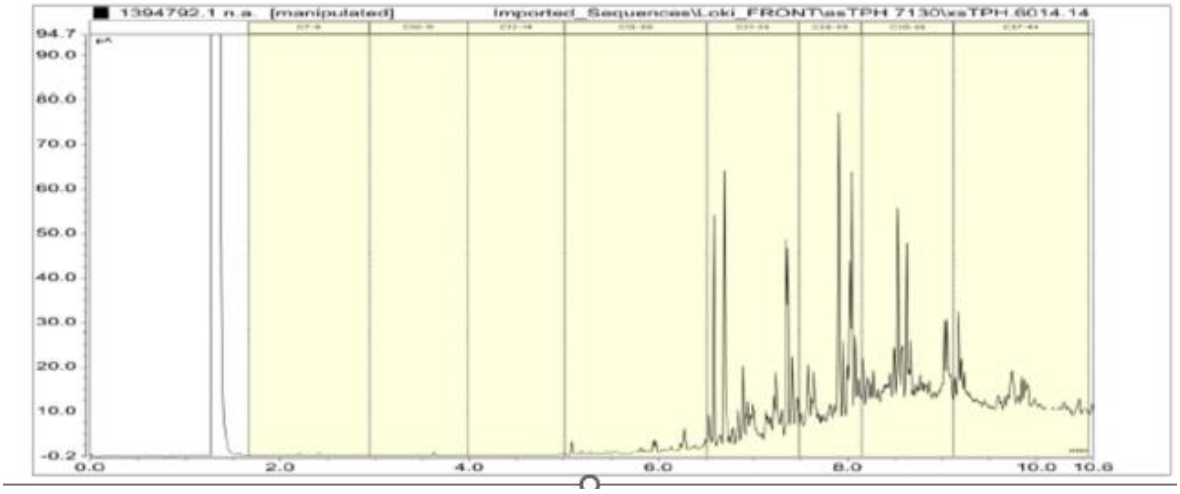
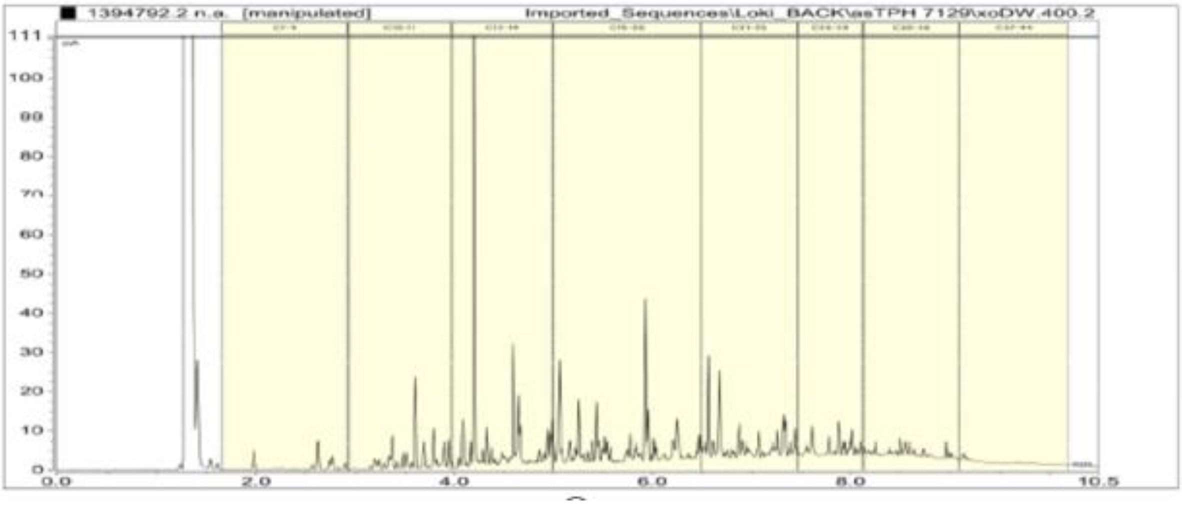


Figure 10. Example gas chromatogram of coal tar asphalt



PAH Ratios: The use of PAH ratios as indicators for coal tar was explored by Dupree and Ahrens (2007) for the Auckland Regional Council. Pyrogenic PAH sources (such as coal tar) were thought to have a high ratio (ca. 0.55) of benzo(a)anthracene to chrysene and indeno(1,2,3-c,d)pyrene to benzo(g,h,i)perylene, while petrogenic sources were considered to have ratios in the order of 0.2-0.3. The report suggested that petrogenic and pyrogenic sources could be identified on the basis of these ratio values.

However, PAH ratios in hundreds of samples collected from Auckland roads since 2010, as well as reference samples of coal tar and bitumen indicate that they do not provide a sensitive diagnostic tool for differentiating the sources of PAHs in Auckland roading materials. On this basis, these ratios should not be considered as a primary line of evidence of the PAH source.

Relative PAH Concentrations: Rather than relying on rations of individual PAH compounds, a radar plot, showing the relative percentage of each of the 16 US EPA priority PAHs, as shown in figure 11 below, can provide a fingerprint of PAH source.

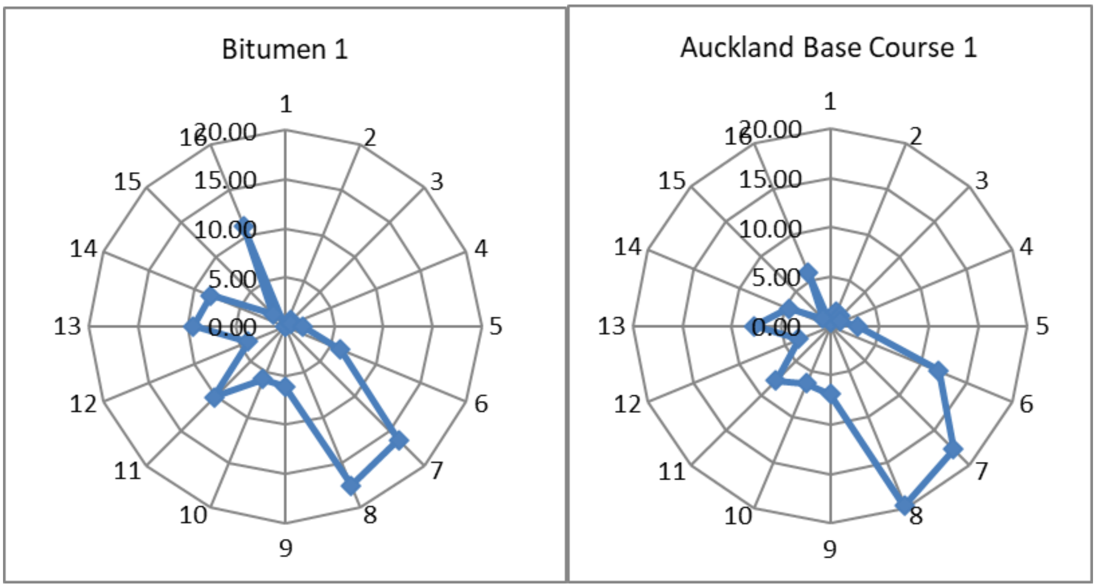
Radar plots are generated by taking the ratio of the concentration of each PAH to the total concentration of the 16 PAHs and expressing the ratio as a percentage. The results are plotted in a circular plot, allowing a visual comparison of samples containing different concentrations of PAHs to be viewed on the same scale. The profile of the radar plot is not a definitive diagnostic tool but adds to the weight of evidence required to identify the likely source of the PAHs examined. It is recommended that the order of plotting is based on molecular weight from smallest to largest to allow comparison between reports.

Table 5: PAH data for radar plots

Data and plots courtesy of Cathy Bebelman (Auckland Transport)

		Akd Basecourse CT		Bitumen	
		ppm	%	ppm	%
1	Naphthalene	2.7	0.30	0	0.00
2	Acenaphthylene	13.9	1.53	0	0.00
3	Acenaphthene	13.9	1.53	0.03	0.88
4	Fluorene	10.1	1.11	0.02	0.58
5	Anthracene	25	2.75	0.06	1.75
6	Phenanthrene	108	11.89	0.21	6.14
7	Fluoranthene	161	17.72	0.56	16.37
8	Pyrene	179	19.70	0.6	17.54
9	Benzo(a)anthracene	63	6.93	0.21	6.14
10	Chrysene	57	6.27	0.2	5.85
11	Benzo(b)fluoranthene+Benzo(j)	71	7.81	0.35	10.23
12	Benzo(k)fluoranthene	31	3.41	0.14	4.09
13	Benzo(a)pyrene	70	7.70	0.32	9.36
14	Indeno[1,2,3-c,d]pyrene	41	4.51	0.28	8.19
15	Dibenzo(a,h)anthracene	9.1	1.00	0.06	1.75
16	Benzo(g,h,i)perylene	53	5.83	0.38	11.11
		908.7	**100.0**	**3.42**	**100.00**

Figure 11. Example PAH fingerprinting plots for bitumen (L) and coal tar roading material (R)



Bitumen 1

Auckland Base Course 1

Appendix E LEACHATE TESTING METHODS

E.1 INTRODUCTION

The leaching of contaminants from solid material by water can be a significant migration mechanism whereby the contaminants can be mobilised and transported a long way from their point of origin. Leaching can present a significant risk to ecological receptors and groundwater. Historically, leachability of contaminants from solid material have largely been determined by two tests – Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP). Due to the hydrophobicity of PAHs, since both TCLP and SPLP employ the use of aqueous extractants (water or dilute acid), TCLP and SPLP are not appropriate for evaluating the environmental risks from long-term leaching of PAH contamination, other than to inform disposal to Class I and Class II landfills, for which the tests were originally designed.

E.2 TCLP AND SPLP

The TCLP leaching test typically involves extraction using a dilute acetic acid solution (pH ~2.9) at a ratio of 1:20 (solid/liquid) and tumbling for ~18 hours. The extractant solution is then filtered, and the filtered solution is analysed for the contaminants of concern. The TCLP test is designed to mimic conditions in a landfill and is used as part of waste characterization to inform disposal efforts. TCLP analysis of waste is typically required for Class 1 and Class 2 landfill waste acceptance, but this method is not recommended to assess PAH leaching risk outside of a landfill with engineered containment (for which the test was designed).

The SPLP test is methodologically nearly identical to the TCLP test. It was originally developed by the US EPA as Method 1312 and was designed to mimic the interaction of soil and acid rain. In New Zealand, the SPLP test uses ultra-pure, reagent grade water as the extractant in place of the dilute acetic acid solution used in TCLP or very dilute acids in other versions of the SPLP test.

For trace elements such as “heavy metals” (e.g. arsenic, chromium, lead, copper), both the TCLP and SPLP extraction methods work reasonably well if the contaminants are in a form that are relatively soluble. However, they are inherently limited in that they can never fully reflect natural processes, especially in evaluating long-term leaching potential of contaminants. Therefore, while TCLP and SPLP are tools that are available for determining the leaching potential of some contaminants, they are not appropriate for PAHs because of the relative insolubility of PAH compounds. Despite their hydrophobic nature and relatively low solubility, PAHs can nonetheless leach from material such as coal tar-contaminated roading. TCLP and SPLP testing may be required by some disposal facilities as part of their consented waste acceptance criteria. In this case, testing of coal tar roading materials must be conducted as indicated in the consent.

E.3 NON-FILL PAH LEACHING INVESTIGATIONS

For all other instances, it is more appropriate to employ other leaching analyses for PAHs that are not yet common in New Zealand. At some point in the future, PAH leaching analysis (using supercritical carbon dioxide extraction, resin bead extraction, etc.) might become more widely available. If such tests become available, the Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines for ecological protection provide water quality guideline values and trigger limits that are applicable to a broad suite of contaminants (typically expressed in units of mg/L). The NZ Drinking Water Standards only have guideline values for a small subset of PAHs, so the ANZECC guidelines are preferable for surface water quality protection, if analytical methods become available.

Methods for the analysis of PAH release from contaminated soils and sediments have been the subject of significant research over 20+ years. This body of work has shown that a simple ~18-hour water extraction (that is, SPLP) is inadequate for assessing the risks of groundwater or surface water contamination and adverse environmental effects arising from PAH-contaminated materials.

E.4 TOTAL MATRIX ANALYSIS

At present, the "total matrix method" of extraction should be used to measure the concentration of PAHs in contaminated material such as soil (typically expressed in units of mg/kg). Appropriate guideline values must then be selected, that are protective of water resources, human health, ecological health, and Te Mana o Te Wai.

The NESCS defines BaP and a mixture of other carcinogenic PAHs as priority contaminants and sets out soil contaminant standards for human health protection in terms of BaP TEQ. These values are for surface soils and are not necessarily appropriate for the protection of water resources. The Drinking-water Standards for New Zealand (revised 2018) considers BaP itself an "organic determinant of health significance," with a maximum allowable value in drinking water of 0.0007 mg/L, and the ANZECC water quality guidelines for ecological protection give similar values (0.0001-0.0007 mg/L) for species protection, especially since BaP bioaccumulates in organisms. Thus, there exist values which might be applied in a regulatory context to determine whether leachate from PAH-containing soil or waste is "safe." But since PAHs are very hydrophobic, the accuracy of risk assessment is highly dependent on the suitability of the extraction method used for leachate testing. At the time of writing these guidelines there was no commercially available methodology to determine leachability potential.

Another possible approach to assessing water quality impacts of PAHs is based on the total concentration of PAHs in the solid (i.e. soil or sediment), and relies on assumptions regarding PAH release to water. The ANZECC sediment quality guidelines for the protection of water quality in aquatic ecosystems provide guideline values for total PAHs (a sum of a variety of PAHs of concern) in sediment. The Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand (1999, revised 2011) also sets out some parameters that are intended to be protective of groundwater, based on analysis of a suite of PAHs in the soil or sediment.

Analytical testing for assessment of sediment or soil typically relies on a "total matrix" extraction of a variety of PAHs from the soil using an organic solvent, rather than a water-based extractant solution. "Total matrix" extraction with organic solvent is a reliable measurement for PAHs in soils and sediments since the hydrophobic nature of PAHs makes them resistant to water-based extraction methods. It is hydrophobicity that makes the long-term leaching potential and water quality impacts of PAHs difficult to determine.

Appendix F POTENTIAL TREATMENT AND RE-USE OPTIONS

F.1 LITERATURE REVIEW OF INTERNATIONAL TREATMENT AND REUSE OPTIONS

Recycling of asphalt paving during road construction, maintenance and rehabilitation has become a common approach to improving resource use and minimising the environmental, economic, and social impacts of these processes. The use of recycled, instead of virgin, material has sustainability benefits of easing landfill pressure, reducing demand for the extraction of virgin materials, improved energy efficiency (lower carbon emissions), and potentially fewer transport movements (Rathore et al. 2019). However, the presence of coal tar in asphalt presents a barrier to effective reuse and recycling of this material. The two main concerns associated with the reuse of coal tar roading material are the safety of workers exposed to volatilised tar fumes and the contamination of increasing quantities of asphalt, with the appendant concerns regarding contaminant leaching or migration (Depree and Fröbel 2009; Arm et.al. 2017).

Within the last twenty years, cold recycling of asphalt has emerged as an accepted road construction practice with the potential to beneficially reuse coal tar asphalt whilst safeguarding human health and the environment. Cold recycling involves pulverising the existing roading material and using the arisings to produce a dense, non-permeable material, which encapsulates and stabilises coal tar asphalt as part of the recycling process. Stabilisation is achieved using a binder, such as cement, pulverised fuel ash, lime, or bitumen. Processing can take place either *in situ* using specialised machinery or *ex situ* at an asphalt plant. Because processing occurs at low temperatures, it has been shown to reduce emissions of PAHs. Cold recycling addresses the workplace health and safety concerns of hot-mix recycling of coal tar roading material (Depree and Fröbel 2009).

However, due to uncertainty regarding critical contaminant behaviour during reuse and concerns regarding contaminant leaching from recycled asphalt, there is inconsistent regulatory oversight of recycling or reuse of coal tar roading material internationally. In part, this is attributable of the use of variable laboratory and risk assessment methodologies. As a result, definitions of coal tar roading material are inconsistent, with jurisdictions at national or regional level setting variable thresholds for PAHs, BaP, and/or phenol content in asphalt.

Europe:

Within Germany, asphalt could be considered hazardous waste when total PAH content exceeds 1,000 mg/kg, 400 mg/kg, or 25 mg/kg, depending on the federated state (Bundesland). Recycling for use on roads is prohibited; however, there is substantial demand for construction materials at certified landfill sites, and it is considered best practice to use coal tar roading material for construction purposes at these sites (Fédération Internationale du Recyclage n.d.).

In the Netherlands, asphalt is considered a hazardous substance when total PAH content exceeds 75 mg/kg. Roading authorities are obliged to separate coal tar material at source and take it to one of three thermal plants in the country for treatment and recycling of inert material (Depree and Fröbel 2009, Fédération Internationale du Recyclage n.d.).

According to the Swedish regulations (Waste Ordinance, SFS, 2011:927), asphalt containing a concentration ≥0.1 wt% of PAH (i.e. ≥1000 mg/kg) is classified as hazardous waste and must be taken to landfill for disposal (Kumpiene et al. 2021).

United Kingdom:
In England, asphalt waste containing coal tar is considered hazardous when it contains more than 0.1% coal tar. Because the proportion of coal tar in asphalt cannot be measured directly, a BaP concentration of greater than 50 mg/kg is used as a threshold. The Environment Agency does not require permits for use of treated asphalt waste containing coal tar, provided the material is processed using an accepted ex-site cold-recycling or hydraulically bound mixture process, and the recycled material is exclusively used in bound sub-surface layers, e.g. sub-base, base, and binder layers. Use in the surface, wearing layer, is not allowed (Environment Agency 2014).

In Scotland, regulatory approval to recycle coal tar roading material in existing roads is provided by the Scottish Environment Protection Agency on a site-by-site basis. Recent guidance prepared for Transport Scotland provides approaches to *in situ* or *ex situ* cold recycling to ensure that sound environmental and civil engineering out comes are obtained. This guidance requires that recycled coal tar roading material is used only in bound sub-surface layers, e.g. as sub-base, base, and binder course (WSP 2021).

Australia:
In New South Wales, the Roads and Maritime Services (RMS) considers material containing more than 1% coal tar to be coal tar roading material. Rather direct quantification of PAH as an indicator of coal tar, RMS have a published laboratory method to identify the coal tar based on the presence or absence of phenol (considered an indicator of coal tar asphalt in NSW) (NSW Transport RMS 2015). In NSW, all excavated coal tar asphalt must be taken to a licensed landfill for disposal and is not to be reused for any purpose, including reincorporation as fill in subsurface road layers or reused to manufacture new asphalt (NSW Transport RMS 2015).

F.2 In Situ Stabilisation and Reuse

Using this process, a relatively thin layer of an asphalt road is milled or scarified, after which new material (bitumen/aggregate) is added and mixed before laying and compacting the recycled asphalt. Additives such as foamed bitumen, lime or cement can be added during the process to stabilise the material. The primary purpose of stabilisation is to prevent or minimise the mobility of PAHs in coal tar asphalt or coal tar impacted sub-base materials reused in improved or new roads. The stabilisation of road pavement and subgrade materials (Depree and Fröbel 2009) is common practice in Australia and the United Kingdom (Browne 2020). In most jurisdictions, stabilised coal tar asphalt material is permitted to be used as the sub-base, base or binder course beneath the new bitumen-based roading surface or seal to prevent direct human or environmental exposure to the bound coal tar asphalt material (Moala and Browne 2008, Depree and Fröbel 2009, CH2MHILL 2015).

The effectiveness of stabilisation as a method for remedying coal tar asphalt is subject to the inherent effectiveness of the stabilisation additive or method used, in terms of PAH binding capability and the long-term effectiveness of stabilisation media. Specific to New Zealand, Depree and Fröbel (2009) suggest that foamed bitumen stabilisation of coal tar asphalt is the most readily implemented solution. They found that while the environmental risks could be effectively managed, a major limitation of applying the *in situ* recycling technique to coal tar-contaminated roads in New Zealand was that the affected streets are typically composed of thin construction layers. Unless it is possible to apply sufficient make-up aggregate, the stabilised road base will be of substandard strength and prone to early failure. This suggests the potential for re-exposure of coal tar bound sub-base and base materials.

There are no recent case studies in New Zealand which document the successful implementation of this stabilisation approach on a large scale, however this approach could potentially be undertaken with the right pavement conditions, and appropriate resource consents from relevant councils.

F.3 EX SITU REUSE

Coal tar containing roading material could also be excavated from the road surface and taken to an off-site asphalt processing plant, where it could, theoretically, be fed into the plant at low rates to allow dilution of the PAH concentrations to acceptable levels. Stakeholders (including but not limited to territorial local authorities, regional councils, Waka Kotahi, local iwi, and roading construction companies) involved in this process would have to agree on appropriate metrics for risk. Noting the relative PAH concentrations in coal tar compared to bitumen in Table 1 of this guidance, stakeholders would need to clarify if risk should be informed by total PAH concentrations or by the specific concentrations of PAH constituents (i.e., as ranges or fixed values). Stakeholder agreement on the degree of quality assurance and quality control that would be required to ensure that the final product meets environmental and engineering performance standards. Unlike in situ processing, the thickness of the road construction layers and capacity for using make-up aggregate is not constrained by the available cross-sectional profile of the design surface, and the new road could be constructed using conventional methods.

Based on initial feedback from roading contractors, barriers to ex situ recycling of coal tar containing roading material are currently perceived to include:

- The requirement to re-purpose bitumen asphalt manufacturing plants to accommodate recycling of uncertain coal tar asphalt quantities,
- Likely stringent quality assurance/quality control and unrealistic regulatory compliance requirements around achieving satisfactory concentrations of PAHs in roading products that incorporate recycled coal tar asphalt,
- Possible issues associated with air discharge quality (i.e., for dust, odours, and volatile vapours during the coal tar asphalt recycling process), and
- A lack of appropriate leachate testing methods for recycled materials.

These factors could make achieving practical *ex situ* recycling cost prohibitive and commercially unviable, but it is the view of this guidance, that this should be explored further with likely stakeholders. Further, limits around the on-going supply of bitumen in NZ may make this option more attractive in the future.

F.4 BIOREMEDIATION OF COAL TAR

Bioremediation of coal tar roading material is based on the principles of bacterial and fungal biodegradation pathways for PAHs and has been demonstrated to be successful in controlled studies, as described by Sayara and Sánchez (2020). However, this process appears to be more readily applied for soils as opposed to coal tar asphalt and coal tar impacted sub-base materials, and the bioremediation process would require long-term handling and monitoring (i.e. potentially over many months) at great expense. As Sayara and Sánchez (2020) further imply, more work is needed to identify the requirements for efficient, large-scale implementation of this coal tar roading material treatment option, and this is not an option that would be readily implemented in New Zealand.

F.5 Incineration

Roading material containing coal-tar can be incinerated at specifically designed and engineered thermal plants, as is currently the case in the Netherlands. There are no such plants currently operating in New Zealand, and is currently a prohibited activity in many regions, however it is possible that this may be an option in the future.

F.6 Solvent extraction / washing

Coal tar could theoretically be chemically and physically extracted from the roading material using an appropriate solvent. The clean aggregate could be reused, and the resultant solvent/coal tar mixture incinerated (not currently an option in New Zealand) or distilled to recover the solvent. While this type of process may be possible from a chemical engineering standpoint, it would incur significant costs to establish an industrial processing facility and such a process is likely to require significant volumes of solvent. The solution arising from the coal tar removal from aggregate would then require treatment and/or disposal itself, likely as a hazardous substance.

F.7 Mechano-chemical Destruction

Theoretically, coal tar roading material could be rendered into inert material using a high energy ball mill. Like other treatment techniques, there are currently no large-scale processing facilities in New Zealand, but there is potential for this in future. Further research may also be necessary to establish the commercial viability and consenting requirements of this option.

F.8 Summary

Review of international reuse and treatment options for coal tar roading material, carried out for developing this guidance, indicates that international authorities categorise coal tar as a hazardous substance; however, their approach for what is acceptable in terms of coal tar reuse and the associated risk is variable. In some jurisdictions, complete removal of coal tar impacted materials from road networks and subsequent disposal to landfill is mandated, while others accept reuse of coal tar in roads subject to specific controls and requirements. In general, relevant published information about international treatment options (i.e. *in situ* or *ex situ*) is lacking.

Table 5 summarises the currently available reuse and treatment options for coal tar roading material and the technical feasibility and commercial viability of each option in New Zealand.

Table 6. Summary of reuse and treatment options

Option	**In use internationally?**	**Technically feasible?**	**Commercially viable?**	**What is needed?**
In situ stabilisation	Yes	Yes	Unknown	Successful case studies. Regulatory approval
Ex situ reuse	Yes	Yes	Unknown	Removal of technology barriers. Regulatory approval
Treatment options				

Bioremediation	Unknown	Unknown	Unknown	Proof of concept. Regulatory approval
Incineration	Yes	Yes	Unknown	Regulatory approval and economic incentives. Regulatory approval
Solvent Extraction	Unknown	Yes	Unknown	Proof of economic viability. Regulatory approval
Mechano-chemical Destruction	Unknown	Yes	Unknown	Proof of concept and economic incentives. Regulatory approval