

Australian Oil Recyclers Association
Used oil use in ANFO Blasts
Literature review of potential risks

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Acronyms and Abbreviations

Acronym	Definition
AORA	Australian Oil Recyclers Association
Used Oil	Petroleum or synthetic oils that have been used and that, as a result of such use, are contaminated by physical or chemical impurities
Virgin Oil	Petroleum or synthetic oils that are unused
Hazardous Waste	Waste products as defined in the <i>Hazardous Waste (Regulation of Exports and Imports) Act 1989</i>

Executive Summary

Used oils are petroleum or synthetic oils that have been used and that, as a result of such use, are contaminated by physical or chemical impurities (1).

Used oil is an identified hazardous waste in Australia and Internationally (2) (3), and as such strict regulations govern its storage, transport, disposal and recycling.

Used oil can be re-refined for use as an alternative to virgin oil, dewatered and filtered for use as an additive in other products, or burned as an industrial fuel (4). Alternatively, used oil can be disposed of by thermal destruction in purpose-built facilities that ensure appropriate handling and conditions to manage contaminated and limit health, safety and environmental risks (5). Mishandling or disposing of used oil the wrong way has the potential to pollute the environment (6) and impact human health.

Australian Oil Recyclers Association (AORA) represents the Australian oil recycling industry. The charter of the association is to promote oil recycling by the dissemination of information relating to all phases of the industry, to encourage scientific investigation, experimental and research work in all phases of the industry, and to protect and improve the quantity and quality of oil recycling resources and to co-operate with all bodies interested in environmental protection through the use of recycled oil

The members of AORA have observed a decline in used oil feedstock on the market and consider that this may, in part, be associated with an increase in the use of used oil as a bulking agent in explosives, particularly the ammonium nitrate fuel oil (ANFO) type.

In addition to the known hazards associated with the contaminants contained in used oil (2), AORA have raised concerns that it's use in ANFO products may pose additional health, safety and environmental risks.

Arup have been commissioned by AORA to undertake a literature review to report on the following:

- Available information on potential health, safety and/or environmental risks associated with used oil use in ANFO blast practices
- Potential next steps for further detailed investigation

The key findings of the literature review are as follows:

Key findings:

- The requirements according to AS2187.2 for fuel oil in ANFO are merely that it shall be “clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate”.
- Used oil is identified as a hazardous waste by the *Hazardous Waste (Regulation of Exports and Imports) Act 1989*. This Act limits the trade of used oil as a waste for final disposal and encourages recycling, reclamation and recovery of energy, though this does not include direct incineration.
- The Basel Convention Technical Guidelines on Waste Oils from Petroleum Origins and Sources (Y8) identifies that lubricating oils contain contamination from their use that can cause health and safety problems for humans (including cancer), harm to the environment, or react after disposal to have these effects.
- Untreated used oil contains many chemicals that are hazardous to human health and the environment if not managed competently. These contaminants include dioxins and furans, heavy metals, chlorinated or sulphonated contaminants and polycyclic aromatic hydrocarbons.
- The introduction of impurities to ANFO through contaminants in used oil, provides a pathway for contaminants to be released to the environment. As the conditions in a blast are uncontrolled it is unlikely that emissions will achieve environmentally sound emission standards. It is also unknown if chemicals such as dioxins and furans are formed due to the temperature/residence time in the blasting process.
- During an ANFO blast, the contaminants in used oil may cause an increase in the side reactions that occur during detonation, potentially resulting in poor blast performance, elevated post-blast NO_x fumes and increased risk of unplanned detonation (7) (8).
- It is not fully understood in what ways contamination of ANFO with used oil may cause diversions from the ideal ANFO blast chemical reaction series, potentially increasing the risk of unplanned detonation.
- Although workplace exposure standards exist for NO_x and CO, human health risks from fumes of surface blasting are largely unknown as most investigation has focussed on underground mining, with more confined ventilation spaces. It is possible that exposure risk is increased due to elevated levels of post-blast fumes when the ANFO is manufactured with used oil.
- Further investigations and studies are required to better understand the risk of contaminants in untreated used oil and impacts to environment, health and safety associated with ANFO blast products.
- Further investigation, legal opinion and Regulatory Guidance may be beneficial for determining if the use of used oil in ANFO explosive mixtures could be considered a particular case of incineration of hazardous waste and as such the used oil product would be subjected to product specification and quality control and potential emissions controls to achieve environmentally sound emissions standards in line with the Basel conventions technical guidelines recommendations. (16 pp. 25,33)
- Used oils for use in explosives such as in ANFO, are not currently considered by Product Stewardship (Oil) Act and its associated quality specifications.

1 Introduction

1.1 Project background

Used oils are petroleum or synthetic oils that have been used and that, as a result of such use, are contaminated by physical or chemical impurities (1).

Used oil is an identified hazardous waste in Australia and Internationally (2) (3), and as such strict regulations govern its storage, transport, disposal and recycling.

Used oil can be re-refined for use as an alternative to virgin oil, dewatered and filtered for use as an additive in other products, or burned as an industrial fuel (4). Alternatively, used oil can be disposed of by thermal destruction in purpose-built facilities that ensure appropriate handling and conditions to manage contaminated and limit health, safety and environmental risks (5). Mishandling or disposing of used oil the wrong way has the potential to pollute the environment (6) and impact human health.

Australian Oil Recyclers Association (AORA) represents the Australian oil recycling industry. The charter of the association is to promote oil recycling by the dissemination of information relating to all phases of the industry, to encourage scientific investigation, experimental and research work in all phases of the industry, and to protect and improve the quantity and quality of oil recycling resources and to co-operate with all bodies interested in environmental protection through the use of recycled oil.

The members of AORA have observed a decline in used oil feedstock on the market and consider that this may, in part, be associated with an increase in the use of used oil as a bulking agent in explosives, particularly the ammonium nitrate fuel oil (ANFO) type.

In addition to the known hazards associated with the contaminants contained in used oil (2), AORA have raised concerns that its use in ANFO products may pose additional health, safety and environmental risks.

1.2 Scope

Arup have been commissioned by AORA to undertake a literature review to report on the following:

- Available information on potential health, safety and/or environmental risks associated with used oil use in ANFO blast practices including:
 - Contaminants typically found in used oil
 - Chemical nature of ANFO product
 - Chemical reactions of ANFO blast
 - Potential impact of used oil contaminants on the ANFO blast
 - Conditions that present risk to incomplete destruction of used oil in ANFO blast
 - Potential associated health, safety and environmental risks

- Potential next steps for further detailed investigation:
 - Further investigations and studies that could be conducted to assist in informing AORA on the risk and impacts associated with used oil in ANFO blast products
 - Opportunities for (and limitations of) laboratory simulation and testing of ANFO blasts to gain empirical data

2 Used Oil

- *Used oil contains many chemicals that are hazardous to human health and the environment*
- The introduction of impurities to ANFO through contaminants inherently contained in used oil may cause an increase in the side reactions that occur during detonation, potentially resulting in poor blast performance, elevated post-blast NO_x fumes and increased risk of unplanned detonation (7) (8) (9)

2.1 Definitions

Used oil is an identified hazardous waste in Australia and Internationally (10) (11) (12) and as such strict regulations govern its storage, transport, disposal, use and recycling.

The recycling of used oil is incentivised through the Australian Government's Product Stewardship for Oil Scheme (PSO) and administered under the *Product Stewardship (Oil) Act 2000 and subordinate regulations* (1), which applies standards to waste oil recycling products eligible for benefit (refer Appendix A). This reduces the environmental risks posed by this potentially serious pollutant and ensures a long term future for oil recycling in Australia (13).

By contrast, the requirements according to AS2187.2 for fuel oil in ANFO are merely that it shall be "clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate".

Therefore, of most relevance to this literature review are the definitions provided under the following categories and outlined in detail in Appendix B:

1. Hazardous waste management:
 - Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (10)
 - Hazardous Waste (Regulation of Exports and Imports) Act 1989 (Cth) (12)
 - National Environment Protection Council Act 1994 (Cth) (11)
 - Australian Government Hazardous Waste Data and Reporting Standard 2017 (2)
2. Recycling of used oil incentivisation in Australia
 - Product Stewardship (Oil) Act 2000 (Cth) (1) and Product Stewardship for Oil Scheme (13)

3. Used oil for energy use:
 - Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (10)
 - Hazardous Waste (Regulation of Exports and Imports) Act 1989 (Cth) (12)
4. Oil use in ANFO
 - AS2187.2 Explosives - Storage and use, Part 2: Use of explosives (14)

2.2 Contaminants

Oil is used for the lubrication of machinery and engine parts, also serving to keep surfaces clean, facilitate start-up and reduce corrosion. Over time, breakdown by-products (including carbon and soot), and heavy metals from machinery or engine wear, build up as contaminants in the oil and reduce its effectiveness.

While the contaminants accumulated over time eventually affect the performance of the oil to the point that it must be changed out, the physical properties of the oil itself do not degrade.

Used oil can be re-refined for use as an alternative to virgin oil, dewatered and filtered for use as an additive in other products, or burned as an industrial fuel (4). Alternatively, used oil can be disposed of by thermal destruction in purpose-built facilities that ensure appropriate handling and conditions to manage contaminated and limit health, safety and environmental risks. (5)

In contrast to virgin oil, used oil typically contains a number of components that pose health, safety and environmental risks. (15) (16)

These include:

- particulate matter
- polycyclic aromatic hydrocarbons (PAHs) with 3–7 rings, which include benzo[a]pyrene, benzo[a]anthracene, and chrysene
- organic volatile contaminants that may be found in used oil include benzene, ethylbenzene, toluene and xylenes (BETX) and naphthalene (17)
- metals, including zinc, lead, cadmium, barium, iron, copper, chromium, nickel
- zinc diaryl or dialkyl dithiophosphates, molybdenum disulphide, zinc dithiophosphate, heavy-metal soaps and other organometallic compounds which contain heavy metals (18), acids (esters, peroxides) (16)
- potential for PCB, dioxin and furans. These are these are reported in waste oil (10) and re-refined base oil is required to be tested for these contaminants as per the Product Stewardship Act.

Many of these components have been reported to have carcinogenic, mutagenic, and/or toxic effects on humans and other organisms in the environment. (17)

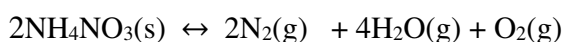
3 ANFO

3.1 Product

Ammonium Nitrate becomes an explosive when mixed with a carbonaceous additive, most commonly fuel oil, in the correct oxygen balanced proportions. Ammonium Nitrate (AN) and Fuel Oil (FO) = ANFO is a commonly used bulk industrial explosive used in mining, quarrying, civil construction and other applications. It is a free flowing (loose poured) mixture of porous prilled ammonium nitrate (NH_4NO_3), formulated to be oxygen balanced for use in dry blastholes (19).

AN is a strong oxidant which acts as the oxidizing agent and absorbent for the fuel oil component of the product. Pure and compact AN is relatively stable and very difficult to detonate. AN is combined with FO, to produce ANFO, which is classified under the GHS as a Division 1.1 explosive and Category 2 carcinogen (20). Ammonium Nitrate of any form is not permitted to be transported on the same vehicle load as any sensitising or initiating agent Table 9.3 (21)

The overall equation for AN decomposition is outlined below:



3.2 Blast emissions

The fumes emitted from ANFO blasts include toxic gases NO_x (NO , NO_2), CO and methane generated during blast activities. Under certain reaction conditions, undesirable side reactions can proceed, resulting in the increased production of these gases and by-products (22). The use of used oil may contribute to an increase of blast emissions as outlined below:

3.2.1 Fuel balance and contaminants

Ingredient mixes vary between manufacturers of ANFO. Anecdotal reports suggest that products from different manufacturers behave differently during blasting, and operators have complained about poor blast outcomes as a result of alternate ANFO suppliers. ⁽²⁵⁾

The requirements according to AS2187.2 for fuel oil in ANFO are merely that it shall be “clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate” (23).

In ideal fuel ratios, ANFO is composed of 94wt% ammonium nitrate (NH_4NO_3) (AN), and 6wt% fuel oil (FO). ANFO can, however, comprise a range of fuel ratios with AN >90% and FO <10%, supplemented with dyes <0.99% ⁽²⁴⁾.

An ANFO mixture containing 5.6% oil by weight is said to be “oxygen balanced” and will produce the minimum quantity of toxic fumes when detonated. Mixtures with too much fuel tend to produce increased levels of CO and those with too little fuel produce increased levels of NO_x (9).

The nonstoichiometric ANFO composition, that is poor fuel balance, will lead to non-ideal detonations producing more toxic fumes of NO, NO₂, CO and methane.

The risk of non-ideal fuel balance is increased with used oil when compared to virgin oil due to contaminants and metals that may possibly cause a deviation in the chemical reactions that occur during the blast (7).

3.3 Sleep times

Detonation of explosives that have been unused for periods (sleep times) beyond recommended limits may lead to degradation of product through changes to the composition of the ANFO. This can contribute to elevated levels of post-blast emissions.

This effect has been shown to be more prominent in ANFO mixtures where the FO component comprises used oil containing metal and chemical contaminants. In particular, a study by Oxley *et al* (24) has demonstrated that ammonium nitrate begins to decompose more quickly with used oil, with elevated N₂ to N₂O ratios observed through detonation.

4 Health, Safety & Environmental Considerations

- *It is not fully understood in what ways contamination of fuel oil may cause diversions from the ideal chemical reaction series, potentially increasing the risk of unplanned detonation*
- *Wicking of fuel oil from ANFO and AN dissolution are well-known phenomena. Where the ANFO product comprises used fuel oil, there is an increased risk of land and/or water contamination through heavy metals and other chemicals leaching into the ground.*
- *Human health risks from fumes associated with underground mining have been studied however for surface blasting are largely unknown. However, it is possible that exposure risk is increased due to elevated levels post-blast fumes when the ANFO is manufactured with used fuel oil.*
- *As contaminants can catalyse an exothermic reaction, the incorporation of used fuel oil in ANFO presents a higher risk of self-detonation and product instability.*
- *Another consequence of oil wicking and AN dissolution is the formation of heterogeneities in the ANFO composition, reducing the detonation velocity of the explosive and thus adversely affecting the detonation performance.*
- *Used oils for use in explosives such as in ANFO, are not currently considered by Product Stewardship (Oil) Act and its associated quality specifications*

4.1 Introduction

The health, safety and environmental risks associated with ANFO explosives storage and use are not largely reported in published literature. Of the published literature that has been reviewed for this literature review, the studies are predominantly bench-scale laboratory tests, with little field data on contaminants within specific industries being reported.

Additionally, as the health and environmental implications of fuel oil in ANFO are not well understood, caution should be applied in extending findings to use of used oil in explosives. In particular, it is not fully understood:

- In what ways contamination of fuel oil component of explosives may cause diversions from the ideal chemical reaction series, potentially increasing the risk of unplanned detonation
- To what extent deviations in the ANFO mixture due to used oil composition can lead to increased NO_x production
- The impact of ‘sleep times’ on used fuel oil composition through degradation, in addition to the uncertainty of initial composition

4.2 Environmental risks

Many of these components and contaminants of used oil have been reported to have carcinogenic, mutagenic, and/or toxic effects on humans and other organisms in the environment (17).

These include: particulate matter; polycyclic aromatic hydrocarbons (PAHs); BTEX suite of organic volatiles; heavy metal compounds; and potential for PCB, dioxin and furans as outlined in Section 2.2. The ANZECC Water quality guidelines outlines limits of contaminants in water and sediment receiving environments as well as potential levels associated with ecotoxicity of biota (refer to Appendix B). Many of the contaminants of used oil have receiving environment limits set to minimise environmental harm.

The pathway of exposure for environmental risks from ANFO are associated with the storage, loading and in-situ placement of the ANFO explosive itself as well as the impacts of the ANFO blast i.e. chemical release from the ANFO explosion.

4.2.1 Storage, loading and in-situ placement

Dry, soft, and porous overburden may wick away significant amounts of fuel oil from ANFO during sleep times or long intervals between explosive loading and firing (25).

Studies have demonstrated that up to 25% of the fuel component can be lost from a loaded ANFO charge into the surrounding ground over a 30-day period due to wicking. Mine blasts are commonly 'slept' for this amount of time, giving ample opportunity for used oil to leach into the ground, groundwater and to surrounding ecosystems.

Due to the presence of heavy metal and chemical contaminants in used oil, there is a risk of contaminating land with these pollutants as a result of wicking during sleep times. When compared to uncontaminated virgin oil, the resultant environmental risk is significantly higher when using used oil.

4.2.2 Blast activities

Undetonated ANFO can lead to the dispersion of ammonia and nitrate in the environment, which could have either short or long-term toxic effects on biota. A study in Canada found concentrations of nitrate in mine effluents in the range of 25 to 300 mg/L, which is well above the local environmental regulator (CCME) criteria for the protection of aquatic life (13 to 16 mg/L). The concentration of ammonia from the same study was found to vary from 10 to 40 mg/L, which is also well above the CCME criteria for the protection of aquatic life of 0.019 mg/L (26). The presence of nitrate in aquatic environments will cause eutrophication of waterways, potential algal blooms, representing negative and possible long-term impacts to the water environment.

As discussed in Section 3.2.1, a potential cause of post-detonation NO_x fumes from ANFO is that the mix consisted of a poor fuel balance, or that boreholes are wet. If under-fuelling occurred as a result of the use of used oil, the production of NO_x may be expected due to incomplete reduction of the nitrates to nitrogen.

The National Pollutant Inventory notes that oxides of nitrogen are rapidly broken down by reacting with other substances found in the air. Nitrogen dioxide can form nitric acid in sunlight, and is a major constituent of acid rain, tropospheric ozone and smog. Nitrogen oxides react in the soil and the water to nitric acid (27). The lowered pH in the groundwaters and soil can have harmful effects, possibly even death, on a variety of biological systems (27).

4.3 Health and safety risks

4.3.1 Exposure to emissions

Research and testing has largely focussed on underground mining operations (28). Human health risk and impacts during storage, transport and blasting of ANFO blast products are largely unknown. The following review considers the potential constituents present in the ANFO product and blast.

Safe Work Australia – Workplace exposure standards (29) has identified Hazardous chemicals are substances, mixtures and articles that can pose a significant risk to health and safety if not managed correctly. They may have health *hazards*, physical *hazards* or both. The following are included on the list:

- include benzopyrene, benzantracene, and chrysene
- organic volatile contaminants that may be found in used oil include benzene, ethylbenzene, toluene and xylenes (BETX) and naphthalene (17)
- metals, including zinc, lead, cadmium, barium, iron, copper, chromium, nickel
- zinc diaryl or dialkyl dithiophosphates, molybdenum disulphide, zinc dithiophosphate, heavy-metal soaps and other organometallic compounds which contain heavy metals (18), , acids (esters, peroxides) (16)
- potential for PCB, dioxin and furans.

Safe Work Australia sets the workplace exposure standards for airborne contaminants and drinking water guidelines in Australia including for oxides of nitrogen (NO_x) (27) and carbon monoxide (CO), to protect human health.

Carbon monoxide has a maximum eight hour time weighted average (TWA) of 30ppm; nitrogen dioxide of 3ppm; nitric oxide of 25ppm; and nitrous oxide of 25ppm (27). Nitrogen dioxide has a threshold limit value of 5 ppm for short-term exposure (STEL) (27), which is comparable to hydrogen cyanide by the US EPA. (30).

Blasters working in underground or confined environments have long been aware of the hazards of these gases and must ensure adequate ventilation to quickly disperse them below harmful levels. Numerous measurements of NO_x in underground mines in the USA from AN-based explosive have consistently shown hazardous concentration levels. (31). The concentrations of NO_2 , NO and CO that are considered “Immediately Dangerous to Life or Health” (IDLH) are 20, 100, and 1,200 ppm respectively, according to the US EPA National Institute for Occupational Safety and Health.

Given that elevated levels of post-blast fumes have been associated with the use of used oil in ANFO products, the risk of exposure to those fumes may correspondingly increase.

From the literature review undertaken, it appears inconclusive whether known contaminants within used oil are transferred into ANFO blast fumes. However heavy metal contaminants will not be destroyed during the ANFO blast reaction, and are therefore likely released into the surrounding environment, on the land or in nearby waterways.

Drinking water standards for Nitrites have a maximum eight hour time weighted average (TWA) of 3mg/L for health purposes while Nitrates are 50mg/L for health purposes for infants <3mths, otherwise 100mg/L (27).

4.3.2 **Unplanned detonation**

AN and FO are not considered explosives in isolation, however, in correctly mixed ratios, the resultant product is a high-power explosive. The addition of reactive contaminants to ANFO, introduced through the used oil component or introduced during handling or storage can present a risk of unplanned explosion (8)

The sensitivity of contemporary bulk explosives relies on the presence of voidage. Voidage provides local “hot spots” within the explosive matrix that concentrate heat and act as localised points of initiation in the charge column. (32) ANFO may become sensitive due to increased levels of impurities from the used oil component, and this has been found to be of particularly high risk in hot conditions (8). Various research papers have raised concerns regarding ANFO thermal stability and unplanned explosions. A paper by Ruhe and Bajpayee (8) stated that the worst-case concern is that, warmed in storage, the temperature of ANFO made with used oil could rise due to self-reactivity and reach the point of self-detonation. Self-reactivity can arise due to the presence of other contaminants that could catalyse an exothermic reaction – be it within the mixture or stored near AN or ANFO.

The presence of zinc from galvanized steel near ANFO has also been suggested to lower the temperature at which the exothermic reaction begins to occur (as low as 106°C) (8). Zinc can be a commonly introduced contaminant in the course of manufacturing, handling, and storing of oils, AN, and ANFO. Zinc compounds are used as additives in lubricating oils. New (detergent-type) engine oil contains about 0.15% zinc. There is a possible exposure to galvanized sheet metal and pipe

fittings in tanks, bins, chutes, etc. associated with the transport and storage of ANFO or AN.

Sensitivity can also arise at some low temperatures (such as winter ambient conditions at northern mines). Research by Ruhe and Bajpayee also found that in mass storage of ANFO, the pressure and temperature can rise at a higher rate than it can dissipate to the point where the ANFO could burn and possibly detonate. Their recommendation is that ANFO mixtures made from used oil be evaluated for thermal stability before large-scale field use, especially mixtures intended to be stored under high ambient temperature conditions (8).

Ammonium nitrate, and thus ANFO, can also become less stable and at greater risk of detonation due to exposure to chloride and metal contaminants, a decrease in pH (increased acidity), or if bubbles are permitted to form in molten ammonium nitrate or solutions of ammonium nitrate. As the presence of contaminants can catalyse an exothermic reaction, the incorporation of used oil in ANFO presents a higher risk of self-detonation and product instability.

4.4 Incomplete destruction and blast performance

Key conditions that present a risk to incomplete destruction of used oil in ANFO blast products include poor fuel balance and wicking that results in heterogeneities in ANFO product.

These ANFO blasts that do not reach full detonation, due to poor fuel balance or leakages from ANFO, are also known to produce post-blast NO_x fumes and leave undetonated product in the affected vicinity of the blast. When compared to virgin oil, used oil presents an increased risk of contamination due to proliferation of chemicals and incomplete destruction of used oil contaminants when used in the ANFO mixture. Heavy metals for instance cannot be destroyed by temperature and are therefore emitted.

Studies by Ruhe et al evaluated the potential for oil and nitrates to leak out of ANFO mixtures into soil, to determine the short- and long-term effects on the environment. The results identified that a common issue related to dissolution of AN and oil wicking (explored further in Section 4.2) is that they lead to the formation of heterogeneities in the ANFO composition, which in turn decrease the detonation velocity of the explosive, adversely affecting the detonation performance of ANFO and increasing the risk of incomplete detonation. With incomplete detonation comes the potential risk of incomplete destruction of these contaminants found within the used oil component of ANFO.

The contamination risks outlined above can be contrasted with the destruction of waste oil through purpose-built thermal destruction facilities, in which conditions, temperature and residence time are controlled to fully react and destroy contaminants. In these facilities emissions are also monitored to ensure compliance. The contamination risk can be reduced also with the practice of recycling and re-refining used oil, where the removal of contaminants from used oil and effective product testing against set specifications occurs.

5 Further investigations

Further investigations and studies that would support informing AORA in evaluating the risk and impacts to environment, health and safety associated with ANFO blast products:

- **Simulation and testing:** Simulation of the ANFO blast to investigate the health and environmental risks, as well as optimisation of blast activities has often been limited to laboratory testing that is unable to adequately simulate the unique on-site conditions (33). An outline of opportunities and potential limitations related to simulation and testing, as well as re-refining of oil, are presented in the Section 5.1 below.
- **Regulatory requirements:** Utilising the used oil as a raw material in producing base oil is a key re-refining method and the focus of AORA member companies. These re-re-refining techniques appear to have a greater degree of prescriptive regulation around product quality and environmental monitoring. Details related to re-refining activities are outlined in Section 4.2 below.

5.1 Simulation and testing

Research on the chemical products, blast fumes and risk of incomplete detonation has largely been limited to laboratory testing and computer simulation. This often involves laboratory determinations of toxic fumes from explosives, consisting of detonating a small quantity of explosives in a small chamber followed by sampling and analysis of the residual fumes (including Crawshaw-Jones, Bichel Gage, and Dolgov Bomb tests). However, for ANFO the levels of NO_x produced in laboratory have been found to be less than those in on-site (31).

One challenge associated with laboratory testing is the inability to reproduce consistent detonation conditions as on a mine-site (due to non-homogenous ANFO mixtures), and confinement within the laboratory affects the composition of the expanded product. Additionally, due to small expansion volumes in the laboratory setting, higher residual pressure build-up can lead to condensation of water and removal of NO_x fumes by absorption. Theoretical models to calculate the ideal detonation properties of ANFO use computational methods, however, there are unknowns regarding the exact gas mixtures, pressures and temperatures actually occurring with explosives as these are hard to measure on site (31). The degree of confinement plays an important role in determining the detonation conditions and the composition of the expanded detonation products (25).

Therefore, it is not generally possible to extrapolate quantitative toxic fumes data to mine site conditions, and measurements of fumes produced by blasts in one mine tell us little about the fumes that would be produced for a different blast pattern in different material at another mine (25).

From preliminary engagement with academic researchers, the University of Wollongong may be the only explosives lab in Australia. However, they do not produce explosions as part of experiments. Instead they facilitate "pressure simulation" blasts largely to estimate the physical impacts for structural engineering purposes (7).

Outside of Australia, some military facilities test blasts in laboratory for defence force purposes, though the findings from these studies are not made publicly available. The opportunity to undertake experiments in open fields using Australian Defence Force land, where detonation exercises are currently conducted, may offer an opportunity for future research.

5.2 Re-refining engine oil

Engine oil is used as a thin, lubricating layer to ensure the constantly moving metal parts of internal combustion engines do not come into contact with one another, thereby preventing wear and reducing friction to minimise heat damage. Oil also serves to keep surfaces clean, facilitate start-up and reduce corrosion. Over time, breakdown by-products (including carbon and soot), and heavy metals from engine wear, build up as contaminants in the oil and reduce its effectiveness. The performance-enhancing additives in engine oil also become depleted with wear, further reducing effectiveness with continued use.

On the other hand, the physical properties of the oil itself do not degrade. By removing contaminants through re-refining processes, it is possible to recover a new "base oil", which can then be mixed with fresh additives to produce oil having the same effectiveness as the original product. The applications of this product could include simple use in machinery again or, alternatively, incorporation in ANFO as the FO instead of virgin oil or untreated used oil.

According to the US EPA, one gallon (3.8 litres) of used motor oil provides 2.5 quarts (2.4 litres) of re-refined oil, whereas 42 gallons (159 litres) is required to produce the same amount of virgin product. Re-refining oil also requires less energy per volume of product than producing base stock from crude oil (34). Further, in Australia, the recycling of used oil is incentivised through the Product Stewardship for Oil Scheme (PSO) and administered under the *Product Stewardship (Oil) Regulations 2000* ("the Regulations") (13).

However, while the PSO may encourage the recycling of used oil when compared against conventional disposal, the incentive to re-refine oil instead of using untreated used oil in ANFO may not be as strong, when considering the relative requirements of each activity. The Regulations provide specific requirements for the quality of the re-refined oil product (see list reproduced in Appendix A). By contrast, the requirements according to AS2187.2 for fuel oil in ANFO are merely that it shall be "clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate".

Of note, AORA has stated that all members claiming Category 1 PSO benefits are required to send re-refined oil for review and testing twice a year, despite being a substantially clean product, whereas no such requirement appears to be placed on the use of used oil in ANFO (35). A higher burden also exists on recycling operations in terms of environmental monitoring compared to use in ANFO. In view of the potential health, safety, environmental and performance concerns associated with used oil in ANFO, it may be that there is an undesirable balance of incentives and/or lack of effective regulation to use clean virgin or re-refined oil in ANFO compared with untreated used oil.

6 Conclusions

Key findings:

- The requirements according to AS2187.2 for fuel oil in ANFO are merely that it shall be “clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate”.
- Used oil is identified as a hazardous waste by the *Hazardous Waste (Regulation of Exports and Imports) Act 1989*. This Act limits the trade of used oil as a waste for final disposal and encourages recycling, reclamation and recovery of energy, though this does not include direct incineration.
- The Basel Convention Technical Guidelines on Waste Oils from Petroleum Origins and Sources (Y8) identifies that lubricating oils contain contamination from their use that can cause health and safety problems for humans (including cancer), harm to the environment, or react after disposal to have these effects.
- Untreated Used oil contains many chemicals that are hazardous to human health and the environment if not managed competently. These contaminants include dioxins and furans, heavy metals, chlorinated or sulphonated contaminants and polycyclic aromatic hydrocarbons.
- The introduction of impurities to ANFO through contaminants in used oil, provides a pathway for contaminants to be released to the environment. As the conditions in a blast are uncontrolled it is unlikely that emissions will achieve environmentally sound emission standards. It is also unknown if chemicals such as dioxins and furans are formed due to the temperature/residence time in the blasting process.
- During an ANFO blast, the contaminants in used oil may cause an increase in the side reactions that occur during detonation, potentially resulting in poor blast performance, elevated post-blast NO_x fumes and increased risk of unplanned detonation (7) (8).
- It is not fully understood in what ways contamination of ANFO with used oil may cause diversions from the ideal ANFO blast chemical reaction series, potentially increasing the risk of unplanned detonation.
- Although workplace exposure standards exist for NO_x and CO, human health risks from fumes of surface blasting are largely unknown as most investigation has focussed on underground mining, with more confined ventilation spaces. It is possible that exposure risk is increased due to elevated levels of post-blast fumes when the ANFO is manufactured with used oil.
- Further investigations and studies are required to better understand the risk of contaminants in untreated used oil and impacts to environment, health and safety associated with ANFO blast products.
- Further investigation and legal opinion may be beneficial for determining if the use of used oil in ANFO explosive mixtures could be considered a particular case of incineration of hazardous waste and as such the used oil product would be subjected to product specification and quality control and potential emissions controls to achieve environmentally sound emissions standards in line with the Basel conventions technical guidelines recommendations. (16 pp. 25,33)
- Used oils for use in explosives such as in ANFO, are not currently considered by Product Stewardship (Oil) Act and its associated quality specifications

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Appendix A

Product Stewardship (Oil)
Regulations 2000

A1 Requirements under the Product Stewardship (Oil) Regulations 2000

The Product Stewardship for Oil Scheme (PSO) was introduced by the Australian Government in 2001 to incentivise greater used oil recycling. The general framework and benefit entitlements of the PSO scheme are set out in the *Product Stewardship (Oil) Act 2000*. This includes a levy-benefit system, where an 8.5 cents per litre levy on new oil helps fund benefit payments to used oil recyclers.

In order to be entitled to a product stewardship (oil) benefit, a producer must be registered for entitlement, and:

- have an ABN or provide evidence of having applied for an ABN;
- have an excise manufacturing licence under the Excise Act 1901; and
- comply with relevant Australian and State/Territory legislation and requirements (particularly environmental criteria).

The recycler must undertake recycling prior to the end use and the final product must be used or sold for end use (i.e., for the recycler to be considered for benefits, the used oil cannot be simply processed and stockpiled).

The *Product Stewardship (Oil) Regulations 2000* (“the Regulations”) set out specific rates of the benefits and levies, and also sets out minimum health, safety and environment requirements to be eligible. According to the Regulations, the purpose of the criteria in Schedule 1 is to “ensure that re-refined base oil, for which a product stewardship benefit is payable, is of a quality that is not damaging to the health and safety of workers and users of the oil”.

The requirements for re-refined base oil according to the Regulations are relatively heavily prescribed. By contrast, the requirements according to AS2187.2 for fuel oil in ANFO are merely that it shall be “clean, with a closed-cup flashpoint of 60.5°C or higher. The oil shall be of such a viscosity that it is readily absorbed by the ammonium nitrate”.

Schedule 1 is listed on the next page.

Schedule 1 Re-refined base oil criteria

Schedule 1—Re-refined base oil criteria

(regulation 4, table, item 1)

Note: The purpose of the criteria in this Schedule is to ensure that re-refined base oil, for which a product stewardship benefit is payable, is of a quality that is not damaging to the health and safety of workers and users of the oil.

1 Mutagenicity

The oil must be non-carcinogenic, demonstrated by having a mutagenicity index of less than 1 using the Modified Ames Test.

2 Poly-aromatic hydrocarbons

- (1) The oil must contain less than the following for each kilogram of oil:
 - (a) 10 mg of benzo(a)pyrene;
 - (b) 10 mg of dibenz(ah)anthracene;
 - (c) 100 mg of benz(a)anthracene;
 - (d) 100 mg of benzo(b)fluoranthene;
 - (e) 100 mg of benzo(k)fluoranthene;
 - (f) 100 mg of chrysene;
 - (g) 100 mg of indeno(123-cd)pyrene.
- (2) The total amount of poly-aromatic hydrocarbons mentioned in subclause (1) that the oil contains must be less than 400 mg for each kilogram of oil.
- (3) The total amount of all poly-aromatic hydrocarbons that the oil contains (including poly-aromatic hydrocarbons mentioned in subclause (1)) must be less than 1 000 mg for each kilogram of oil.

3 Polychlorinated biphenyls

The oil must contain less than 2.0 mg of polychlorinated biphenyls for each kilogram of oil.

4 Polychlorinated dibenzo-p-dioxins

The total amount of dioxins and furans that the oil contains must be less than 10 picograms Toxic Equivalent for each gram of oil.

5 Total acid number

The oil must have a total acid number of less than 0.07 mg of potassium hydroxide for each gram of oil.

6 Heavy metals

The oil must contain less than the following for each kilogram of oil:

Re-refined base oil criteria Schedule 1

- (a) 5 mg of arsenic;
- (b) 2 mg of cadmium;
- (c) 10 mg of chromium;
- (d) 100 mg of lead.

7 Appearance

The oil must have a clear and bright appearance.

Appendix B Definitions (Legislation and Standards)

6.1.1 Hazardous Waste management

Used oil is considered a hazardous waste as described in the Australian Government Hazardous Waste Data and Reporting Standard 2017 (2), where hazardous waste is defined as *Waste that, by its characteristics, poses a threat or risk to public health, safety or to the environment (36). In national reporting this term is taken to correspond with:*

- *wastes that cannot be imported or exported from Australia without a permit under the Hazardous Waste (Regulation of Exports and Imports) Act 1989*
- *wastes that any jurisdiction regulates as requiring particularly high levels of management and control, namely: regulated waste (Queensland); trackable waste (New South Wales); prescribed waste (Victoria); listed waste (South Australia and NT); or controlled waste (ACT, Tasmania and Western Australia)*
- *additional wastes nominated as hazardous by the Australian Government (37).*

In addition, waste that has hazardous characteristics and has been stored on a site for more than one year should be considered hazardous waste (2).

International movement and disposal

The international movement and disposal of hazardous waste is governed by the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their disposal (10), which Australia ratified in 1992 (3). The *C'wlth Hazardous Waste (Regulation of Exports and Imports) Act 1989* gives effect to the convention within Australian jurisdiction.

Waste oil is identified as a hazardous waste by the *Hazardous Waste (Regulation of Exports and Imports) Act 1989*² where waste oil includes used oil as defined in this report. Hazardous wastes are defined as those that exhibit any of the characteristics described in Annex III of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their disposal (10) (which Australia ratified in 1992 (3) which are:

- Explosive;
- Flammable liquids and solids;
- Poisonous;
- Toxic;
- Ecotoxic; and
- Or infectious substances.

² Available online: <https://www.environment.gov.au/protection/hazardous-waste/what-hazardous-waste>, last accessed 1/11/2020

Used oil belongs to category Y8, which is for waste mineral oils that are unfit for their originally intended use. The Basel Convention Technical Guidelines on Waste Oils from Petroleum Origins and Sources (Y8) identifies that lubricating oils contain contamination from their use, but also from the additives. They will contain various contaminants including heavy metals, combustion by-products and substances arising from the original use (10).

Used oils are considered to have the following characteristics as defined by Annex III of the Basel Convention:

- H11- Substances or wastes which, if they are inhaled or ingested or if they penetrate the skin, may involve delayed or chronic effects, including carcinogenicity;
- H12 - Substances or wastes which if released present or may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems; and
- H13 - Capable, by any means, after disposal, of yielding another material, e.g., leachate, which possesses any of the characteristics hazardous waste as described earlier in this section.

Australian interstate movement and disposal

Under the *National Environmental Protection (Movement of Controlled Waste between States and Territories) Measure 1998*, used oil meets the hazardous waste classification of J100 – Oils- Waste mineral oils unfit for their original intended use (11).

6.1.2 Oil recycling

Used oils as defined in the Product Stewardship (Oil) Act 2000 are oils (petroleum or synthetic) that have been used and that, as a result of such use, are contaminated by physical or chemical impurities (1). Used oil, in the context of this literature review, refers more specifically to waste lubricant, hydraulic or other non-terminal use oils. The recycling of used oil is incentivised through the Australian Government's Product Stewardship for Oil Scheme (PSO) and administered under the *Product Stewardship (Oil) Regulations 2000* ("the Regulations") (1).

The PSO Scheme (13) aims to encourage the environmentally sustainable management and re-refining of used oil and its re-use. The PSO incentivises higher order re-refining (and contaminant removal) and recycling by providing higher benefit payment rates for its production. This reduces the environmental risks posed by this potentially serious pollutant and ensures a long term future for oil recycling in Australia (13).

The Regulations provide specific requirements for the quality of the re-refined oil product (see list reproduced in Appendix A). Of particular note are the requirements to ensure that the re-refined oil has restrictions (ie sets upper limits) for the following range of contaminants:

- Mutagenicity;
- Polycyclic aromatic hydrocarbons (PAH's);
- Polychlorinated biphenyls;
- Polychlorinated dibenzo-p-dioxins;
- Total acid number; and
- The following heavy metals:
 - Arsenic;
 - Cadmium;
 - Chromium; and
 - Lead.

6.1.3 Used oils use for energy content

As noted in the commentary of Y8 technical guidelines of the Basel Convention (10), large volumes of waste oil is used for its energy content, as a secondary or substitute fuel. The inherent high energy content of used oil streams encourages their direct use as fuels, without any pre-treatment and processing, and without any quality control or product specification. Such direct uses do not constitute good practice, unless it can be demonstrated that combustion of the waste can be undertaken in an environmentally sound manner.

Y8 states that where used oils are used for their energy content, “every encouragement should be given to measures which improve the quality and control of this type of activity.³”. Further “it is certainly desirable that waste oils are subjected to both source and quality screening, and that products are supplied to a specification, even if only rudimentary. Where activities of this type are subject to a licence, permit or authorization system, conditions should be specified to ensure that a minimum level of control is established, and that equipment for blending, separation etc. is provided, used when necessary and maintained properly.”

Further, “Whilst many oil products are burnt without the application of clean-up technologies to the combustion gases, this may well not be acceptable for oil wastes. Such wastes may contain heavy metals, chlorinated or sulphonated contaminants, or particulate matter which would not easily burn. Incineration of such materials is likely to require emission control/gas cleaning equipment to achieve environmentally sound emission standards.⁴”

³ Available online:

<http://www.basel.int/Implementation/TechnicalMatters/DevelopmentofTechnicalGuidelines/TechnicalGuidelines/tabid/8025/Default.aspx>, paragraph 25

⁴ *ibid*, paragraph 33

Appendix C ANZECC Water Quality Guidelines

Table 3.4.1

3.4.2 How guidelines are developed for toxicants

Table 3.4.1 Trigger values for toxicants at alternative levels of protection. Values in grey shading are the trigger values applying to typical *slightly–moderately disturbed systems*; see table 3.4.2 and Section 3.4.2.4 for guidance on applying these levels to different ecosystem conditions.

Chemical		Trigger values for freshwater (µg/L ⁻¹)				Trigger values for marine water (µg/L ⁻¹)			
		Level of protection (% species)				Level of protection (% species)			
		99%	95%	90%	80%	99%	95%	90%	80%
METALS & METALLOIDS									
Aluminium	pH >6.5	27	55	80	150	ID	ID	ID	ID
Aluminium	pH <6.5	ID	ID	ID	ID	ID	ID	ID	ID
Antimony		ID	ID	ID	ID	ID	ID	ID	ID
Arsenic (As III)		1	24	94 ^c	360 ^c	ID	ID	ID	ID
Arsenic (AsV)		0.8	13	42	140 ^c	ID	ID	ID	ID
Beryllium		ID	ID	ID	ID	ID	ID	ID	ID
Bismuth		ID	ID	ID	ID	ID	ID	ID	ID
Boron		90	370 ^c	680 ^c	1300 ^c	ID	ID	ID	ID
Cadmium	H	0.06	0.2	0.4	0.8 ^c	0.7 ^a	5.5 ^{a,c}	14 ^{a,c}	36 ^{a,a}
Chromium (Cr III)	H	ID	ID	ID	ID	7.7	27.4	48.6	90.6
Chromium (CrVI)		0.01	1.0 ^c	6 ^a	40 ^a	0.14	4.4	20 ^c	85 ^c
Cobalt		ID	ID	ID	ID	0.005	1	14	150 ^c
Copper	H	1.0	1.4	1.8 ^c	2.5 ^c	0.3	1.3	3 ^c	8 ^a
Gallium		ID	ID	ID	ID	ID	ID	ID	ID
Iron		ID	ID	ID	ID	ID	ID	ID	ID
Lanthanum		ID	ID	ID	ID	ID	ID	ID	ID
Lead	H	1.0	3.4	5.6	9.4 ^c	2.2	4.4	6.6 ^c	12 ^c
Manganese		1200	1900 ^c	2500 ^c	3600 ^c	ID	ID	ID	ID
Mercury (inorganic)	B	0.06	0.6	1.9 ^c	5.4 ^a	0.1	0.4 ^c	0.7 ^c	1.4 ^c
Mercury (methyl)		ID	ID	ID	ID	ID	ID	ID	ID
Molybdenum		ID	ID	ID	ID	ID	ID	ID	ID
Nickel	H	8	11	13	17 ^c	7	70 ^c	200 ^a	560 ^a
Selenium (Total)	B	5	11	18	34	ID	ID	ID	ID
Selenium (SeIV)	B	ID	ID	ID	ID	ID	ID	ID	ID
Silver		0.02	0.05	0.1	0.2 ^c	0.8	1.4	1.8	2.6 ^c
Thallium		ID	ID	ID	ID	ID	ID	ID	ID
Tin (Inorganic, SnIV)		ID	ID	ID	ID	ID	ID	ID	ID
Tributyltin (as µg/L Sn)		ID	ID	ID	ID	0.0004	0.006 ^c	0.02 ^c	0.05 ^c
Uranium		ID	ID	ID	ID	ID	ID	ID	ID
Vanadium		ID	ID	ID	ID	50	100	160	280
Zinc	H	2.4	8.0 ^c	15 ^c	31 ^c	7	15 ^c	23 ^c	43 ^c
NON-METALLIC INORGANICS									
Ammonia	D	320	900 ^c	1430 ^c	2300 ^a	500	910	1200	1700
Chlorine	E	0.4	3	6 ^a	13 ^a	ID	ID	ID	ID
Cyanide	F	4	7	11	18	2	4	7	14
Nitrate	J	17	700	3400 ^c	17000 ^a	ID	ID	ID	ID
Hydrogen sulfide	G	0.5	1.0	1.5	2.6	ID	ID	ID	ID
ORGANIC ALCOHOLS									
Ethanol		400	1400	2400 ^c	4000 ^c	ID	ID	ID	ID
Ethylene glycol		ID	ID	ID	ID	ID	ID	ID	ID
Isopropyl alcohol		ID	ID	ID	ID	ID	ID	ID	ID
CHLORINATED ALKANES									
Chloromethanes									
Dichloromethane		ID	ID	ID	ID	ID	ID	ID	ID
Chloroform		ID	ID	ID	ID	ID	ID	ID	ID
Carbon tetrachloride		ID	ID	ID	ID	ID	ID	ID	ID
Chloroethanes									
1,2-dichloroethane		ID	ID	ID	ID	ID	ID	ID	ID
1,1,1-trichloroethane		ID	ID	ID	ID	ID	ID	ID	ID

Chapter 3 — Aquatic ecosystems

Chemical	Trigger values for freshwater (µg/L ⁻¹)				Trigger values for marine water (µg/L ⁻¹)			
	Level of protection (% species)				Level of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
1,1,2-trichloroethane	5400	6500	7300	8400	140	1900	5500 ^c	18000 ^c
1,1,2,2-tetrachloroethane	ID	ID	ID	ID	ID	ID	ID	ID
Pentachloroethane	ID	ID	ID	ID	ID	ID	ID	ID
Hexachloroethane	8	290	360	420	500	ID	ID	ID
Chloropropanes								
1,1-dichloropropane	ID	ID	ID	ID	ID	ID	ID	ID
1,2-dichloropropane	ID	ID	ID	ID	ID	ID	ID	ID
1,3-dichloropropane	ID	ID	ID	ID	ID	ID	ID	ID
CHLORINATED ALKENES								
Chloroethylene	ID	ID	ID	ID	ID	ID	ID	ID
1,1-dichloroethylene	ID	ID	ID	ID	ID	ID	ID	ID
1,1,2-trichloroethylene	ID	ID	ID	ID	ID	ID	ID	ID
1,1,2,2-tetrachloroethylene	ID	ID	ID	ID	ID	ID	ID	ID
3-chloropropene	ID	ID	ID	ID	ID	ID	ID	ID
1,3-dichloropropene	ID	ID	ID	ID	ID	ID	ID	ID
ANILINE S								
Aniline	8	250 ^a	1100 ^a	4500 ^a	ID	ID	ID	ID
2,4-dichloroaniline	0.6	7	20	60 ^c	ID	ID	ID	ID
2,5-dichloroaniline	ID	ID	ID	ID	ID	ID	ID	ID
3,4-dichloroaniline	1.3	3	6 ^c	13 ^c	85	150	190	260
3,5-dichloroaniline	ID	ID	ID	ID	ID	ID	ID	ID
Benzidine	ID	ID	ID	ID	ID	ID	ID	ID
Dichlorobenzidine	ID	ID	ID	ID	ID	ID	ID	ID
AROMATIC HYDROCARBONS								
Benzene	600	950	1300	2000	500 ^c	700 ^c	900 ^c	1300 ^c
Toluene	ID	ID	ID	ID	ID	ID	ID	ID
Ethylbenzene	ID	ID	ID	ID	ID	ID	ID	ID
o-xylene	200	350	470	640	ID	ID	ID	ID
m-xylene	ID	ID	ID	ID	ID	ID	ID	ID
p-xylene	140	200	250	340	ID	ID	ID	ID
m+p-xylene	ID	ID	ID	ID	ID	ID	ID	ID
Cumene	ID	ID	ID	ID	ID	ID	ID	ID
Polycyclic Aromatic Hydrocarbons								
Naphthalene	2.5	16	37	55	50 ^c	70 ^c	90 ^c	120 ^c
Anthracene	8	ID	ID	ID	ID	ID	ID	ID
Phenanthrene	8	ID	ID	ID	ID	ID	ID	ID
Fluoranthene	8	ID	ID	ID	ID	ID	ID	ID
Benzo(a)pyrene	8	ID	ID	ID	ID	ID	ID	ID
Nitrobenzenes								
Nitrobenzene	230	550	820	1300	ID	ID	ID	ID
1,2-dinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,3-dinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,4-dinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,3,5-trinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-methoxy-2-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-methoxy-4-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-2-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-3-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-4-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-2,4-dinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,2-dichloro-3-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,3-dichloro-5-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,4-dichloro-2-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
2,4-dichloro-2-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID

3.4.2 How guidelines are developed for toxicants

Chemical	Trigger values for freshwater (µg/L ⁻¹)				Trigger values for marine water (µg/L ⁻¹)			
	Level of protection (% species)				Level of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
1,2,4,5-tetrachloro-3-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,5-dichloro-2,4-dinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,3,5-trichloro-2,4-dinitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1-fluoro-4-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
Nitrotoluenes								
2-nitrotoluene	ID	ID	ID	ID	ID	ID	ID	ID
3-nitrotoluene	ID	ID	ID	ID	ID	ID	ID	ID
4-nitrotoluene	ID	ID	ID	ID	ID	ID	ID	ID
2,3-dinitrotoluene	ID	ID	ID	ID	ID	ID	ID	ID
2,4-dinitrotoluene	16	65 ^c	130 ^c	250 ^c	ID	ID	ID	ID
2,4,6-trinitrotoluene	100	140	160	210	ID	ID	ID	ID
1,2-dimethyl-3-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,2-dimethyl-4-nitrobenzene	ID	ID	ID	ID	ID	ID	ID	ID
4-chloro-3-nitrotoluene	ID	ID	ID	ID	ID	ID	ID	ID
Chlorobenzenes and Chloronaphthalenes								
Monochlorobenzene	ID	ID	ID	ID	ID	ID	ID	ID
1,2-dichlorobenzene	120	160	200	270	ID	ID	ID	ID
1,3-dichlorobenzene	160	260	350	520 ^c	ID	ID	ID	ID
1,4-dichlorobenzene	40	60	75	100	ID	ID	ID	ID
1,2,3-trichlorobenzene	8	3	10	30 ^c	ID	ID	ID	ID
1,2,4-trichlorobenzene	8	85	170 ^c	220 ^c	20	80	140	240
1,3,5-trichlorobenzene	8	ID	ID	ID	ID	ID	ID	ID
1,2,3,4-tetrachlorobenzene	8	ID	ID	ID	ID	ID	ID	ID
1,2,3,5-tetrachlorobenzene	8	ID	ID	ID	ID	ID	ID	ID
1,2,4,5-tetrachlorobenzene	8	ID	ID	ID	ID	ID	ID	ID
Pentachlorobenzene	8	ID	ID	ID	ID	ID	ID	ID
Hexachlorobenzene	8	ID	ID	ID	ID	ID	ID	ID
1-chloronaphthalene	ID	ID	ID	ID	ID	ID	ID	ID
Polychlorinated Biphenyls (PCBs) & Dioxins								
Capacitor 21	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1016	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1221	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1232	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1242	8	0.3	0.6	1.0	1.7	ID	ID	ID
Aroclor 1248	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1254	8	0.01	0.03	0.07	0.2	ID	ID	ID
Aroclor 1260	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1262	8	ID	ID	ID	ID	ID	ID	ID
Aroclor 1268	8	ID	ID	ID	ID	ID	ID	ID
2,3,4'-trichlorobiphenyl	8	ID	ID	ID	ID	ID	ID	ID
4,4'-dichlorobiphenyl	8	ID	ID	ID	ID	ID	ID	ID
2,2',4,5,5'-pentachloro-1,1'-biphenyl	8	ID	ID	ID	ID	ID	ID	ID
2,4,6,2',4',6'-hexachlorobiphenyl	8	ID	ID	ID	ID	ID	ID	ID
Total PCBs	8	ID	ID	ID	ID	ID	ID	ID
2,3,7,8-TCDD	8	ID	ID	ID	ID	ID	ID	ID
PHENOLS and XYLENOLS								
Phenol	85	320	600	1200 ^c	270	400	520	720
2,4-dimethylphenol	ID	ID	ID	ID	ID	ID	ID	ID
Nonylphenol	ID	ID	ID	ID	ID	ID	ID	ID
2-chlorophenol	T	340 ^c	490 ^c	630 ^c	870 ^c	ID	ID	ID
3-chlorophenol	T	ID	ID	ID	ID	ID	ID	ID
4-chlorophenol	T	160	220	280 ^c	360 ^c	ID	ID	ID
2,3-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID
2,4-dichlorophenol	T	120	160 ^c	200 ^c	270 ^c	ID	ID	ID

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Chemical		Trigger values for freshwater (µg/L ⁻¹)				Trigger values for marine water (µg/L ⁻¹)			
		Level of protection (% species)				Level of protection (% species)			
		99%	95%	90%	80%	99%	95%	90%	80%
2,5-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,6-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
3,4-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
3,5-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,3,4-trichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,3,5-trichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,3,6-trichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,4,5-trichlorophenol	T,B	ID	ID	ID	ID	ID	ID	ID	ID
2,4,6-trichlorophenol	T,B	3	20	40	95	ID	ID	ID	ID
2,3,4,5-tetrachlorophenol	T,B	ID	ID	ID	ID	ID	ID	ID	ID
2,3,4,6-tetrachlorophenol	T,B	10	20	25	30	ID	ID	ID	ID
2,3,5,6-tetrachlorophenol	T,B	ID	ID	ID	ID	ID	ID	ID	ID
Pentachlorophenol	T,B	3.6	10	17	27 ^a	11	22	33	55 ^a
Nitrophenols									
2-nitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
3-nitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
4-nitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
2,4-dinitrophenol		13	45	80	140	ID	ID	ID	ID
2,4,6-trinitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
ORGANIC SULFUR COMPOUNDS									
Carbon disulfide		ID	ID	ID	ID	ID	ID	ID	ID
Isopropyl disulfide		ID	ID	ID	ID	ID	ID	ID	ID
n-propyl sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Propyl disulfide		ID	ID	ID	ID	ID	ID	ID	ID
Tert-butyl sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Phenyl disulfide		ID	ID	ID	ID	ID	ID	ID	ID
Bis(dimethylthiocarbamyl)sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Bis(diethylthiocarbamyl)sulfide		ID	ID	ID	ID	ID	ID	ID	ID
2-methoxy-4H-1,3,2-benzodioxaphosphorin-2-sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Xanthates									
Potassium amyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Potassium ethyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Potassium hexyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Potassium isopropyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium ethyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium isobutyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium isopropyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium sec-butyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
PHTHALATES									
Dimethylphthalate		3000	3700	4300	5100	ID	ID	ID	ID
Diethylphthalate		900	1000	1100	1300	ID	ID	ID	ID
Dibutylphthalate	B	9.9	26	40.2	64.6	ID	ID	ID	ID
Di(2-ethylhexyl)phthalate	B	ID	ID	ID	ID	ID	ID	ID	ID
MISCELLANEOUS INDUSTRIAL CHEMICALS									
Acetonitrile		ID	ID	ID	ID	ID	ID	ID	ID
Acrylonitrile		ID	ID	ID	ID	ID	ID	ID	ID
Poly(acrylonitrile-co-butadiene-co-styrene)		200	530	800 ^c	1200 ^c	200	250	280	340
Dimethylformamide		ID	ID	ID	ID	ID	ID	ID	ID
1,2-diphenylhydrazine		ID	ID	ID	ID	ID	ID	ID	ID
Diphenylnitrosamine		ID	ID	ID	ID	ID	ID	ID	ID
Hexachlorobutadiene		ID	ID	ID	ID	ID	ID	ID	ID
Hexachlorocyclopentadiene		ID	ID	ID	ID	ID	ID	ID	ID

3.4.2 How guidelines are developed for toxicants

Chemical	Trigger values for freshwater (µg/L ⁻¹)				Trigger values for marine water (µg/L ⁻¹)			
	Level of protection (% species)				Level of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
Isophorone	ID	ID	ID	ID	ID	ID	ID	ID
ORGANOCHLORINE PESTICIDES								
Aldrin	8	ID	ID	ID	ID	ID	ID	ID
Chlordane	8	0.03	0.08	0.14	0.27 ^c	ID	ID	ID
DDE	8	ID	ID	ID	ID	ID	ID	ID
DDT	8	0.006	0.01	0.02	0.04	ID	ID	ID
Dicofol	8	ID	ID	ID	ID	ID	ID	ID
Dieldrin	8	ID	ID	ID	ID	ID	ID	ID
Endosulfan	8	0.03	0.2 ^a	0.6 ^a	1.8 ^a	0.005	0.01	0.02
Endosulfan alpha	8	ID	ID	ID	ID	ID	ID	ID
Endosulfan beta	8	ID	ID	ID	ID	ID	ID	ID
Endrin	8	0.01	0.02	0.04 ^c	0.06 ^a	0.004	0.008	0.01
Heptachlor	8	0.01	0.09	0.25	0.7 ^a	ID	ID	ID
Lindane		0.07	0.2	0.4	1.0 ^a	ID	ID	ID
Methoxychlor	8	ID	ID	ID	ID	ID	ID	ID
Mirex	8	ID	ID	ID	ID	ID	ID	ID
Toxaphene	8	0.1	0.2	0.3	0.5	ID	ID	ID
ORGANOPHOSPHORUS PESTICIDES								
Azinphos methyl		0.01	0.02	0.05	0.11 ^a	ID	ID	ID
Chlorpyrifos	8	0.0004	0.01	0.11 ^a	1.2 ^a	0.0005	0.009	0.04 ^a
Demeton	ID	ID	ID	ID	ID	ID	ID	ID
Demeton-S-methyl	ID	ID	ID	ID	ID	ID	ID	ID
Diazinon		0.0003	0.01	0.2 ^a	2 ^a	ID	ID	ID
Dimethoate		0.1	0.15	0.2	0.3	ID	ID	ID
Fenitrothion		0.1	0.2	0.3	0.4	ID	ID	ID
Malathion		0.002	0.05	0.2	1.1 ^a	ID	ID	ID
Parathion		0.0007	0.004 ^c	0.01 ^c	0.04 ^a	ID	ID	ID
Profenofos	8	ID	ID	ID	ID	ID	ID	ID
Temephos	8	ID	ID	ID	ID	0.0004	0.05	0.4
CARBAMATE & OTHER PESTICIDES								
Carbofuran		0.06	1.2 ^a	4 ^a	15 ^a	ID	ID	ID
Methomyl		0.5	3.5	9.5	23	ID	ID	ID
S-methoprene	ID	ID	ID	ID	ID	ID	ID	ID
PYRETHROID								
Deltamethrin	ID	ID	ID	ID	ID	ID	ID	ID
Esfenvalerate	ID	0.001 ^a	ID	ID	ID	ID	ID	ID
HERBICIDES & FUNGICIDES								
Bypyridilium herbicides								
Diquat		0.01	1.4	10	80 ^a	ID	ID	ID
Paraquat	ID	ID	ID	ID	ID	ID	ID	ID
Phenoxyacetic acid herbicides								
MCPA	ID	ID	ID	ID	ID	ID	ID	ID
2,4-D		140	280	450	830	ID	ID	ID
2,4,5-T		3	36	100	290 ^a	ID	ID	ID
Sulfonylurea herbicides								
Bensulfuron	ID	ID	ID	ID	ID	ID	ID	ID
Metsulfuron	ID	ID	ID	ID	ID	ID	ID	ID
Thiocarbamate herbicides								
Molinate		0.1	3.4	14	57	ID	ID	ID
Thiobencarb		1	2.8	4.6	8 ^c	ID	ID	ID
Thiram		0.01	0.2	0.8 ^c	3 ^a	ID	ID	ID
Triazine herbicides								
Amitrole	ID	ID	ID	ID	ID	ID	ID	ID
Atrazine		0.7	13	45 ^c	150 ^c	ID	ID	ID

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Chemical	Trigger values for freshwater (µg/L ⁻¹)				Trigger values for marine water (µg/L ⁻¹)			
	Level of protection (% species)				Level of protection (% species)			
	99%	95%	90%	80%	99%	95%	90%	80%
Hexazinone	ID	ID	ID	ID	ID	ID	ID	ID
Simazine	0.2	3.2	11	35	ID	ID	ID	ID
Urea herbicides								
Diuron	ID	ID	ID	ID	ID	ID	ID	ID
Tebuthiuron	0.02	2.2	20	160 ^c	ID	ID	ID	ID
Miscellaneous herbicides								
Acrolein	ID	ID	ID	ID	ID	ID	ID	ID
Bromacil	ID	ID	ID	ID	ID	ID	ID	ID
Glyphosate	370	1200	2000	3600 ^a	ID	ID	ID	ID
Imazethapyr	ID	ID	ID	ID	ID	ID	ID	ID
Isoxynil	ID	ID	ID	ID	ID	ID	ID	ID
Metolachlor	ID	ID	ID	ID	ID	ID	ID	ID
Sethoxydim	ID	ID	ID	ID	ID	ID	ID	ID
Trifluralin	B	2.6	4.4	6	9 ^a	ID	ID	ID
GENERIC GROUPS OF CHEMICALS								
Surfactants								
Linear alkylbenzene sulfonates (LAS)	65	280	520 ^c	1000 ^c	ID	ID	ID	ID
Alcohol ethoxylated sulfate (AES)	340	660	850 ^c	1100 ^c	ID	ID	ID	ID
Alcohol ethoxylated surfactants (AE)	50	140	220	360 ^c	ID	ID	ID	ID
Oils & Petroleum Hydrocarbons	ID	ID	ID	ID	ID	ID	ID	ID
Oil Spill Dispersants								
BP 1100X	ID	ID	ID	ID	ID	ID	ID	ID
Corexit 7664	ID	ID	ID	ID	ID	ID	ID	ID
Corexit 8667		ID	ID	ID	ID	ID	ID	ID
Corexit 9527	ID	ID	ID	ID	230	1100	2200	4400 ^a
Corexit 9550	ID	ID	ID	ID	ID	ID	ID	ID

Notes: Where the final water quality guideline to be applied to a site is below current analytical practical quantitation limits, see Section 3.4.3.3 for guidance.

Most trigger values listed here for metals and metalloids are *High reliability* figures, derived from field or chronic NOEC data (see 3.4.2.3 for reference to Volume 2). The exceptions are *Moderate reliability* for freshwater aluminium (pH >6.5), manganese and marine chromium (III).

Most trigger values listed here for non-metallic inorganics and organic chemicals are *Moderate reliability* figures, derived from acute LC₅₀ data (see 3.4.2.3 for reference to Volume 2). The exceptions are *High reliability* for freshwater ammonia, 3,4-DCA, endosulfan, chlorpyrifos, estenvalerate, tebuthiuron, three surfactants and marine for 1,1,2-TCE and chlorpyrifos.

^a = *High reliability* figure for estenvalerate derived from mesocosm NOEC data (no alternative protection levels available).

^A = Figure may not protect key test species from acute toxicity (and chronic) — check Section 8.3.7 for spread of data and its significance. 'A' indicates that trigger value > acute toxicity figure; note that trigger value should be <1/3 of acute figure (Section 8.3.4.4).

^B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered (see Sections 8.3.3.4 and 8.3.5.7).

^C = Figure may not protect key test species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species) — check Section 8.3.7 for spread of data and its significance. Where grey shading and 'C' coincide, refer to text in Section 8.3.7.

^D = Ammonia as TOTAL ammonia as [NH₃-N] at pH 8. For changes in trigger value with pH refer to Section 8.3.7.2.

^E = Chlorine as total chlorine, as [Cl₂]; see Section 8.3.7.2.

^F = Cyanide as un-ionised HCN, measured as [CN⁻]; see Section 8.3.7.2.

^G = Sulfide as un-ionised H₂S, measured as [S²⁻]; see Section 8.3.7.2.

^H = Chemicals for which algorithms have been provided in table 3.4.3 to account for the effects of hardness. The values have been calculated using a hardness of 30 mg/L CaCO₃. These should be adjusted to the site-specific hardness (see Section 3.4.3).

^J = Figures protect against toxicity and do not relate to eutrophication issues. Refer to Section 3.3 if eutrophication is the issue of concern.

ID = Insufficient data to derive a reliable trigger value. Users advised to check if a low reliability value or an ECL is given in Section 8.3.7.

T = Tainting or flavour impairment of fish flesh may possibly occur at concentrations below the trigger value. See Sections 4.4.5.3/3 and 8.3.7.

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Table 3.5.1 Recommended sediment quality guidelines^a

Contaminant	ISQG-Low (Trigger value)	ISQG-High
METALS (mg/kg dry wt)		
Antimony	2	25
Cadmium	1.5	10
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1
Nickel	21	52
Silver	1	3.7
Zinc	200	410
METALLOIDS (mg/kg dry wt)		
Arsenic	20	70
ORGANOMETALLICS		
Tributyltin ($\mu\text{g Sn/kg dry wt.}$)	5	70
ORGANICS ($\mu\text{g/kg dry wt.}$)^a		
Acenaphthene	16	500
Acenaphthalene	44	640
Anthracene	85	1100
Fluorene	19	540
Naphthalene	160	2100
Phenanthrene	240	1500
Low Molecular Weight PAHs ^b	552	3160
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Dibenzo(a,h)anthracene	63	260
Chrysene	384	2800
Fluoranthene	600	5100
Pyrene	665	2600
High Molecular Weight PAHs ^c	1700	9600
Total PAHs	4000	45000
Total DDT	1.6	46
p,p'-DDE	2.2	27
o,p'- + p,p'-DDD	2	20
Chlordane	0.5	6
Dieldrin	0.02	8
Endrin	0.02	8
Lindane	0.32	1
Total PCBs	23	—

^a Primarily adapted from Long et al. (1995);^b Normalised to 1% organic carbon;^c Low molecular weight PAHs are the sum of concentrations of acenaphthene, acenaphthalene, anthracene, fluorene, 2-methylnaphthalene, naphthalene and phenanthrene; high molecular weight PAHs are the sum of concentrations of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene.