MWH

End-of-Life Tyre Management: Storage Options

Final Report for the Ministry for the Environment

July 2004

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Ministry for the Environment
End-of-life Tyre Management: Storage Options

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1 Introduction

1.1 Background

New Zealand currently generates approximately 4 million end-of-life tyres per annum, which equates to approximately 36,000 tonnes of waste. These tyres are currently landfilled, stockpiled or used as silage cover in the agricultural industry. The Sustainable Industry Group of the Ministry for the Environment is working with councils, the tyre industry and other stakeholders to ensure a sustainable management regime for end-of-life tyres.

Ministry for the Environment (the Ministry) would ultimately like to see a high proportion of tyres recycled or utilised as an energy source. It is not yet clear when or if demand for tyres will increase to the point where they are sought after by recyclers. In the short to medium term, the Ministry seeks to encourage environmentally appropriate management of end-of-life tyres.

Appropriate management may include use for engineering purposes, storage or final disposal of end-of-life tyres in specially created monofills, or above ground storage where land owners bank on an eventual increase in the economic value of end-of-life tyres. Factors to be addressed in developing appropriate management practices include the following:

- any leachate associated with engineering activities may need to be managed
- storage and disposal facilities need be designed to ensure that environmental risks such as fire and leachate generation are eliminated or managed
- the design of storage facilities and monofills should also ensure that the potential for deterioration is minimised and that the tyres can be retrieved relatively easily when, and, or if their value as a recoverable resource increases
- storage facilities may need to be covered by bonds or other financial risk management tools, in case the value of tyres does not increase and funds need to be available to cover final disposal.

As an input to its work, the Ministry requires information on international research and on current best practice with regard to in-ground and above ground storage and disposal, and its application to New Zealand. The project brief for this investigation is given in Appendix B.

1.2 Scope

The Ministry is seeking short- to medium-term solutions for the management of end-of-life tyres. In particular, the Ministry is facilitating an investigation into best practice for the in-ground or above ground storage of end-of-life tyres.

This report records the review work undertaken by MWH, which includes:

- reviewing relevant literature on end-of-life tyres and their management
- assessing in-ground and above ground management solutions in the context of relevant New Zealand legislation and Ministry for the Environment guidelines
- identifying best practice in relation to in-ground and above ground tyre storage.

2. Research Methodology

2.1 Preliminary Literature Review

A preliminary literature review of recent journals, conference papers, theses, government reports, newspapers and periodicals was carried out by Nerac Incorporated (Nerac) on behalf of MWH. Nerac performed two keyword searches. The first search on "use or disposal of old used tires (sic.)" provided 17 references and the second on "storage of old used tires (sic.)" provided 10 references. The majority of the references were not related directly to storage. The low number of references returned suggests there is little published research material related directly to tyre storage.

2.2 Review of *Technical Guidelines on the Identification and Management of Used Tyres*

This document, produced by the Technical Working Group of the Basel Convention in 1999, provided the starting point for the research. It provided a description of tyre properties, an overview of potential environmental risks of tyre storage, an outline of various reprocessing options for used tyres and a description of landfilling and stockpiling used tyres. This document was poorly referenced to source material; however references were followed up when given.

2.3 Preliminary Outline for Guideline on Management of End-of-life Tyres

A preliminary outline structure of a best practice guideline for the management of end-of-life tyres was prepared by MWH and is presented in Appendix C. This guideline set the context for the investigation to ensure the research was focused on the output required by the Ministry.

2.4 Review of Previous MWH Work

MWH has had limited experience in the area of tyre storage. Research was carried out in 2003 on the development of a regional waste recovery/processing sector in the Wellington region.[1] The research included reprocessing technologies for end-of-life tyres but did not include tyre storage.

2.5 Review of Recent Literature from Waste Management Organisations

Recent literature was reviewed from international waste management organisations, including:

- United States Environmental Protection Association, USEPA, United States
- Rubber Manufacturers Association, RMA, United States
- Clear Washington Council, CWC, United States

[1] MWH New Zealand Ltd (June 2003) *"Development of a Regional Waste Recovery / Processing Sector"*. A report prepared for the Wellington City Council, Ministry for the Environment and Ministry of Economic Development.

- Used Tyre Working Group, United Kingdom
- United Kingdom Environmental Agency, UKEA, United Kingdom
- Oregon Department of Environmental Quality, DEQ, United States
- National Research Council Canada, NRC, Canada
- California Integrated Waste Management Board, CIWMB, United States
- National Fire Protection Association, NFPA, United States
- International Association of Fire Chiefs, IAFC, United States
- Scrap Tyre Management Council, STMC, United States
- Ministry of Waste, Land and Air Protection, Canada
- South Australian Environmental Protection Agency, Australia
- EcoFlex, Australia.

2.6 Key Word Web Search

Several key word searches were also done using the search engine “Google”. Key words used in various searches included: scrap tires, used tyres, storage, monofill, best practice, guidelines, and leachate. References obtained through these searches were reviewed.

2.7 International Experts and Practitioners

Contact was established with a variety of national and international experts and practitioners in the hazardous waste field. Communications were made by telephone, e-mail or by using MWH’s Intranet system known as Knet. In many cases these experts admitted to little direct knowledge of the specific area of end-of-life tyre storage and disposal, perhaps indicating just how specialised this issue is.

However Owen Douglas, a contact provided by Ministry for the Environment, was able to provide MWH with a copy of the *Scrap Tire and Rubber Users Directory, 2003 Edition*. It contains many contacts throughout the world. The directory was received too late to be used in this investigation; however it would be a useful resource for the Ministry in further investigations on end-of-life tyres.

Owen Douglas also provided contact details for Michael Playton, who has 20 years’ experience in the tyre reprocessing industry and is currently the International Sales Manager for Columbus McKinnon, manufacturers of tyre shredding machines. Mr Playton has experience with tyre storage throughout the world, including Asia and the United States, and provided information for this report.

2.8 Reference List

During this investigation a list of relevant references and websites was compiled. This list is presented in Appendix A.

3. End-of-life Tyre Properties

3.1 Definition of End-of-life Tyre

An end-of-life tyre is a used tyre that cannot or is not reused for its originally intended purpose and is not retreaded. Such tyres may have a further use as a raw material for other processes or be destined for final disposal. End-of-life tyres are called "scrap tires" in the United States.

3.2 Physical Properties

Tyres consist of a rubber compound usually reinforced with steel and textile. Depending on their size and utilisation, tyres vary in design, construction and total weight. The weight of a used passenger car tyre in Europe is about 6.5 kg and that of a truck tyre is about 53 kg.[2] Passenger car and truck tyres make up approximately 85% of the total tyres manufactured globally.[3]

3.3 Chemical Composition

Approximately 80% of the weight of car tyres and 75% of truck tyres is rubber compound.[4] The compositions of tyres produced by different manufacturers are reported to be similar. Table 3.1 shows the material composition of passenger car and truck tyres from the European Union (EU) as well as the composition of tyre rubber from Canada.

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2 Basel Convention Working Group (1999) *"Basel Convention Technical Guidelines on the Identification and Management of Used Tyres"*. Basel Convention on the control of transboundary movements on hazardous wastes and their disposal. Document No. 10.

3 Ibid.

4 Ibid.

Table 3.1: Comparison of material composition of passenger car and truck tyres in the EU as well as tyre rubber in Canada

Material	Car tyre[5]	Truck tyre[6]	Tyre rubber[7]
Rubber/elastomers	47%	45%	62%
Carbon black*	21.5%	22%	31%
Metal	16.5%	25%	NA
Textile	5.5%	–	NA
Zinc oxide	1%	2%	2%
Sulphur	1%	1%	1%
Additives	7.5%	5%	4%

Notes:

* Part of the carbon black may be replaced by silica in certain types of tyres.

3.4 Hazardous Waste Composition

Tyres contain a total of approximately 1.5% by weight of hazardous waste compounds listed in Annex 1 of the Basel Convention. These compounds, outlined in Table 3.2, are encased in the rubber compound or present as an alloying element.

Table 3.2: Hazardous waste constituents[8]

Chemical name	Remarks	Content (% weight)
Copper compounds	Alloying constituent of metallic reinforcing material	Approximately 0.02%
Zinc compounds	Zinc oxide, retained in the rubber matrix	Approximately 1%
Cadmium	On trace levels, as cadmium compounds attendant substance of the zinc oxide	Maximum 0.001%
Lead Lead compounds	On trace levels, as attendant substance of the zinc oxide	Maximum 0.005%
Acidic solutions or acids in solid form	Stearic acid, in solid form	Approximately 0.3%
Organohalogen compounds	Halogen butyl rubber (tendency: decreasing)	Maximum 0.1%

5 Ibid.

6 Ibid.

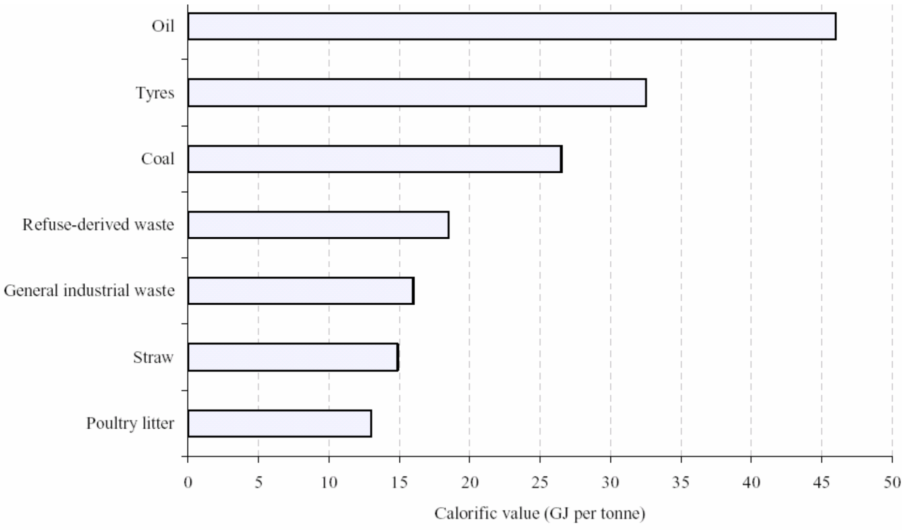
7 O'Shaughnessy VO and Garga VK. (2000) Tire-Reinforced Earthfill. Part 3: Environmental Assessment. *Canadian Geotechnical Journal* 37: 117–131.

8 Basel Convention Working Group (1999) "*Basel Convention Technical Guidelines on the Identification and Management of Used Tyres*". Basel Convention on the control of transboundary movements on hazardous wastes and their disposal. Document No. 10.

3.5 Thermal Properties

The net calorific value of a tyre is between 26 and 34 GJ/tonne,[9] which is similar to that of common fuel sources such as coal (Figure 3.1). A tyre is difficult to ignite. It burns almost completely at 650°, producing principally carbon dioxide and water, plus inert resides such as ash and slag.

Figure 3.1: Comparison of energy content of tyres and other fuels[10]



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9 MWH New Zealand Ltd (June 2003) *"Development of a Regional Waste Recovery / Processing Sector"*. A report prepared for the Wellington City Council, Ministry for the Environment and Ministry of Economic Development.

10 Ibid.

4. Overview of Potential Impacts of Tyre Storage

As part of this investigation it was necessary to consider the potential environmental, financial, cultural and social impacts of tyre storage.

The most commonly reported potential environmental impacts associated with tyre storage were:

- compounds leaching from the tyres and contaminating soil, groundwater and surface water
- uncontrolled open air burning of tyres which releases pyrolytic oils and other compounds into the soil and groundwater as well as large plumes of black smoke and other contaminants into the air. In addition to this, water used to extinguish tyre fires is likely to become contaminated with tyre compounds
- tyre piles may become breeding grounds for insects, rodents and other animals. Mosquitoes, in particular, are a concern in tropical and subtropical countries because they are capable of transmitting diseases to humans.

The potential impacts of tyre leachate and uncontrolled open air burning of tyres are discussed further in Sections 5 and 6 of this report respectively.

The potential financial risks or areas of financial sensitivity associated with tyre storage identified by MWH, based on previous experience in solid waste management, include:

- risks associated with the landowner and storage facility owner
- costs of managing the facility, including meeting any regulatory requirements, insurances, etc
- costs associated with mitigating site contamination
- future value of end-of-life tyres
- cost of future disposal if a viable reprocessing option is not developed.

These issues as well as general factors that influence the level of financial risk are discussed further in Section 7 of this report.

The major potential social impact reported in the literature was the potential health risk posed by insects and vermin breeding in tyre piles. Few reports referred to the physical risk of tyres falling from the tyre pile onto employees and no reports reviewed referred to the visual impacts of tyre storage sites. No reports reviewed discussed the potential cultural impacts of tyre storage sites. Social and cultural impacts of tyre storage were not considered further in this investigation; however they should be taken into account when assessing the suitability of potential tyre storage sites.

5. Potential Environmental Impacts of Tyre Leachate

The literature reviewed on the environmental impact of tyre leachate is summarised in Sections 5.1 and 5.2. It should be noted, however, the review was not an in-depth analysis of the literature.

5.1 Recent Laboratory Research

Recent laboratory research on tyre leachate reviewed in this study is briefly summarised in Table 5.1.

Table 5.1: Summary of reviewed laboratory research on tyre leachate

Paper	Date	Place	Tyre type	Method	Leachate characteristics
Day	1993	CA	Whole new and used	Inundation in GW sample	Toxic to rainbow trout (not other species). Inhibited some metabolic functions. Unclear if new or used tyres less toxic.
Horner	1996	UK	Chips used	Inundation in simulated acid rain	Zn between 169–463 ppm. Negligible Cd and Pb.
Basher	1996	US	Chips with and without wires	Inundation in distilled water	Cr and Pb not detected, Ba <5 mg/L, Ca between 5–57 mg/L, Zn not measured. Level of organics increased with time.
Azizian	2001	US	Crumb rubber asphalt concrete	Inundation in distilled water	V, Zn, As, Ba, Ni, Co, Fe Cr, Cu, Sb, Pb, Cd and Se not detected. Al, Hg and benzonthiazole levels exceeded levels for aquatic toxicity and increased with time.
Collins	1995	UK	Crumb and retread dust	Inundation in salt water sample	Cd, Cu, Cr, Pb and Ni not detected. Zn levels proportional to amount and inversely proportional to size of tyre. Increase in Zn and organics with time.
Nelson	1993	US	Plugs	Inundation in lake water sample or deionised water	Zn was 0.7 mg/L. Cd, Cu and Pb detected at low levels. Toxic for C.dubia but not minnow.
O'Shaughnessy	2000	CA	Chips	Testing in lysimeter	Al, Fe, Mn > DWL (possibly due to steel), Zn < DWL.
Sengupta	1999	US	Chips	Inundation in distilled water	Substances < PDWS. Substances < SDWS except Fe and Mn.
CIWMB	1996	US	NA	Review	Generally low concentrations of metals leached from tyre piles. Levels of Zn, Mn and Al >SDWS.
CWC	1995	US	Shreds	Review	Water becomes acutely toxic to some fish species if tyres submerged in confined, relatively small amounts of water for several days to weeks.

Paper	Date	Place	Tyre type	Method	Leachate characteristics
CIWMB	1998	US	Shreds	Review	Leaching of organics slow, greatest under basic conditions. Metals < PDWS and SDWS except Fe and Mn, greatest leaching under acidic conditions.
Birkholz	2003	CA	Crumb from site	Lab	Toxic to bacteria, invertebrates, fish and green algae tested. 59% reduction in toxicity after crumb onsite for three months.
Gunter	1996	US	Chips, used	Inundated with GW and surface water samples	Fe, Pb, Mn > Wisconsin State Groundwater Quality Standards. Benzene only volatile organic detected.
Texas Department of Transportation	NA	US	Chips	Leaching test of unknown method	Substances < PDWS and SDWS except Mn and Fe. Volatile and semi-volatile organics not detected.
Atech Group	2001	AS	NA	Review	No major environmental impact of tyres in controlled landfills, but limited evidence of long-term impacts.

Notes:

1. Abbreviations used in table for place names: CA, Canada; UK, United Kingdom; US, United States of America; AS, Australia.
2. General abbreviations used in table: DWL, Canadian drinking water limits; NA, Not available; PDWS, United States primary (health) drinking water standard; SDWS, United States secondary (aesthetic) drinking water standards.

In the laboratory tyre leachate is often generated by inundating a tyre sample (plug, shred, chip, or crumb) with water. There are limitations when comparing the results of the reviewed laboratory studies as different makes of tyres were used and different compounds were measured; however the following general observations can be made about the tyre leachate generated in the laboratory:

- it may be toxic to some fish species (eg rainbow trout but not minnow), bacteria, invertebrates and green algae
- levels of aluminium and manganese are likely to be elevated, especially where steel is exposed
- levels of mercury and lead may be elevated; however most studies reported negligible levels
- levels of zinc and organic compounds are likely to be dependent on individual circumstances as a wide range of levels have been reported in the studies reviewed
- levels of other substances are likely to below United States Drinking Water Standards
- levels of leachate compounds (metals and organic compounds) are likely to increase with time of inundation, increase proportionally with amount of tyre and decrease proportionally with size of tyre exposed to inundation.

5.2 Recent Field Trials

Recent field trials on tyre leachate reviewed in this study are briefly summarised in Table 5.2.

Table 5.2: Summary of reviewed field trials on tyre leachate

Paper	Date	Place	Method	Leachate Characteristics
Humphrey	1997	US	Tyre chips above GWT in Maine, GW or leachate collected for 2.5 years, control well.	Substances < PDWS. Substances < SDWS except Fe and Mn. Organics not detected.
Horner	1996	UK	Soil samples taken from 10-year-old tyre dump in West London.	Elevated soil Cd, Pb and Zn at base of dump, levels decreased exponentially with distance.
O'Shaughnessy	2000	CA	Tyre reinforced earthfill, leachate collected for two years, no control well.	No significant adverse effects on groundwater. Cd, Cr and Pb not detected. Zn and Fe < regulatory limits.
Humphrey	2001	US	Tyre shreds below GWT in Maine, leachate and downstream GW collected for 2.5 years, control well.	Highest level of contamination seen at site, with contamination decreasing to near background 3 m downstream. Substances < PDWS at site. Substances < SDWS at site except Fe, Mn, Zn and some organics.
Humphrey	2000	US	Tyre chips above GWT in Maine, leachate collected for five years, control well.	Substances with PDWS not altered. Al, Zn, Cl and SO_4 not increased at site. Fe and Mn increased at site. Negligible level of organics at site.
Riaz	2001	CA	Shredded tyres in baselayer of road in Manitoba, GW collected, no control well.	Substances < PDWS below site. Substances < SDWS below site except Al, Fe and Mn. Organics not detected.

Notes:

1. Abbreviations used in table for place names: CA, Canada; UK, United Kingdom; US, United States of America.
2. General abbreviations used in table: PDWS, United States primary (health) drinking water standard; SDWS, United States secondary (aesthetic) drinking water standards; GWT, groundwater table; GW, groundwater.

In field trials tyre leachate is generated by water percolating through the tyre sample (whole tyre, shred or chip). There are limitations when comparing the results of the reviewed field trials as different makes of tyres were used and different compounds were measured; however the following general observations can be made about the nature of tyre leachate generated in the field:

- levels of manganese and iron are likely to be elevated in groundwater, especially when steel is exposed
- levels of aluminium, zinc and organic compounds may be elevated in groundwater; however the majority of studies reported negligible levels
- level of cadmium and lead may be elevated in soil; however no studies reviewed reported elevated levels in groundwater
- levels of other substances measured are likely to be below United States Drinking Water Standards
- level of leachate compounds in groundwater are likely to decrease down gradient of the tyre site.

5.3 General Observations

The potential environmental impacts of tyre leachate are contamination of soil, surface water and groundwater on the site and surrounding area. Based on the reviewed literature and previous MWH experience in site contamination, factors that may affect the rate of leaching and/or the concentration of tyre leachate compounds in soil, surface water and groundwater include:

- *tyre size:* leaching from whole tyres is likely to be slower than leaching from tyre chips or shreds – this is because of the differences in the surface area to volume ratio
- *amount of exposed steel:* if steel is exposed, say in tyre chips, there is likely to be faster leaching of manganese and iron than from whole tyres where the steel is not exposed
- *chemical environment:* leaching of metals is likely to be more rapid under acidic conditions while leaching of organic compounds is likely to be more rapid under basic conditions
- *permeability of soil:* leaching is likely to be faster when soils are permeable
- *distance to groundwater table:* the greater the vertical distance to the groundwater table, the less likely the contamination of groundwater
- *distance from tyre storage site:* the further the downstream distance from the tyre storage site, the lower the contaminant concentration in the soil and groundwater
- *contact time with water:* the longer the tyres are in contact with water, the greater the risk of groundwater contamination
- *vertical water flow through soil:* the greater the water flow through the soil (eg, from rainfall), the greater the dilution of contaminants
- *horizontal groundwater flow:* the greater the groundwater flow, the greater the spread of the contaminant plume
- *leached compounds at site:* levels of manganese and iron are likely to be elevated in groundwater when steel is exposed. Levels of aluminium, zinc and organic compounds may be elevated in groundwater. Levels of zinc, cadmium and lead may be elevated in soil.

Specific and general mitigation measures to address the environmental risks associated with tyre leachate are outlined in Section 8.8.

6. Potential Environmental Impact of Uncontrolled Tyre Fires

6.1 Uncontrolled Tyre Fires

Tyres are not subject to spontaneous combustion. However, as a tyre fire grows in intensity it generates higher temperatures, allowing the fire to spread and the generation of large plumes of dense smoke and other combustion products. The pile composition affects the rate and direction of fire spread.[11] Fires occurring in piles of whole tyres tend to burn down into the middle of the pile where air pockets allow continued combustion. Fires occurring in piles of chipped or shredded tyres tend to spread over the surface of the pile.

6.2 Decomposition Products

A wide variety of decomposition products are generated during scrap tyre fires. Many of the decomposition products have been characterised in test burns[12] and include:

- ash (typically containing carbon, zinc oxide, titanium dioxide, silicon dioxides, etc)
- sulphur compounds (carbon disulfide, sulphur dioxide, hydrogen sulphide)
- polynuclear aromatic hydrocarbons (such as benzo(a)pyrene, chrysene, benzo(a)anthracene, etc) are usually detected in oil runoff
- aromatic, naphthenic and paraffinic oils
- oxides of carbon and nitrogen
- particulates
- various light-end aromatic hydrocarbons (such as toluene, xylene, benzene, etc).

These decomposition products are extensive and varied depending on a variety of factors,[13,14] including:

- tyre type
- burn rate
- pile size
- ambient temperature
- humidity.

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[11] International Association of Fire Chiefs (IAFC), Scrap Tyre Management Council (STMC) and National Fire Protection Association (NFPA) (2000) *"The Prevention and Management of Scrap Tire Fires"*.

[12] Ibid.

[13] Ibid.

[14] Basel Convention Working Group (1999) *"Basel Convention Technical Guidelines on the Identification and Management of Used Tyres"*. Basel Convention on the control of transboundary movements on hazardous wastes and their disposal. Document No. 10.

6.3 Potential Environmental Impact

Uncontrolled tyre fires usually have major environmental impacts,[15] which include:

- *air pollution:* black smoke and other substances such as volatile organic compounds, dioxins and polycyclic aromatic hydrocarbons are released into the atmosphere
- *water pollution:* the intense heat allows pyrolysis of the rubber to occur, resulting in an oily decomposition product which is manifested as an oil runoff. This runoff can be carried by water, if water is used to put out the fire. Other combustion residues (such as zinc, cadmium and lead) can also be carried by fire water off the site
- *soil pollution:* residues that remain on the site after the fire can cause two types of pollution; these are immediate pollution by liquid decomposition products penetrating soil, and gradual pollution from leaching of ash and unburned residues following rainfall or other water entry.

A more comprehensive analysis of the environmental impact of uncontrolled tyre fires has been carried out by the United States Environmental Protection Association.[16]

Specific and general mitigation measures to address the environmental risks associated with tyre fire are outlined in Section 8.8.

[15] Ibid.

[16] EH Pechan & Associates Inc. (October 1997) *"Air Emissions from Scrap Tire Combustion"*. A report prepared for United States Environmental Protection Agency.

7. Potential Financial Risks Associated with Tyre Storage

7.1 General

The storage of tyres will create financial risks that include:

- those associated with ownership of the land on which the tyres are stored
- those associated with ownership of a tyre storage facility, in addition to the risks of land ownership if the two ownerships are different, and management of the facility
- those associated with the value of the tyres at the end of a design or permitted storage period
- those associated with tyre degradation or contamination
- those associated with site closure.

These risks are described in this section. The majority of the descriptions are based on previous experience MWH has had in solid waste management.

7.2 Risks Associated with Landowner

There are financial risks associated with owning land on which a tyre storage facility is located. These risks, based on previous MWH experience in solid waste management, include:

- the landowner may abandon the land, creating a large liability associated with the cost of either cleaning up the site or continuing to operate the site
- the landowner may not have sufficient funds to cover future costs associated with the site, again creating potentially large liability associated with the costs of either cleaning up the site or continuing to operate the site
- the landowner may sell the land without informing the new owner that tyres are/were stored on the land. If the new landowner is unaware of the situation, they may not have sufficient funds to cover the costs associated with the site.

If the owner does abandon the site or becomes unable to cover the future costs associated with the site, sufficient funding should be available either to continue to manage the site or to dispose of the tyres in an environmentally sound manner and reinstate the site. This is also true if a new owner is unable to meet the costs associated with site.

7.3 Risks Associated with Facility Owner

There are financial risks associated with the ownership of the storage facility. These risks, based on previous MWH experience, include:

- the facility owner may abandon the facility, leaving potentially large costs associated with operation of the facility, tyre disposal and/or site cleanup
- the facility owner may not have sufficient funds to cover future costs associated with operating the facility, again leaving potentially large costs associated with continuing to operate the facility, tyre disposal and/or site cleanup
- the facility owner may sell the facility without informing the new owner of the correct procedures for operating the facility. The new owner may not have sufficient funds to rectify the consequences of the facility being operated incorrectly
- the facility owner may sell the facility without informing the new owner of any adverse environmental impacts the facility has had on the environment. If the new landowner is unaware of the situation, they may not have sufficient funds to cover the costs associated with cleaning up the site.

Two major potential sources of revenue for a private tyre storage facility are gate fees collected when tyres are received at the facility and monies received when tyres are later on-sold to a reprocessing facility.

Factors that may affect the financial situation of a storage facility, based on previous MWH experience in solid waste management, include:

- collection and transport costs
- regulatory requirements, which could address environment protection measures, environmental monitoring measures, operational control measures, and financial risk mitigation measures
- change in credit rating of facility operator
- change in economic climate, eg, land rental increases (for leased sites), cost of borrowing increases, cost of insurance increases, cost of bonds increases, etc
- underestimation of time before a reprocessing facility will be established
- reprocessing facility is not established and the owner must pay for disposal of stored tyres
- overestimation of tyre volumes or gate fees received at the facility. This may occur if there are no legal requirements to dispose of tyres at a specific type of storage facility
- unexpected remediation requirements.

If the owner does abandon the facility or becomes unable to cover the operating costs of the facility, sufficient funding should be available to either continue to operate the storage facility, or dispose of the tyres in an environmentally sound manner. This is also true if a new owner is unable to meet the costs associated with running the facility.

7.4 Future Value of End-of-life Tyres

The future value of end-of-life tyres is largely dependent on more economically viable reprocessing option being established in New Zealand. The major financial risks associated with reprocessing options identified in previous MWH work[17] and during this investigation include:

- cost of developing reprocessing technology in New Zealand (which will be dependent on the reprocessing option(s) implemented)
- initial cost of establishing the reprocessing facility (including consents, buildings and equipment)
- cost of retrieving tyres from storage (which will be dependent on the method of storage)
- transport cost of hauling stored tyres to the reprocessing facility (which will be independent of storage method but dependent on the location of the storage site)
- cost of maintaining the reprocessing facility
- supply cost of manufacturing reprocessed tyre product(s) compared to similar product(s) available in the market place
- establishment of product in the market place and continual product demand
- limitations associated with quality of feedstock (such as quality degeneration through dirt contamination on the tyre)
- dependency on volume of feedstock.

7.5 Risks of Contamination and Fire

A site used for tyre storage may become contaminated in two ways:

- there may be a slow release of contaminants into the soil, surface water groundwater (eg heavy metals from tyre leachate) during the normal operation of the facility. This release of contaminants may lead to downstream liability for the owner of the storage facility and/or the landowner
- there may be a rapid release of contaminants into the soil, surface water and groundwater, for example due to flooding of the area. This would also lead to downstream liability for the facility owner and landowner.

[17] MWH New Zealand Ltd (June 2003) *"Development of a Regional Waste Recovery / Processing Sector"*. A report prepared for the Wellington City Council, Ministry for the Environment and Ministry of Economic Development.

Tyre fires are an extreme example of a rapid release of contaminants, resulting in smoke damage to nearby areas and large discharges to air, water and soil. There are generally large costs associated with tyre fires,[18] including:

- costs associated with fire fighting, which are usually large because tyre fires can take weeks or years to extinguish
- costs associated with onsite and offsite environmental clean-up, which tend to be large because of the severe environmental damage caused directly by the fire and smoke plume fallout and indirectly by the water runoff from fire fighting
- financial losses associated with losing the tyre stores
- cost associated with litigation associated with, for example, health and safety matters, and property damage.

In many instances the site contamination will need to be mitigated. The cost of this remedial work will be dependent on factors that include the extent of environmental damage and the sensitivity of the receiving environment. Sufficient funding should be available to carry out the necessary remedial work, and either to continue to operate the storage facility or to dispose of the tyres in an environmentally sound manner.

7.6 Future Disposal Costs

In the event that the tyres at the facility must be disposed of, there should be sufficient funding available to do so in an environmentally sound manner. The cost of disposal will be dependent on factors that, based on previous MWH experience, include:

- volume of tyres for disposal
- availability of suitable disposal site(s)
- costs of transport and technology to shred tyres
- time frame, as it is likely the cost of disposal of tyres will increase with time
- nature of temporary storage
- changes in materials regarded as creating hazards, etc.

[18] International Association of Fire Chiefs (IAFC), Scrap Tyre Management Council (STMC) and National Fire Protection Association (NFPA) (2000) *"The Prevention and Management of Scrap Tire Fires"*.

7.7 General Factors Influencing Level of Risk

Many factors influence the level of uncertainly posed by the financial risks, some of which have been discussed previously in this section. Some general factors that influence the level of risk, based on previous MWH experience, include:

- length of time in storage: for example, the longer the tyre storage facility is in operation, the greater the risk of the landowner abandoning the land
- quantity of tyres in storage: for example, the greater the number of tyres stored at the facility, the greater the risk of adverse environmental effects on the site or surrounding area
- quality control: for example, the greater the level of quality control, the lower the risk of the tyres being unsuitable for reprocessing options. However, a greater level of quality control is likely to be more expensive
- site infrastructure: for example, a greater level of site infrastructure generally lowers the risk of adverse environmental effects
- site selection: some sites are more suitable for tyre storage facilities than others, and hence pose a lower risk than other sites. For example a storage facility located on a flood plain underlain by permeable soils would pose a higher risk than one located away from surface water bodies on top of relatively impermeable clayey soils.

General mitigation measures to address the financial risks discussed above are outlined in Section 8.9.

8. Review of Best Practice on Tyre Storage

8.1 Introduction and Definitions

The main focus of this section is on current best practice of short to medium term tyre storage. The following definitions were developed for the purpose of reading this report:

- *end-of-life tyre:* a used tyre that is not reused for its originally intended purpose and is not retreaded. End-of-life tyres will be referred to as 'tyres'
- *temporary storage:* short to medium term storage of end-of-life tyres with an intent of future reuse or reprocessing. The most common form of temporary storage for large volumes of tyres is in outdoor tyre stockpiles that are typically uncovered
- *disposal:* permanent disposal of end-of-life tyres. Disposal options for end-of-life tyres include a sanitary landfill (that receives other solid waste) and a tyre monofill[19]
- *tyre monofill:* essentially a sanitary landfill, or portion of a landfill, that receives only end-of-life tyres. The landfill has an appropriate liner, cover, leachate collection system and monitoring system.[20]

This section outlines best practice with regard to establishing and operating a new storage facility, rather than best practice for existing tyre storage sites. Existing tyre storage sites could be assessed by constructing a site model and comparing the existing site model to best practice standards. Existing sites could be classed as high, moderate or low risk, with high risk sites requiring intensive ongoing monitoring and low risk sites requiring ongoing monitoring considered to be best practice for new tyre storage facilities.

8.2 Legal Matters

Rules for the management of end-of-life tyres are obligatory in a number of countries. In the United States end-of-life tyres are managed primarily at state level, with about 48 states having laws or regulations specifically dealing with the management of end-of-life tyres. In the United Kingdom end-of-life tyres are managed primarily under the provisions of the Environmental Protection Act 1990. A detailed review of legislation or compliance monitoring was not included in this investigation.

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[19] Centre for Advanced Engineering (2000) *"Landfill Guidelines"*.

[20] Ibid.

8.3 Collection and Transport of Tyres

In the United Kingdom and in most states of the United States, end-of-life tyres must be collected and hauled by approved companies and can only be deposited at approved facilities for disposal or reprocessing. At least in the United States, there is a manifest system that must be completed to allow state regulatory authorities to track the movement of end-of-life tyres. A detailed review of the collection and transport of tyres was not included in this investigation.

8.4 Temporary Storage of Tyres

8.4.1 Information sources

End-of-life tyres can be stored temporarily in outdoor tyre stockpiles. The majority of technical information obtained during this study that specifically addresses the design and operation of tyre stockpiles refers to guidelines published by IAFC, STMC and NFPA in the United States. There is a guideline produced by the United Kingdom Environmental Agency; however this has not been obtained.

The Basel Convention[21] recommends that tyres should only be stored in stockpiles temporarily, prior to reprocessing. While the Basel Convention does not give a time frame for storage, tyre facilities in the United States are only allowed to store the number of tyres that they can process within a month (30 days).[22] However there is a continual flux of tyres through the facilities, so the guidelines from the United States should go some way to minimising environmental impacts of tyre storage.

8.4.2 Design of a facility

Issues to consider during design and operation of an above ground tyre stockpile storage facility, based on literature reviewed during this study, include:

- site selection
- fire prevention and minimisation of fire spread, eg, prevent ignition and spread of a fire by setting a minimum distance between daily cells
- minimise leachate production, eg by covering tyre pile
- minimise leachate contamination into soil and groundwater, eg, by having a compacted clay surface
- minimise vermin and insects breeding in monofill.

Table 8.1 compares the best practice for the design of tyre stockpile facilities given in guidelines published by IAFC, STMC and NFPA with that recommended by a practitioner with 20 years' experience in the tyre reprocessing industry.

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[21] Ibid.

[22] Personal communication[2], Michael Playdon, Columbus McKinnon, February 2004.

Table 8.1: Comparison of best practice for the design of tyre stockpile facilities

Criteria	**IAFC, STMC and NFPA Guidelines**[23]	**Practitioner**[24]
Storage time	N/R	Tyres in facility 30 days
Tyre pile maximum dimensions	6 m height 76 m length 15 m width	4.5 m height 60 m length 15 m width
Pile slope	N/R	30^0 slope if naturally piled 90^0 slope if laced in piles See Figure 8.1.
Clear space on site	Edge of pile 15 m from perimeter fence Area 60 m from pile devoid of vegetation, debris and buildings	Edge of pile 15 m from perimeter fence
Fire breaks	18m between piles	15 m between piles at base
Site selection	Avoid wetlands, flood plains, ravines, canyons, steeply graded surfaces, powerlines	NA
Ground surface/liner	Ideally flat site Concrete or hard packed clay surface Not asphalt or grass	Compacted area
Cover	N/R	Not effective
Runoff	Capture and contain	Soil bund around pile to minimise runoff due to fire fighting water
Ignition sources	No open air burning within 300 m No welding or other heat generating devices within 60 m	NA
Water supply	63 L/s for 6hrs if tyres>1400m^3 126 L/s if storage area >1400m^3	NA
Other fire fighting resources	Foam, chemicals, fill dirt on site Access to heavy equipment/materials	NA
Fuel-fired vehicles	Fire extinguisher on board	NA
Perimeter of facility	Chain-link, > 3 m high with intruder controls	NA
Signage	Visible with regulations and hours	NA
Security	Qualified attendant	NA
Emergency vehicle access routes	Well maintained and accessible at all times Clear width >18 m and height 4 m	NA
Gates at access point	6 m width at all times Locked when closed	NA

Notes:

Abbreviations used in Table: NR, not recommendations; NA, not asked.

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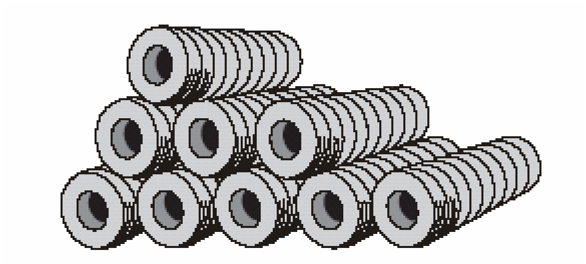
23 International Association of Fire Chiefs (IAFC), Scrap Tyre Management Council (STMC) and National Fire Protection Association (NFPA) (2000) *"The Prevention and Management of Scrap Tire Fires"*.

24 Personal communication[2], Michael Playdon, Columbus McKinnon, February 2004.

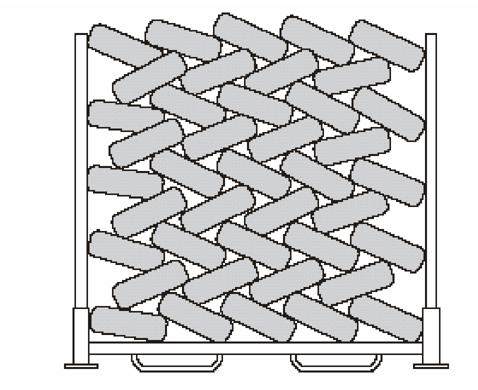
The two most common ways of stacking tyres within outdoor tyre stockpiles are shown in Figure 8.1.

Figure 8.1: Two tyre stacking arrangements[25] A: Banded B: Laced

A



B



The guidelines summarised in Table 8.1 are the same as those recommended by Hamilton Fire Service[26] and are similar to those in the Basel Convention[27] and those produced by the South Australian Environmental Protection Agency.[28] However, the Basel Convention recommends that the maximum width of a tyre pile is 6m and the South Australian guidelines highlight the importance of not locating tyre storage sites near groundwater recharge points.

In addition to the IAFC, STMC and NFPA guidelines given in Table 8.1, the NFPA also recommends minimum separation distances between adjacent tyre piles based on the size of the exposed face and the tyre pile height. These are outlined in Table 8.2. These distances are also recommended between tyre piles and buildings; however soil bunds of one and a half the height of the tyre piles can be used.

Table 8.2: Minimum exposure separation distances[29]

Exposed face dimension (m)	Tyre storage pile height (m)						
	2.4	3	3.7	4.3	4.9	5.5	6.1
7.6	17.1	18.9	20.4	22.3	23.5	25.0	25.9
15.2	22.9	25.6	28.3	30.5	32.6	34.4	36.0
30.5	30.5	35.4	39.0	41.8	44.5	47.2	50.0
45.7	30.5	35.4	39.0	41.8	44.5	47.2	50.0
61.0	30.5	35.4	39.0	41.8	44.5	47.2	50.0
76.2	30.5	35.4	39.0	41.8	44.5	47.2	50.0

25 National Fire Protection Association (2003) *"Standard No 230: Standard for the Fire Protection of Storage"*.

26 Berryman M. (2002) *"Recommendations for the Storage of Used Vehicle Tyres"*. Hamilton Fire District Recommendations.

27 Basel Convention Working Group (1999) *"Basel Convention Technical Guidelines on the Identification and Management of Used Tyres"*. Basel Convention on the control of transboundary movements on hazardous wastes and their disposal. Document No. 10.

28 South Australian Environmental Protection Agency (July 2003) *"EPA Guidelines: Waste Tyres"*.

29 National Fire Protection Association (2003) *"Standard No 230: Standard for the Fire Protection of Storage"*.

8.4.3 Facility management issues

Issues to consider during management and operation of an outdoor tyre stockpile storage facility, based on literature reviewed during this study, include:

- minimisation of environmental risk by routine operation, eg due to tyre leachate
- minimisation of risk of tyre fire starting
- minimisation of environmental impacts caused by a tyre fire.

Little information was found regarding the management and day-to-day operation of an outdoor tyre storage facility. However the following practices were noted by Mr Playdon:[30]

- monitoring is not carried out, unless the site is in an environmentally sensitive area
- the United States tyre manifest documents record the numbers of tyres that are received and removed from a tyre storage facility, and hence the number of tyres stored at a facility can be calculated at any given time.

8.5 Tyre Monofills

8.5.1 Information sources

End-of-life tyres can be disposed of within tyre monofills, which can be located above ground, below ground, or partly below ground. Tyre monofills are essentially landfills, or portions of a landfill, that receive only end-of-life tyres.

Little technical information that specifically addresses the design and operation of tyre monofills was sourced during this review. No technical information was available from Canadian, Australian or United Kingdom sources. This may be a reflection on the banning of landfilling of tyres in Canada and the United Kingdom.

Information was obtained from current waste management regulations contained in the California Code of Regulations (administered by the California Integrated Waste Management Board, CIWMB) and in the Ohio Administrative Rules (administered by the Ohio Branch of the Environmental Protection Agency, Ohio EPA). This information suggests tyre monofills are constructed and operated as sanitary landfills with a liner and leachate collection system.

The Basel Convention document does contain information about landfilling. However, the majority of this information appears to be sourced from “Annex F: Guidelines for Outdoor Storage of Scrap Tires” contained within the document *NFPA 231D: Standard for Storage of Rubber Tires (1998).* Annex F was developed to aid in the prevention and management of fire incidents that occur in whole, baled or processed end-of-life tyre stockpiles, rather than for tyre monofills. Accordingly, this information is outlined in Section 8.4 of this report.

[30] Personal communication[2], Michael Playdon, Columbus McKinnon, February 2004.

8.5.2 Design of a monofill facility

The components of a tyre monofill, based on the Centre for Advanced Engineering (CAE) Landfill Guidelines,[31] include a liner system, daily cover and intermediate cover, final cap system, leachate collection system, stormwater collection system and a monitoring system.

Issues to consider during design and operation of a tyre monofill, based on literature reviewed during this study, include:

- site selection
- fire prevention and minimisation of fire spread
  - limit potential for internal heating by setting a minimum size limit to tyre chips, for example
  - prevent ignition and spread of a fire by setting a minimum distance between daily cells, for example
- minimisation of leachate production by having adequate cover
- minimisation of contamination of soil and groundwater at the site and in the surrounding area
- minimisation of vermin and insects breeding.

Table 8.3 compares the best practice for the design of tyre monofill facilities outlined in the Basel Convention as well as in regulations administered by CIWMB and Ohio EPA.

Table 8.3: Comparison of published best practice for monofill design

Criteria	Basel Convention[32]	CIWMB[33]	Ohio EPA[34]
Site selection	Avoid wetlands, flood plains, ravines, or steeply graded surfaces	Avoid areas subject to flooding (100-year return period)	>300 m from environmentally significant areas, groundwater wells Avoid areas subject to flooding, seismic activity, and land subsidence 90 m from boundary 60 m from surface water
Accepted waste		Baled, shredded, chopped, split tyres Minimum limit to tyre chip sizes Maximum limit to protruding metal	N/R
Maximum dimensions		N/R	N/R

31 Centre for Advanced Engineering (2000) *"Landfill Guidelines"*.

32 Basel Convention Working Group (1999) *"Basel Convention Technical Guidelines on the Identification and Management of Used Tyres"*. Basel Convention on the control of transboundary movements on hazardous wastes and their disposal. Document No. 10.

33 California Integrated Waste Management Board (October 2003) *"Waste Tire Monofill Proposed Regulatory Requirements"*.

34 Ohio Administrative Code, *"Rule 3745-27-60: General Storage and Handling of Scrap Tires"*, *"Rule 3745-27-73: Final Closure of a Scrap Tire Monofill Facility"* and *"Rule 3745-27-74: Post-Closure Care of Scrap Tire Monofill Facilities"*.

Criteria	Basel Convention[32]	CIWMB[33]	Ohio EPA[34]
Ground surface	Ideally flat site	N/R	No abrupt changes in grade >1.5 m insitu geological material between aquifer and liner
Liner system	Compacted clay layer	Clay liner or synthetic liner with hydraulic conductivity of < 1 x 10^{-6} cm/sec	1m layer of graded soil, compacted at an optimum moisture content OR 0.5 m soil layer with geosynthetic clay liner
Daily cell design	Maximum layer height of 2.5 m	Maximum depth 6 m Maximum cell area 1161 m^2 Minimum of 0.6 m between tire shreds in adjacent cells	N/R
Daily cell cover		150 mm cover of soil with <5% organic matter	Minimum of 0.3 m layer of fine graded, non-putrescible soil
Working face	Start with biggest tyres and fill gaps with inert material. Minimise tyres left uncovered	Not more than two cells uncovered at any given time	N/R
Intermediate cover	0.3 m layer of inert material (earth or hard core)	Soil with <5% organic matter, compacted to maximum density at optimum moisture content	0.6m thick fine graded, non-putrescible soil layer and geotextile fabric
Final cap system	Minimum thickness of hard core, vegetation layer	< 1 x 10^{-6} cm/sec Last lift compacted to provide flat and stable surface Cutoff walls required where there is potential for lateral movement of fluid	Geotextile fabric, 1.5 m recompacted soil barrier, 0.5 m geosynthetic clay liner, flexible membrane liner, 0.3 m drainage layer/drainage net, frost protection layer, vegetation layer
Leachate collection system		As per landfill guidelines	> 0.3 m drainage layer able to rapidly collect leachate Maintain < 0.3 m head on liner
Stormwater collection	Capture and contain runoff	Accommodate precipitation of 100y, 24-hour storm event	Accommodate peak flow of 25 year, 24-hour storm event
Water supply		N/R	N/R
Clear space		N/R	N/R
Ignition sources		N/R	N/R
Stockpiles and fire fighting equipment	Stockpile of hard core to smother fire	Cover for minimum depth 0.9 m on all exposed tyre waste and equipment	N/R
Seismic design		To withstand at least the maximum probable earthquake	N/R

Notes:

Abbreviations used in Table: NR, not recommendations.

Previous MWH work[35] reported monofills in the United States have been designed using 0.9 m recompacted liners and 1.5 m soil caps, however it noted that this design does not address the issue of fire. This work also reported tyres could be evenly distributed along the base of a landfill cell, however it noted shredded or quartered tyres would leave exposed 'band wire' which has the potential to damage liner systems. It also noted that the issue of differential settlement from waste compaction should be considered when placing whole tyres in one area.

8.5.3 Facility management issues

Issues to consider during management and operation of a tyre monofill, based on literature reviewed during this study, include:

- minimisation of environmental risk in routine operations, eg from tyre leachate
- minimisation of risk of tyre fire starting
- minimisation of environmental impacts caused by a tyre fire.

Table 8.4 provides an overview of best practice for the management of tyre monofill facilities outlined in regulations administered by CIWMB and Ohio EPA.

Table 8.4: Comparison of published best practice for management of monofill facilities

Criteria	CIWMB[36]	Ohio EPA[37]
Operating criteria	General landfill procedure	N/R
Monitoring	Temperature sensors within underlying cells if >1 cell thick Monthly collection of waste tyre samples and analysed for degradation/protruding wire Cover should contain less than 5% organic matter	N/R
Records	Monitoring results and tyre handling manifests	Annual operating report
Closure and post closure maintenance	General landfill procedure	General landfill procedure

[35] MWH New Zealand Ltd (June 2003) *"Development of a Regional Waste Recovery / Processing Sector"*. A report prepared for the Wellington City Council, Ministry for the Environment and Ministry of Economic Development.

[36] California Integrated Waste Management Board (October 2003) *"Waste Tire Monofill Proposed Regulatory Requirements"*.

[37] Ohio Administrative Code, *"Rule 3745-27-60: General Storage and Handling of Scrap Tires"*, *"Rule 3745-27-73: Final Closure of a Scrap Tire Monofill Facility"* and *"Rule 3745-27-74: Post-Closure Care of Scrap Tire Monofill Facilities"*.

8.6 Future Reprocessing of End-of-life Tyres

8.6.1 Reprocessing options for tyres

New Zealand currently generates approximately 4 million end-of-life tyres each year, which equates to approximately 36,000 tonnes per annum.[38] These tyres are currently landfilled, used as silage cover weights in the agricultural industry, recycled, stockpiled or dumped. There is little information available on respective quantities.

Current reprocessing options used internationally and described in previous MWH work,[39] include:

- *Feedstock production:* tyre shredding, tyre crumbing plant
- *Recycling:* rubberised asphalt concrete, civil engineering applications, playground mats, flooring
- *Energy recovery:* cement kilns, pyrolysis, gasification, polymerisation.

8.6.2 Compatibility of tyre storage methods with reprocessing options

It is important that the storage of tyres in New Zealand is compatible with current and potential reprocessing options. Table 8.5 outlines the suitability of tyres stored above ground in outdoor stockpiles and buried in tyre monofills for various reprocessing options. It should be noted that it would be more expensive to remove tyres from monofills than from stockpiles, making all reprocessing options more economically viable if tyres are stored in stockpiles.

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[38] MWH New Zealand Ltd (June 2003) *"Development of a Regional Waste Recovery / Processing Sector"*. A report prepared for the Wellington City Council, Ministry for the Environment and Ministry of Economic Development.

[39] Ibid.

Table 8.5: Comparison of the suitability of end-of-life tyres in monofills and stockpiles for various reprocessing options[40,41,42]

Reprocessing option	Tyre monofills	Outdoor tyre stockpiles
Feedstock production		
Tyre shredding	Unsuitable due to dirt and surface contamination	Suitable
Tyre crumbing plant	Unsuitable due to dirt and surface contamination	Suitable
Alternative applications		
Rubberised asphalt concrete	Probably unsuitable as cannot shred tyres	Suitable
Civil engineering	Suitable for some applications if can use tyres as placed in monofill (eg, whole, quartered, shredded)	Suitable
Playground mats and flooring	Probably unsuitable	Suitable
Energy recovery		
Cement kilns	Suitable, however kilns require modification to accept whole tyres	Suitable, kilns do not require modification to accept shredded tyres
Pyrolysis	Suitable if can use tyres as placed in monofill (eg, whole, quartered, shredded)	Suitable
Gasification	Suitable if can use tyres as placed in monofill (eg, whole, quartered, shredded)	Suitable
Polymerisation	Suitable if can use tyres as placed in monofill (eg, whole, quartered, shredded)	Suitable

From Table 8.5 it appears there are more issues associated with reprocessing tyres from monofills (eg dirt contamination rendering tyres unsuitable for shredding). No tyre monofills have been identified as being 'mined' to date. However, it may be possible to reuse tyres from monofills if:

- tyre monofill design is altered to have clean linings etc to minimise dirt and contamination. However, this design would have to be carefully analysed to ensure the risk of fire is minimised
- an inexpensive way can be developed to remove tyres from a monofill and clean them. However, the tyres would still be unsuitable for crumbing as it is unlikely the cleaning procedure would be able to remove small soil fines from the tyres
- tyres are shredded to a suitable size for reuse prior to being placed in a monofill.

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40 Personal communication[2]. Michael Playdon, Columbus McKinnon, February 2004.

41 MWH New Zealand Ltd (June 2003) *"Development of a Regional Waste Recovery / Processing Sector"*. A report prepared for the Wellington City Council, Ministry for the Environment and Ministry of Economic Development.

42 Personal communication[3], Timothy Scott, Matta Products Ltd, February 2004.

8.7 Future Disposal

In the event that further reprocessing options are not implemented in New Zealand, end-of-life tyres must be disposed of in an environmentally acceptable manner.

Tyres from temporary outdoor tyre stockpiles will need to be removed and transported to a suitable disposal site, which is monitored for tyre leachate and is appropriately managed to minimise the risk of fire. The temporary tyre storage site may also require remedial work, such as the removal of the top layer of soil if it is contaminated.

Tyres stored in an appropriately closed tyre monofill should be able to remain in the monofill. However, such a site will still require ongoing post-closure maintenance, monitoring of tyre leachate and appropriate management of the risk of fire. Based on literature and MWH experience in solid waste management, issues that need to be considered include:

- low density of tyres
- compressibility of tyres
- large void space in tyres, which may allow a large volume of water storage within the monofill. There is likely to be a low flow through these void spaces, which increases the risk of water contamination by tyre compounds
- stability of monofill
- ongoing fire risks
- limited future land use options.

The overall costs associated with the final disposal of tyres from temporary outdoor tyre stockpile facilities are likely to be greater than those for final disposal of tyres in monofills.

8.8 Environmental Risk Mitigation

The major environmental risks associated with tyre storage are the risk of tyre fires (which have severe potential environmental impacts) and the risk of tyre leachate contaminating groundwater, surface water and soil. Specific mitigation measures have been addressed previously in both the design and operation of storage facilities (Section 8.4 and Section 8.5), however this section will outline general mitigation measures based on literature reviewed and previous MWH experience in solid waste management.

Risks associated with tyre fires at tyre storage facilities can be mitigated in several ways, including:

- design of the storage facility to minimise the volume of tyres in one area (eg, with fire breaks between above ground piles and minimum allowable daily cover depths on below ground stores)
- operation of the storage facility to minimise risk of fires starting (eg, ensuring all ignition sources are kept beyond a specific distance from the tyres and setting a minimum allowable size on tyre chips in monofills)

- operation of the storage facility to maximise the chances of fires being extinguished quickly, and hence minimise the production of tyre decomposition products (eg, ensuring the site has adequate stockpiles of cover material to smother fires and clear access for fire service vehicles at all times)
- operation of storage facilities to minimise environmental impacts of tyre decomposition products (eg, ensuring there are contingency plans to enable water runoff from fire fighting to be collected).

The risk of tyre leachate contaminating groundwater and soil can be mitigated in several ways, including:

- design of the storage facility to minimise the amount of water runoff from tyre piles (eg, by designing a suitable stormwater collection system, covering tyres to minimise water contact with tyres, installing an adequate cover and liner system)
- monitoring surface water and groundwater levels for evidence of tyre leachate (eg, presence of iron, manganese and organic compounds, see Section 5) and carrying out remedial work if levels are significantly greater than baseline levels. It should be noted that the location and number of monitoring points and frequency of monitoring would be site specific
- removal of top layer of soil from sites when facilities are closed if soil testing results indicate contamination (eg, presence of zinc, cadmium and lead, see Section 5). Contaminated soil would need to be treated or disposed of in a landfill
- appropriate site selection, such as avoiding areas with low permeable soils, flood prone areas and areas near groundwater recharge points. An example of a suitable area would be one located away from surface water bodies on top of relatively impermeable clayey soils.

8.9 Financial Risk Mitigation

The major financial risks associated with tyre storage are related to the landowner, facility owner, costs of managing the facility, contamination, future value of end-of-life tyres and future final disposal costs if reprocessing options do not prove viable.

There are several financial assurance mechanisms, currently used internationally for landfills,[43] that could be used to minimise the major financial risks associated with tyre storage, including:

- operating liability insurances, eg, to cover the costs associated with tyre fires
- bonds, eg, to cover potential costs of final disposal, site monitoring and remedial work
- charges, eg, to cover potential costs of final disposal, site monitoring and remedial work
- trust funds, eg, to cover potential costs of final disposal, site monitoring and remedial work
- letter of credit, eg, to cover potential costs of final disposal, site monitoring and remedial work
- use of multiple mechanisms.

Insurances and bonds appear to be the most commonly used financial assurance mechanisms for tyre storage facilities in the United States.

[43] United States Environmental Protection Agency (1995) *"Decision-Makers' Guide to Solid Waste Management, Volume II"*.

Other ways to minimise financial risks, based on previous MWH experience in solid waste management, include:

- having a review period for licensing of a tyre storage facility – this allows bonds to be increased at the end of the review to reflect inflation as well as increases in, say, disposal costs
- appropriate site selection with appropriate hydrogeological and geotechnical studies of the site
- limit the time of operation
- limit the size of the facility
- having an appropriate quality assurance system to ensure the end-of-life tyres are suitable for a wide range of reprocessing options.

9. Conclusions

9.1 Collection and Transport

A nationally or regionally integrated system for the collection and transport of end-of-life tyres to specific storage facilities would provide the level of monitoring and control that, given the literature, appears to be required to manage end-of-life tyres. Such a system is provided in the United Kingdom and the United States, in which there are specific companies that are authorised to collect end-of-life tyres and transport them to authorised tyre storage facilities. An integrated system would also maximise the amount of tyres that could be used in tyre reprocessing operations.

9.2 Tyre Storage and Site Management

The following general conclusions can be drawn regarding suggestions for best practice of tyre storage in New Zealand.

- there appears to be a consistent approach to the design of tyre monofills in the United States, with the typical requirements being there for a sanitary landfill, with an appropriate liner system, a cover, a leachate collection system, stormwater collection system and monitoring system. Such a design is likely to be suitable for use in New Zealand
- tyres stored in a standard monofill would become contaminated by dirt, rendering them unsuitable for use in most reprocessing options, unless a financially viable option were to be developed for cleaning the tyres. It is also likely to be expensive to remove tyres from the monofill while minimising the risk of fire
- there appears to be consistency in the design of temporary tyre storage facilities in the United States, Australia and Asia. Tyre storage facilities in the United States are only allowed to store the number of tyres that they can process within a month (30 days). The standard designs do not include monitoring measures to assess the environmental effects on groundwater or surface water quality. As long term environmental assessments are not available, it would be prudent to install appropriate monitoring measures at temporary tyre storage sites in New Zealand
- tyres temporarily stored in a standard outdoor tyre stockpile facility appear to be suitable for use in most reprocessing options
- financial assurance mechanisms should be used to minimise the financial risks associated with the landowner, facility owner, costs of managing the facility, contamination, future value of end-of-life tyres and any final disposal to landfill.

Appendix A: References

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Useful Websites

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Rubber Manufactures Association	www.rma.org
UK Environment Council	www.the-environment-council.org.uk
UK Environmental Agency	www.environment-agency.uk
US Department of Environmental Quality	www.deq.state.or.us
US Environmental Protection Agency	www.epa.gov
Used Tyre Working Group	www.tyredisposal.co.uk