Environmental Impact of Industrial By-products in Road Construction – a Literature Review

R.J. Peploe, Bartley Consultants Ltd, New Zealand

A. Dawson, University of Nottingham, UK

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PO Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64-4 931 8700; Facsimile 64-4 931 8701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

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1 Bartley Consultants Ltd, New Zealand
2 University of Nottingham, UK

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An important note for the reader

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Abbreviations

ALT-MAT:	ALTernative MATerials
ARC:	Auckland Regional Council
AASHTO:	American Association of State Highway and Transportation Officials
BTEX:	benzene, toluene, ethyl benzene, xylenes.
CEN:	Comité Europeén de Normalisation (European Committee for Standardisation)
ERMA:	Environmental Risk Management Authority, New Zealand
HSNO:	Hazardous Substances and New Organisms
MfE:	Ministry for the Environment, New Zealand
RAP:	Recycled Asphalt Pavement
RMA:	Resource Management Act
SUDS:	Sustainable Urban Drainage Systems
TA:	Territorial Authority
WRAP:	Waste and Recycling Action Programme

Contents

Executive summary

This report presents the results of a literature review, undertaken 2005/6, on the topic of the environmental impact of industrial by-products in road construction.

The international technical literature has been reviewed and a number of issues with regard to the presence and liberation of contaminants have been discussed. The literature shows that the topic of environmental impact is extremely complex, and by necessity, any assessment strategy needs to be relatively conservative for it to be practical, cost effective and reliable.

The New Zealand literature has also been reviewed and it indicates that a number of documents currently available in New Zealand address the issues of hazardous substances and acceptance criteria for contaminants. Of particular interest are the criteria published by the Ministry for the Environment regarding Class B landfills, the Auckland Regional Council criteria for urban receiving environments and the strategy for material assessment presented by Herrington et al.

A new assessment process has been suggested as a result of the literature review. It basically involves a three-tier classification system where industrial by-products proposed for road construction applications are deemed to be inert, notifiable or assessable depending on their composition, intended use and track record.

The proposed assessment system will place the onus for testing and categorising of industrial by-products on the suppliers, while territorial authorities will have the final sign-off on the application of such products using the level of acceptance criteria that the various authorities are comfortable with.

Abstract

The objectives of this project, undertaken 2005/6, were to:

- review the international technical literature on the topic of environmental issues relating to the use of waste and industrial by-products in road construction applications, and
- recommend a set of guidelines to allow road controlling authorities and environmental agencies to determine if various waste or environmental by-products are appropriate for use in road construction.

The international literature shows that the topic of environmental impact is extremely complex and, by necessity, any assessment strategy needs to be relatively conservative for it to be practical, cost effective and reliable. The study has shown that a number of documents that address the issues of hazardous substances and acceptance criteria for contaminants are currently available in New Zealand.

A new assessment process has been suggested as a result of the literature review. It basically involves a three-tier classification system where industrial by-products proposed for road construction applications are deemed to be *inert, notifiable* or *assessable* depending on their composition, intended use and track record.

1. Introduction

1.1 Objectives

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- review the international technical literature on the topic of environmental issues relating to the use of waste and industrial by-products in road construction applications, and
- recommend a set of guidelines to allow road controlling authorities and environmental agencies to determine if various waste or environmental by-products are appropriate for use in road construction.

The initial impetus for this project was provided by Transit New Zealand and the Auckland Regional Council (ARC). These organisations wish to promote innovation, particularly recycling, so they need to be sure that materials used in roading applications are environmentally secure.

The research was carried out during 2005/06.

1.2 Background information

In the past, most areas of New Zealand have benefited from plentiful supplies of good quality roading aggregate. However, depletion of rock resources and increasingly stringent controls on quarrying have meant that high quality aggregates have become more scarce and expensive.

The challenge for the present and future of road construction is the appropriate implementation of waste or industrial by-products as roading materials. This will provide a number of significant benefits to the roading industry as well as to the country as a whole, e.g:

- conservation of natural resources,
- reduced volume of waste to landfills,
- lower cost construction materials,
- lower waste disposal costs,
- reduced cartage demands, and
- promotion of a 'clean, green' image.

The challenge is not only to identify waste materials that provide suitable mechanical properties but also to ensure that they are environmentally secure. The environmental security of a material in this context requires consideration of issues such as:

- the potential for leaching of contaminants to groundwater or surface water receptors,
- leachate composition, toxicity and concentration, and/or
- the potential to liberate airborne contaminants by way of dust and/or fumes.

The use of waste or industrial by-products must not compromise the safety of workers or the general public, nor should it have the potential to cause damage of any kind to adjacent property.

1.3 Industrial by-products used in New Zealand

Relatively few industrial by-products are currently used in the New Zealand road construction industry. However, as demand for improved infrastructure grows and the supply of natural construction resources diminishes, a wider range of materials will become viable.

Industrial by-products currently used in New Zealand are listed in Table 1.1.

Table 1.1 Industrial by-products currently used in the New Zealand road construction industry.

Material	Typical applications
Crushed concrete	Pavement base or sub-base aggregate
Recycled asphalt pavement (RAP)	Recycled asphalt, sub-base aggregate
Melter slag	Sub-base aggregate, sealing chip, stabilising additive
Steel slag	Sealing chip, asphalt aggregate
Crushed glass	Pavement base or sub-base aggregate
Fly ash	Filler, stabilising additive

Other industrial by-products that may be used in the medium to long-term future include:

- scrap rubber,
- baghouse fines,
- kiln dusts,
- residues from paper-making,
- metropolitan waste incinerator ash, or
- waste plastic granules or fibres.

2. Environmental guideline considerations

2.1 Introduction

In reality, no environmental issues are specific to waste products, and industrial and commercial by-products as regards their use in road construction. Any material, be it of natural or non-natural origin, when used at a location other than its source will bring its own characteristics with it. A widely held perception exists that materials of natural, geologic origin are environmentally benign at their point of use in a road construction site. However, this is not necessarily the case. For example, a limestone aggregate used in an acid wetland environment could have a noticeable impact on pH and hence on biota. Its natural origin does not exempt it from having an undesirable impact. Conversely, demolition waste comprising old slates might be perfectly acceptable in the same situation.

In this review, to encourage brevity, the name ‘secondary’ materials will be used to encompass all road construction materials of waste and by-product origin; ‘conventional’ binders are those commonly used (i.e. bitumen and cement), while ‘primary’ aggregates are those of geologic origin.

2.2 Major issues

2.2.1 Does the material cause a hazard?

In Europe, a material is deemed hazardous if it has properties which would cause it to be:

- explosive,
- oxidizing,
- highly flammable or flammable,
- an irritant,
- carcinogenic,
- infectious,
- toxic for reproduction,
- mutagenic,
- ecotoxic, or
- able, by itself or by combined action or reaction with adjacent materials, to yield a product that would itself be hazardous in one or more of these ways.

Clearly, no-one is likely to plan to use a material which is known to have such a property so, the issue is more likely to be as outlined in Chapter 2.2.2.

2.2.2 Is the concentration of the hazardous element too high?

Typically, regulations set permissible concentration limits for chemical and biological species above which a hazard is deemed to exist. Combustion, explosion and chemical tests can be used to determine some limits, but the majority of the hazards relate to the impact on humans, flora and fauna. It is these latter aspects of hazard which almost invariably must be considered in road construction. For these, concentration limits are set – usually very conservatively – based on toxicological studies. The limits are set conservatively because the information upon which the study is made is necessarily incomplete.

In rare cases, an industrial accident, wartime event or natural disaster has exposed a significant number of people to a particular hazard but at different intensities from person to person. By tracking people's subsequent health, or lack of it, an exposure:impact relationship may be established and its reliability assessed on a statistical basis. Normally, the exposure:impact relationship cannot be assessed in this way and assessors may rely on experiments on animals and somewhat conjectural scaling relationships. When these do not exist, we have to rely on *in vitro* studies and make assumptions, for example about the ease of movement (take-up) from the external environment to the living cells. These concentration limits should be set, in principle, for all relevant exposure routes – air (gas and particulates), solids, groundwater and surface water.

2.2.3 Is the hazardous element 'available'?

Availability describes the ability of the hazardous component to cause the hazard associated with it. If, for example, a chemical lies fused into the centre of a vitreous mineral particle, it will be much less available than if it rested on the surface and could readily be washed off. Many secondary materials have been through a hot process (e.g. slags and ashes) and some metalliferous elements may be at relatively high solid concentrations in the mineral fabric, but it may be difficult or impossible for them to find a route out, even if the mineral is crushed. For this reason, solids analysis on construction materials may be useful for classification but is likely to give larger concentrations than are meaningful for assessing a hazard. In preference, leaching tests are normally performed for any ingestion/dermatological/ecotoxicity assessment.

Some distinction should be made between physical availability and bioavailability. The amount that can be extracted from a material by intense physical means (physical availability) is greater than what a biological organism can extract from a material (bioavailability). This is partly because almost all biological uptake first requires a chemical to be transferred into water from a solid, and partly because biological take-up is sensitive to factors such as valency and complexation. Thus, a straightforward chemical assessment of a sample obtained in a leaching test may yield overly pessimistic values.

2.2.4 Does a scenario exist in which the hazard is likely?

Most hazards require a certain set of circumstances/conditions to occur before the hazard exists. In a clean-up of contaminated sites, it is conventional to make a risk-based assessment of the corrective action which will lower the risks to tolerable levels. A series of scenarios are envisaged and the risk of hazards occurring is assessed for each. If necessary, some intervention is then planned in order to reduce the risk. For construction with a potentially hazardous material on a 'clean' site, risk-based assessments have found less favour. The logic behind this is that a less than perfect clean-up of a contaminated site leaves it much better than it was prior to the clean-up so it is, nevertheless, to be commended, whereas intervention at a 'clean' site should not be allowed to add any hazard.

A further aspect to be considered in the use of scenarios is to assess the passage of a contaminant. The concept of a 'source', a 'pathway' and a 'receptor' (or 'target') is well established. Arguably, we are not interested in the level of the hazard until it reaches the receptor. If the level has then attenuated to an acceptable value, then the use of the material may be satisfactory.

2.2.5 What are the receptors in a road environment?

During construction, wind-borne pollution can occur so the receptors are spread over a wide area around the road and will include many plant and animal species, including humans. Obvious health and safety provision is used on-site and moisture is maintained to minimise dust. During construction and after sealing, the principal targets will be:

- surface waters (streams, rivers, sea),
- groundwater,
- verge vegetation (perhaps), and
- any destination to which cuttings/prunings are taken.

Of course, water is not an ultimate target; the ultimate targets are the people who drink the water, and the fish and vegetation that depend on it. However, most regulators find bodies of water to provide the most convenient opportunity for monitoring and, consequently, policing purposes. Therefore, it is the engineer's task to ensure that the contaminant level is acceptable by the time of reaching the water body. Thus, the value obtained from availability testing will need to be altered to allow for the processes that have taken place in the pathway.

2.2.6 What is the source in a road environment?

In the context of this document, it might be expected that the road construction material is the source. However, contaminants may also be introduced by construction or transportation equipment. Of course, for water-borne contamination, road construction material can only act as a source if water passes through or around the construction layers. That water might come from a variety of sources (pavement surface, surrounding ground, surcharged drains) but rainwater collecting on the pavement surface is likely to be a major source. Rainwater run-off is often heavily contaminated by vehicle wear, exhaust particles, brake wear, cargo spillage and/or tyre debris. Contaminants collected by the surface run-off are at a higher level than contaminants leached from the construction material. In this case, the construction material may act more as a receptor, sorbing run-off contaminants, than as a source which liberates its own contaminants.

2.2.7 What takes place in the pathway?

In some circumstances, most materials can leach amounts of contaminants higher than regulatory or site-specific requirements. Thus, availability testing can, on the face of it, rule out materials (and not only secondary ones). However, few reported cases have arisen where actual hazardous levels have been detected in ground or surface waters. Either the source does not liberate as much of the contaminant as would be expected or the liberated contaminant is attenuated before arrival at the monitoring point.

We have encountered little information on the realities of release of contaminants from pavement layers and embankments. Where construction descends beneath the normal (or high) water table level and saturation can be expected, then a leaching test might give a reasonable assessment on leachability (see Chapter 2.2.8). However, above the water table, the lack of saturation will significantly reduce effective permeability, thereby limiting the rate of egress of water (whether contaminated or not). The unsaturated state will also lead to suctions. Cconsequently, pore water is held and not displaced.

All kinds of alternative mechanisms may be at play in the pathway. Bioattenuation mechanisms are highly effective, as the experience of SUDS (Sustainable Urban Drainage Systems) has shown, though these mechanisms may be selective in what is attenuated and what is not (Scottish Universities SUDS Monitoring Group 2004). Seepage that is directed to surface ditches before arriving at a control point is likely to be affected most, but even sub-surface drainage systems will be populated by bacteria which are likely to attenuate organic species and may affect the concentration or bioavailability of some non-organics. Sorption is a major attenuation process, both by materials encountered in the margins of drainage systems (including settled solids) and by soils and aggregates through which the water passes.

Attenuation by sorption is normally dealt with using partition factors, where a partition factor is defined as the contaminant concentration water:solids for a water specimen in contact with a solid specimen. Published values are available, but may vary by many orders of magnitude and are specific (or should be so used) to each species, pH and soil.

2.2.8 Which leaching test should be used and what should be done with the results?

The range of leaching tests is vast. Most have been developed for landfills and/or contaminated land purposes and therefore may not be appropriate for road construction purposes. Originally, they would be applied to high concentration contaminants, usually below the water table, and often to containment barrier materials. Clearly, these are very dissimilar to pavements.

Leaching tests may be directed primarily at:

- obtaining advection data (i.e. the ease with which a contaminant is carried out of the solids by flowing water),
- obtaining diffusion data (i.e. the ease with which a contaminant will move through static pore, and other water),
- observing fully or partially saturated percolation behaviour,
- observing behaviour under an externally set pH, or under the material's own equilibrium pH (which may change during the test due to the leaching product).

None of the conventional tests will exactly replicate conditions experienced in the construction, mainly because these conditions will vary because of the different parts of the construction and inherent material and water variability. In addition, the timescale is different. A leaching test needs to give quick results (generally, 24 hours to a few months) whereas the construction must perform satisfactorily for decades.

2.2.9 In practice, what is the permission/exemption regime?

When we develop guidelines for the assessment and use of secondary materials in road construction, it is essential to understand the permission/exemption in place. If regulatory officials are responsible for actively permitting an application to use the material, or if they have to be notified and they have the power to prevent use, they may hinder applications for fear that a resulting environmental incident may be attributed to them, however poorly founded this fear may be. The underlying problem is that it is almost impossible to prove the lack of a hazard if any result from any test or assessment indicates a concentration of contaminants greater than a limit value. Scenarios and risk-based assessments can readily indicate that the risks are infinitesimal and/or that run-off values will be of far greater concern, but such calculations do not entirely remove the possibility and, by their nature, include considerable uncertainty for the reasons already discussed in previous sections. Currently, nobody would blame regulators for not permitting a secondary material to be used but certainly public opinion would blame regulators if they allowed a material which resulted in deleterious consequences to be used.

Thus successful guidelines must provide legal 'shelter' for the regulators. It is less important that they provide this for the clients, designers and contractors, as these organisations have a financial and, perhaps, an environmental incentive to consider use. Also, clients, designers and contractors have liability insurance to act as a long-stop.

2.3 Other issues

2.3.1 General

The major issues which need to be addressed in developing guidelines are those hurdles which tend to prevent use. However, other issues influence, or should influence, use.

2.3.2 Ensuring adequate mechanical performance

Achieving adequate mechanical performance is rarely a problem; the problem is achieving this in an acceptable way. Acceptability usually means one of the following:

- ***Economically acceptability:*** Blending and/or adding stabilising agents such as lime, cement or ground pozzolanic slag can make most materials workable, but sourcing (manufacture and transport) these may be costly, so high proportions of such components may make the whole uneconomic.
- ***Sustainability of the solution***: Adding high qualities of cement can often provide a solution, but the high embodied energy in cement might make such a solution undesirable from a sustainability perspective. This would undermine much of the environmental logic in using a secondary material in the first place. More generally, the production, amendment and placement of the secondary material should be at least as sustainable as that which it replaces. At present, the absence of simple ways of measuring the sustainable benefits of reduced dumping, and the benefits of re-use and the sustainable 'costs' of quarrying natural aggregate prevents a simple cost/benefit balance from being achieved.
- ***Similar long-term performance:*** As with any new material, immediate success does not, of itself, presage lasting performance. The general difficulty of predicting long-term adequacy of any material from short-term tests, combined with the unusual mechanisms by which performance is assured in some secondary materials (e.g. weak bonding or different packings), raises some rightful concerns about longevity.

2.3.3 Assessing and specifying for performance

Traditional specifications have often sought to obtain adequate performance by specifying the basic characteristics of a mineral (e.g. grading, plasticity or stone strength). Secondary materials are usually fundamentally unlike conventional materials, having different means by which structural adequacy is provided. They may be more open graded and rely on a network of particle contact points to provide strength and other mechanical properties. Often, they have some natural or added binding property so that performance depends, crucially, on the quality of the inter-granular contacts and the level of binding.

In this situation, it is essential to relate the end-product performance to that of conventional material. Principally, the designer will be interested in:

- strength (in earthworks applications),
- stiffness of the layer of secondary material,
- resistance of the layer to forming ruts,
- long-term ability of the material to hold these properties, and
- cracking behaviour (for stabilised or naturally pozzolanic materials).

As these considerations are not routinely performed on all conventional materials (for example, the propensity for rut formation cannot be assessed at design level), a considerable change is required in roading practice, not just for secondary materials.

Currently, two avenues appear to be opening up. The American Association of State Highway and Transportation Officials (AASHTO) 2004 approach would be to run sophisticated laboratory assessments and modelling. This is probably only possible for the largest road schemes where materials are available for testing long before it is used. Alternatively, repeated load triaxial testing with associated rut depth modelling, *in situ* assessments by dynamic plate tests, and trafficking trials are possibilities. Given that many secondary materials come from an industrial process and are therefore very consistent year-on-year, trial road construction and determining the *in situ* test values associated with adequate performance may be the best way of assessment and site control.

2.3.4 Design

In Europe and North America, pavement structures generally comprise layers of asphalt, the main structural element, over one or more unbound layers (where quality diminishes with depth) over the subgrade. In New Zealand, a common pavement structure comprises a double chipseal layer over a high quality unbound base and (usually) a lower quality aggregate sub-base.

Many secondary materials are ill-suited to act as direct replacements for the critical structural layers. As they do not share any of the original layer’s specific combination of stiffness, permanent deformation or fatigue characteristics, their best application may not be as a replacement for any of the original layers. Instead, the application that best exploits the properties of the material must be found.

As an example, the low tensile strength and high stiffness of many of these materials which have some self-binding characteristics (or have been stabilised) gives them the ability to provide a high structural support, but this needs to be at such a depth that reflection cracking is not an issue. Thus they are unlikely to be best used immediately under a chipsealed area, even though the stiffness and permanent deformation characteristics might exceed those of a granular base layer. Instead, the material might be best placed between two thin aggregate layers, the lower one providing a base for compaction and the upper one providing strain dispersal to prevent reflective cracking of the seal.

2.3.5 Construction

Contractors have a lot to learn about using alternative materials. Few intrinsic difficulties are associated with the use of most materials. Particular issues to consider are:

- ***Moisture content:*** In the case of pozzolanic activity or stabilisation, sufficient moisture must be present in order for hydration to occur. This may require more careful control than is normal for granular materials, with a target 'optimum' being just a little greater than that needed for best compaction.
- ***Compaction technique***: Conventionally, vibrating rollers have been used to compact materials. Where a broad grading exists, this may be best. However, grid rollers have been used successfully for particularly flaky materials, and pneumatic-tyred rollers may be better for materials which are low in fines. A trial will reveal the best practice for each material.
- ***Workability***: Most of the pozzolanic/stabilised materials have much longer workability than conventional cement-bound materials (24 hours is possible). This can have significant implications for batching and local storage.
- ***Slow property gain***: Pozzolanic reactions are generally slow, so immediate full structural behaviour cannot be assured. This can cause problems to contractors who want to use part of a pavement construction as a temporary haul route or to carry diverted traffic.
- ***Placing***: Many materials will need to be placed by a paver rather than by a grader in order to hinder segregation and to maintain a homogenous moisture distribution.

2.3.6 Long-term recyclability

For a truly sustainable use, the secondary material needs to be recyclable in its turn at the end of the life of the pavement into which it has been placed. This means that excavatability, reprocessing and re-stabilisation need to be considered at the outset. Inclusions designed to make the material function only in the short term should either be biodegradable or extractable.

3. Review of international literature

3.1 General

This literature review focuses on leaching. Many reasons can be given as to why a material is considered unsuitable and a number of these have been discussed in the previous section. Usually, non-leaching hazards are well known and the producer has some manner of overcoming them or knows that the material is not sellable, as these hazards are intrinsic to the material. Regulators need to have a strategy for such materials, but in most cases, this can simply be to exclude their use.

3.2 Leaching experience

Relatively few sources of literature concentrate on the leaching of contaminants from the sub-base or base construction. This is partly because leachants have seldom been identified as a key contaminant source. The question whether contaminant leaching from the construction layers is a significant problem or an unrecognised problem needs to be addressed.

To the authors' knowledge, only a few cases have arisen where contamination from leachants has been identified as causative of a problem, and this is not because of lack of opportunity. Slag and ash-based construction was widespread in the UK, France, the US and the Netherlands for many years until about 10 years ago. Some continues to be used, although the concerns that lie behind the commissioning of this report have certainly reduced usage in many of these countries. In addition, many roads still have secondary materials as major components within their structures. However, the authors know of only one case where a demonstrable deleterious leaching effect has been recorded (Taylor 2004), in which slag rich in lime was used beneath the water table adjacent to a river. The alkalinity and calcium levels in the river were raised and fish were killed as a result. This usage was well beyond that recommended for use of slags, i.e. that they should not be used without source preparation, that they should be aged to reduce immediate leachate levels, and that they should not be placed beneath the water table.

The only other occurrences known to the authors concern the indirect effects of spontaneous or other combustion (Humphrey et al. 1997). In the case referred to, large heaps of shredded tyre rubber had been used to form an embankment. They spontaneously caught fire, leading to tar-like organic seepages to the surrounding ground.

In general, contaminant leaching from the construction materials in pavements is not significant. The concentration of contaminants in run-off is far more significant. Several studies have reported high contaminant levels, e.g. Makepeace et al. (1995), Thompson et al. (1997), Barrett et al. (1998), Hares & Ward (1999), Pagotto et al. (2000), Moy et al. (2002) and Kayhanian et al. (2003). The literature almost always reports contaminant levels in excess of typical norms, e.g. drinking water requirements or environmental water standards. As these water quality standards are invariably tightened with passing time, while run-off quality changes little, more and more species in run-off samples will exceed defined limits. However, this is not to say that leaching water quality is not 'worse' in some respects. Typically, surface run-off is high in species associated with engine, tyre and brake debris – e.g. manganese, iron and organics, together with de-icing salts. Typically, depending on the construction material, leachates are high in species such as calcium, magnesium and potassium. To some extent, a direct comparison between run-off and leachate waters is impossible. Nevertheless, leaching from the construction material itself is not likely to give rise to concentrations as excessive as many run-off waters.

Monitoring of leaching from road constructions is almost unknown. Owners are not keen to unearth a problem that no-one is complaining about. Also, if a contaminant is found, it is difficult to determine if it came from the construction material being considered. However, some *in situ* monitoring has been done, though without strong conclusions being reached, as it is difficult to prove that nothing is happening. Nevertheless, the available data (Reid et al. 2001, Arnold et al. 2003) strongly suggest that the alternative materials investigated do not have any significant effect on groundwater quality. Furthermore, some materials remove contaminants and therefore have a positive environmental impact.

3.3 Laboratory and outdoor testing

The ease of performing laboratory testing means that leachate testing has received more attention, but little research has been specifically directed at pavement material leaching. Hill (2004) specifically dealt with this, as did the earlier work by Baldwin et al. (1997). Both documents contain a large database of leached concentrations from different kinds of leachate testing, and form a useful resource for those considering placing materials in a pavement construction.

Wider ranging than either of these was the Alternative Materials (ALT-MAT) project (Reid et al. 2001). The project included use of the 'pH-stat' test, a leachate test in which the pH level is kept constant rather than controlled by the leaching process and the leached materials. Both Reid et al. and Hill performed outdoor lysimeter tests to monitor likely *in situ* behaviour.

All three used the EN 12457-3 (CEN 2002a) laboratory leaching test (or an earlier form of it), as well as other tests. The EN 12457-3 test measures the availability of contaminants under intense shaking and considerably high water volume conditions. Provided these are interpreted and not used as providing a *de facto in situ* leaching value, then the tests confirm the absence of leaching of concern (Reid et al. 2001). More details about the mechanisms at work in leaching tests and their relationship to each other can be found in van der Sloot & Dijkstra (2004).

Van der Sloot and colleagues appear to have adopted a scientific approach that is good in developing an understanding of the process, in informing the regulatory authorities of the meaning and limitations of results obtained from different test methods, and in calibrating analytical models. However, their work is less helpful as an acceptance approach for implementers (designers and contractors). For this latter purpose, an approach that tests materials in as near-simulative a manner as possible seems a more credible method. The closest (standardised) test available to this goal is the 'tank' leaching test (CEN 2002b) that can be performed upon compacted granular materials at laboratory scale at full grading.

The approach of several researchers has to been to build trial constructions (e.g. Dunster et al. 2005) or to investigate old constructions (e.g. Arnold et al. 2003). While these studies provide evidence that past use was satisfactory and therefore raises confidence, the authors' experience is that these are not convincing to many of the regulatory staff.

3.4 Assessing materials

If an aggregate can leach contaminants, site-by-site assessment of a particular material's suitability would be costly and, typically, difficult to achieve in the time available between the award of a contract and the contractor selecting a material source for use in the work. Several attempts have been made to provide generic guidance, either for a specific type of material or for a group of materials. The Waste and Recycling Action Programme (WRAP) in the UK has a government-supplied remit to promote re-use and, to this end, has issued advice on its website (www.wrap.org.uk/construction). It has also published protocols for re-use (WRAP 2005) which are designed to allow suppliers to declare the acceptability of the material being supplied. In particular, WRAP (2005) defines inert wastes as follows:

Waste is inert if:

- it does not undergo any significant physical, chemical or biological transformations;
- it does not dissolve, burn or otherwise physically or chemically react with, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm to human health; and
- its total leachability and pollutant content and the ecotoxicity of its leachate are insignificant and, in particular, do not endanger the quality of any surface water or groundwater.

Several 'Environmental Information Sheets' provide information related to leaching (WRAP 2004a-d). While they are generally helpful, it is likely that these documents will provide a guide to best practice rather than a definitive method by which a candidate material may be judged as satisfactory for use in a pavement.

A detailed assessment of a source material was provided by Abbott et al. (2003) on incinerator bottom ash, about which some were concerned that dioxin migration would be a problem. Abbot et al. undertook a very comprehensive study and risk analysis which could be repeated for other products. However, the cost and time to undertake such a study would prohibit its use in any regular sense.

3.5 Contaminant movement

The preceding parts of Chapter 3 have addressed the source of contaminants and whether or not the source will actually release a contaminant in sufficient quantity to be of concern. If this is a concern then the questions of relevance to ask are:

- Where does it go?
- How long does it take to get there?
- Is it still at a sufficiently high concentration for continuing concern on arrival?

Although principles of contaminant transport are well established, their application to the pavement environment is much less well developed. In particular, the water movement regime is not well established for pavements. Although the common supposition is that run-off goes to a verge drain (and maybe percolates into the pavement a little) then drains laterally to the stormwater drains, the reality may be somewhat different. Vertical drainage through the pavement to a subgrade may be common, particularly on permeable subgrades. A fair amount of evidence exists to show that water does get into pavements through the surface via tiny cracks, construction imperfections and even through intact bitumen films. This is a common issue for the chipsealed pavements commonly used in New Zealand.

Water that enters a lateral drain may not exit it in the manner assumed by the designer. The drain may act as a long soak-away for much of the time and only acting as a conduit in severe storm events when soak-away capacity is exceeded. Thus, the probability is that water carrying contaminants soaks into the subgrade.

Most subgrade soils have a high partitioning ability, i.e. they can sorb contaminants from the water around them. This partitioning ability almost certainly takes contaminants close to the drain or close to the base of the pavement for vertically percolating water very rapidly.

Partitioning is a complex field. Published values of K_d, the partition coefficient (the ratio of the mass of contaminant sorbed per kg of solids to the mass remaining in each litre of groundwater, units = l/kg), can vary by six orders of magnitude. This level of variation can be attributable to factors such as the sensitivity to pH, soil variability, redox condition, cation exchange capacity, mineralogy, complexation and other contaminant concentrations. A discussion of variability is available in a US Environmental Protection Agency (EPA) report (EPA 1999a) and some sample values are given in its second volume (EPA 1999b). Published values of K_d are available in Sheppard & Thibault (1990).

This partitioning ability is not limited to soil. Aggregates themselves have a partitioning capacity. It is probably not so large because of reduced surface area and less favourable surface chemistry. However, it has certainly been observed and is nowadays an additional benefit lauded by the users of so-called ‘permeable pavements’ (also called SUDS) which are promoted in urban areas as a means of run-off hydrograph attenuation (Baladès et al. 1994, Legret & Colandini 1999, Grange 1995, Pratt et al. 2001).

A report by the Scottish Universities SUDS Monitoring Group (2004) studied a range of SUDS chosen to reflect the range and diversity of installations in Scotland. They concluded that while minor levels of contamination were frequently noted, no cases of extreme pollution were observed during the monitoring period. With most SUDS in Scotland serving urban areas and receiving relatively high levels of pollutants in the road run-off, in many instances, without the protection offered by the SUDS (i.e. without the partitioning ability of aggregate and without the sorption of pollutants by the subgrade under the SUDS), chronic levels of receiving water deterioration would have occurred.

The Monitoring Group concluded that:

- The volume of surface water discharged from SUDS was always found to be less than the inflow and, by inference, the pollutant load potentially reaching the environment must be significantly reduced – this appears to support the contention of soak-away action and partitioning of pollutants to the solids in the system. While this may have been a significant finding, no consideration was made of contaminants migrating downward into the subgrade and, potentially, to the groundwater table.
- All SUDS types appeared to contribute to retaining pollutants locally.
- All observed pollutant peaks were reduced, in most cases significantly (i.e. pollutant concentration peaks were attenuated).

While these findings are not directly transferable to conventional roads, they indicate that very significant processes areavailable for attenuating any contaminants that exist at a somewhat elevated level caused by source leaching.

3.6 Modelling water and contaminant movement

Modelling water and contaminant movement has been attempted, but this is still largely at a research stage. A key resource is the report by Apul et al. (2002). This report reviews what is known about water movements and the controlling influences on them. The report also contains some discussion on issues affecting quality in the report, a topic which Apul et al. discuss more fully elsewhere.

The Recycled Materials Resource Center at the University of New Hampshire held a workshop in February 2004, which is probably the single most complete source of information in this area. The workshop was entitled ‘Water Movement and Reactive Transport Modeling in Roads’. Dr Apul’s PhD thesis (2004) provides additional information on this topic.

4. New Zealand literature

4.1 Transit New Zealand specifications

The current status of environmental criteria for industrial by-products in New Zealand is generally reactive rather than proactive. However, Transit New Zealand has recently promoted the use of industrial by-products and recycled materials by including specifications for the use of melter slag, crushed concrete and waste glass in the current (M/4) specification for premium basecourse aggregates (Transit New Zealand 2006). The Transit M/4 specification also includes brief descriptions of environmental mitigation procedures for each material. This approach is consistent with Transit's so-called 'triple bottom line reporting', where all major projects are evaluated in terms of three key factors:

- economic viability,
- environmental viability, and
- social viability.

4.2 Acts of Parliament and government departments

Two main Acts of Parliament are relevant to the use of industrial by-products in road construction:

- the Resource Management Act 1991 (RMA), and
- the Hazardous Substances and New Organisms (HSNO) Act 1996.

The RMA provides the regulatory framework for territorial authorities (TAs) to promote the sustainable management of New Zealand's natural and physical resources. Construction activities requiring resource consent under the RMA will have specific conditions regarding water use and discharges, as well as discharges to air.

The HSNO Act provides definitions of materials and substances that are deemed to be hazardous, and it provides controls over what materials can be used and how they are used. The HSNO Act is administered by the Environmental Risk Management Authority (ERMA). ERMA has a number of statutory functions under the HSNO Act. These include:

- making decisions on applications under the HSNO Act by evaluating risks, costs and benefits, and placing conditions on approvals;
- monitoring and co-ordinating compliance with the Act and Authority decisions;
- promoting public awareness of the risks of hazardous substances and new organisms; and
- enquiring into accidents or emergencies.

The Ministry for the Environment (MfE) maintains the New Zealand Waste List on their website (MfE 2006). This list is also known as the L-code. The L-code was established in 2001 and it lists a large number of waste products that are generated by a wide range of New Zealand industries. The list indicates which of the products are deemed to be hazardous.

ERMA (2001) provides definitions and threshold criteria for various classifications of hazardous substances in New Zealand. The classifications include materials with the following hazardous properties:

- explosive,
- flammable,
- oxidising,
- corrosive,
- toxic, and
- ecotoxic.

In the context of this study, the toxic and ecotoxic threshold criteria are most relevant. The ERMA document provides both test methodologies and guidance regarding interpretation of test data.

The MfE provides guidelines regarding disposal of hazardous waste material. In the context of this study, acceptance criteria for landfills are likely to provide relevant criteria for the use of industrial by-products in roads. In fact, roads are often flippantly referred to as ‘linear landfills’.

The Hazardous Waste Guidelines (MfE 2004) describe two classes of landfill.

- **Class A landfills** are sited in areas to minimize potential adverse effects on the environment and have systems engineered to provide leachate control.
- **Class B landfills** may be in areas that pose a risk to the environment and have limited or no systems engineered to collect leachate.

MfE (2004) provides screening criteria and leachate concentration limits for a number of contaminants. Specific elements and compounds are listed under the following classifications:

- inorganic contaminants,
- aromatic hydrocarbons,
- polynuclear aromatic hydrocarbons,
- halogenated aromatic hydrocarbons,
- benzene, toluene, ethyl benzene and xylenes (BTEX),
- chlorinated aliphatic hydrocarbons,
- halogenated aliphatic hydrocarbons,
- phenols,
- pesticides,
- phthalates,
- other organics, and
- organometallics.

4.3 Auckland Regional Council

The Auckland Regional Council (ARC) is responsible under the RMA 1991 to protect the environment of the greater Auckland area and to ensure that clean air, water and soil resources exist for the future.

ARC has specific pollution and storm water quality teams who monitor the environment and enforce the conditions of the RMA. However, much of the work carried out by the pollution and storm water teams is reactive rather than proactive. This is mainly attributable to the limited personnel available to the ARC and that the teams cannot be aware of all construction activities occurring in the region. However they do (generally) become aware of spills and other environmental incidents after the fact.

ARC (2004) provides a blueprint for monitoring urban receiving environments. It provides a description of the contaminants of particular interest and appropriate environmental response criteria. These parameters are reported in terms of three primary components:

- sediment quality,
- benthic ecology, and
- water quality – for both ecosystem protection and human health.

In terms of the use of industrial by-products and recycled materials in road construction, the main point of interest is the composition of any sediment or leachate that can be liberated to the air, groundwater and/or surface water courses.

ARC (2004) defines three levels of response criteria for sediment contaminants:

- **Green Zones** where sediment contaminant concentrations present a low risk to the biology of the site,
- **Amber Zones** where sediment contaminant concentrations are elevated and the biology of the site is possibly affected, and
- **Red Zones** where the sediment contaminant concentrations are high and the biology of the site is probably affected.

ARC (2004) describes test procedures and acceptance criteria for the primary components of the environment and the critical contaminants. These criteria could be used in developing a set of guidelines for the assessment of industrial by-products and recycled materials in road construction.

4.4 Recent New Zealand Literature

Opus International Consultants Ltd (Herrington et al. 2006) developed a set of guidelines to evaluate and screen new and recycled materials used in road construction with respect to any potential for adverse effects on the environment. Unfortunately, the authors of the current report were unaware of the Opus project at the time that the current brief was established, as the two projects have very similar objectives.

Herrington et al. (2006) recommended that a three-stage material evaluation process be adopted. The process is summarised as follows:

- **Stage 1: initial assessment:** All existing information on the proposed material is gathered and assessed to determine if the material is deemed to be hazardous with respect to ecotoxicity. The L-code and other ERMA information would be used in the assessment. If the information is insufficient for drawing a conclusion regarding the material's properties and environmental security, the evaluation process moves to Stage 2.
- **Stage 2: material screening tests:** Samples of the proposed material are subjected to a testing programme to determine if leachable contaminants are present that could have an unacceptable environmental impact if the contaminants are released. The leachates are analysed to establish their chemical composition and to identify any aquatic ecotoxicity properties. The acceptance criteria for Class B landfills would be applicable. The evaluation process extends to Stage 3 if the acceptance criteria are not achieved.

- **Stage 3: comprehensive environmental impact assessment:** If the first two stages of the evaluation indicate that materials contain contaminants that have the potential to adversely affect the environment, then a more comprehensive study is required. The Herrington et al. (2006) document does not provide a detailed discussion of the process as the testing and assessment requirements would vary on a case-by-case basis. However, in general terms, the Stage 3 evaluation would need to consider factors such as:
  - construction parameters, material location and configuration,
  - contaminant release mechanisms,
  - leaching potential with respect to pH,
  - leaching potential with respect to water/solid ratio,
  - effect of sorption,
  - cumulative release of contaminants, and
  - site-specific acceptance criteria for the receiving environment.

5. Strategy for environmental guidelines

5.1 General

The information presented in this literature review highlights the complexity of the issues associated with assessing the environmental security of industrial by-products and recycled materials in road construction. Consequently, an assessment strategy needs to be somewhat conservative so that a practical and cost effective process can be achieved. Having said that, sufficient documentation on test specifications and acceptance criteria is already in place in New Zealand to develop a sound material assessment process. It simply needs to be pulled together into a concise and logical framework so that the waste processing and road construction industries are clear on their requirements and responsibilities.

Whatever assessment process is implemented, it is important that the whole-of-life cost of using alternative materials in road construction is lower than that for conventional materials. This whole-of-life cost should consider factors such as:

- any compromises in mechanical properties of the material resulting in additional maintenance,
- any additional monitoring or testing required to establish the composition of the material and its potential for contamination,
- assessment of the long-term risk of unforeseen contamination,
- benefits in terms of reduced landfill requirements and consumption of conventional construction resources,
- the residual value of the layer(s) at the end of the pavement life, and
- the political benefit of the recycling image, albeit intangible.

5.2 Suggested materials strategy

5.2.1 Classifications

A materials assessment strategy based on a three-tier classification for waste and industrial by-products is suggested, namely:

- inert materials,
- notifiable materials, and
- assessable materials.

Producers of waste or industrial by-products who wish to supply materials for road construction activities would provide evidence to the presiding TA regarding the classification of their products. The various classifications are described in the following paragraphs.

5.2.2 Inert materials

Inert materials pose no threat to the environment and would be accepted for use in road construction applications without limitations and without the need for prior approval.

Inert material status could be achieved on the basis of precedent, local or international literature, or by showing compliance with appropriate acceptance criteria without necessarily carrying out specific testing. Materials identified as not being hazardous in the MfE L-code list (MfE 2006) would be considered inert, as would materials complying with the MfE acceptance criteria for Class B landfills (MfE 2004). Alternatively, TAs would require compliance with local criteria such as the ARC (2004) 'Blueprint for monitoring urban receiving environments'.

5.2.3 Notifiable materials

Notifiable materials can be considered to be environmentally acceptable in certain applications, locations, quantities or construction processes.

Notifiable materials would receive blanket approval by the presiding TA once the producer or user provides evidence of the material's environmental security to the satisfaction of the TA. Such evidence would need to be specific to the proposed application and could include specific conditions or restrictions on use. For example, some materials could be restricted to applications above the water table or in sealed layers, or possibly restricted to certain locations with low environmental significance. Acceptance criteria would be established by the presiding TA, but would most likely include either the MfE classification for Class B landfills, the ARC (2004) criteria or the criteria reported in Herrington et al. (2006).

Users of notifiable materials would need to notify the TA of any intended use of the particular material, along with a description of the location and application. Permission to use the material would not be withheld unless the application was outside any of the restrictions established for that material.

5.2.4 Assessable materials

Assessable materials may be seen as being a significant risk to the environment. The producer or user would need to provide evidence of a rigorous, site specific environmental assessment for each individual application to the satisfaction of the presiding TA prior to using the particular material.

The assessment would need to include factors such as:

- acquisition,
- stockpiling,
- transportation,
- storage on site,
- construction processes,
- in-service performance,
- long-term performance, and
- reworking or removal strategy.

In addition, each assessment would need to consider the specific location of the intended use, the environmental significance of the location, any performance track-record for the material, and mitigating factors.

The acceptance criteria that the material would be assessed against would be a combination of the MfE Class B landfill criteria (MfE 2004) and the criteria reported in ARC (2004) and Herrington et al. (2006). The actual requirements would be set by the presiding TA.

5.2.5 Environmental information sheets

Under the proposed system, producers of waste or industrial by-products would establish environmental information sheets similar to those used in the UK (WRAP 2004a–d) for each product they produce. The environmental information sheets would provide the evidence of compliance required by the TA, as well as providing guidance for users and any other interested parties.

The environmental information sheets would provide information on topics such as:

- material status (i.e. inert, notifiable or assessable),
- origin of the material,
- acquisition and supply,
- chemical composition,
- appropriate handling/storage/transport procedures,
- appropriate applications,
- appropriate construction procedures,
- mechanical properties,
- environmental compliance test data,
- restrictions on usage, and
- case studies.

The environmental information sheets would be reviewed by the presiding TA to ensure that any conditions or restrictions on the use of the material are appropriate.

5.2.6 Management

The suggested environmental assessment system would require the material processor or supplier to be proactive in the assessment process and that a high level of co-operation should exist between the supplier and the TA. Ultimately, the TA would have the final say in the acceptability of the proposed material and its status for use. The day-to-day working of the system would be contained in the authority's engineering standards documentation.

A schematic diagram of the proposed assessment process is presented in Figure 5.1. The key juncture in the process is the testing and compliance check stage. The level of compliance required would be determined by the presiding TA. However, it is envisaged that the requirements described in MfE (2004) for Class B landfills, ARC (2004) and/or Herrington et al. (2006) would be appropriate.

Under the proposed system, producers of waste and industrial by-product materials would be able to apply to the TA to raise the classification of any particular material on the basis of additional testing and a favourable track record. This means that notifiable materials could achieve 'assessable material' status and assessable materials could achieve 'inert material' status at the discretion of the TA. Similarly, materials could have their status demoted if worse than expected performance or variability in the quality or composition of the material is discovered.

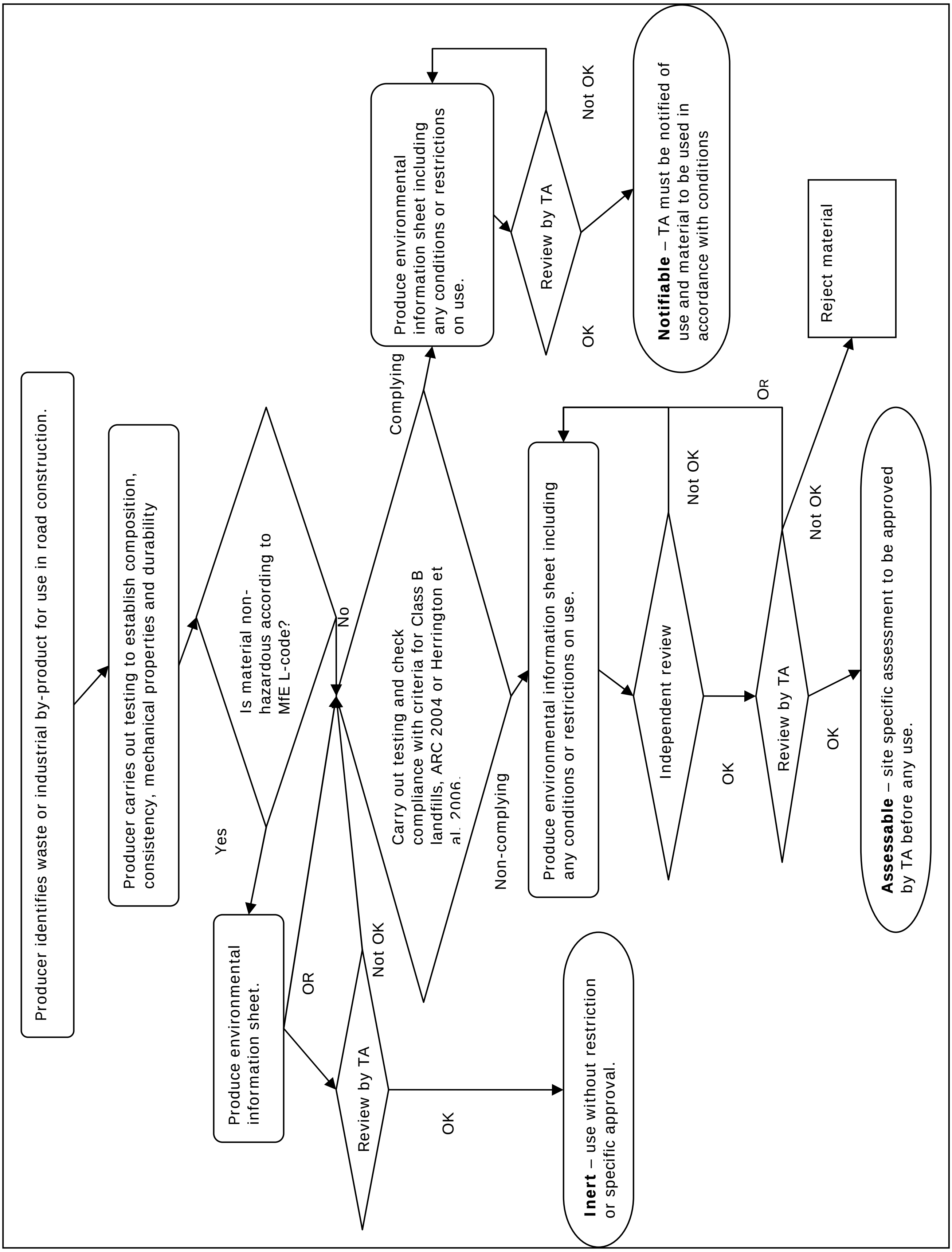

Figure 5.1 Schematic outline of proposed material assessment process.

6. Summary

This report presents the results of a literature review on the topic of the environmental impact of industrial by-products in road construction.

The international technical literature has been reviewed and a number of issues with regard to the presence and liberation of contaminants have been discussed. The literature shows that the topic of environmental impact is extremely complex and, by necessity, any practical assessment strategy needs to be relatively conservative for it to be reliable.

The New Zealand literature has also been reviewed and it indicates that a number of documents are currently available that address the issues of hazard substances and acceptance criteria for contaminants. Of particular interest are the criteria published by MfE regarding Class B landfills (MfE 2004), the ARC (2004) criteria for urban receiving environments and the strategy for material assessment presented in Herrington et al. (2006).

A new assessment process has been suggested as a result of the literature review. It basically involves a three-tier classification system where industrial by-products proposed for road construction applications are deemed to be inert, notifiable or assessable depending on their composition, intended use and track record.

Materials deemed to be *inert* pose no threat to the environment and can be used without restriction. *Notifiable* materials can pose a moderate threat to the environment if not used appropriately. These materials can be used conditionally and their use must be notified to the presiding TA. *Assessable* materials can pose a significant threat to the environment in certain circumstances. A site-specific environmental impact assessment must be lodged with the presiding TA for approval prior to using these materials.

The proposed assessment system will place the onus for testing and categorising of industrial by-products on the suppliers, while TAs will have the final sign-off on the application of such products using the level of acceptance criteria that the various authorities are comfortable with.

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