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Use of Road Stabilizers in Sensitive Environments

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Abstract: ***Road infrastructure is key for any developing country to enable its expansion such as those in Africa. Natural road construction materials can become depleted and increasing traffic loads produce higher maintenance requirements, leading to research to develop additives that can be used to enhance the engineering properties of available pavement soils. Providing all weather roads for large vehicles in rural areas, such as Northern Namibia, are often based only on the available soils, involving compaction and use of stabilizers, is required to both provide a suitable load bearing road surface and maintain the road network. The region is also environmentally sensitive to any potentially adverse impacts of chemicals that may be released into the environment during construction or as breakdown products. A number of road stabilizer products are available and the choice of stabilizer must take into account both its specific properties and the sensitivity of the environment where it is to be used to any environmental impacts. The main stabilizer types are cementitious, bituminous and chemical, with the latter broken down in a range of materials including synthetic polymer binders, organic and ionic compounds, salts, enzymatic products and combinations thereof. Twenty available stabilizer products were considered in terms of their environmental properties and assessed against the published literature and the general findings reported in terms of the overall ranking of the environmental impact of stabilizer types.***

Keywords: ***environmental impact, roads, sensitivity, stabilizers***

I. INTRODUCTION

Provision of a secure road network in developing countries is key to enable the cost effective and safe movement of goods and people. While the use of concrete and tarmac to surface road networks is common in developed countries this is usually not possible in developing countries, except in cities.

As development continues internationally, increasing kilometres of roads are being constructed and multitudes of roads are being rehabilitated and maintained annually. Natural road construction materials that were used historically are being depleted and traffic loads continue to increase. As a result, research is ongoing to develop additives that can be used to enhance the engineering properties of available pavement soils.

Roads in rural areas therefore are based on the soils available in the region and to make them usable for large vehicles in all weathers the soil must be compacted and stabilised to provide a cohesive, load bearing, road surface. This is achieved by a combination of civil engineering measures to form the road surface and use of chemical additives, known as soil stabilizers, added to the soil to enable a compacted road surface to be formed.

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The choice of which stabilizer to apply must take into account both the specific properties of the stabilizer and the sensitivity of the environment where the stabilizer is to be used, to ensure any potential adverse environmental impacts are avoided wherever possible or at least minimised.

One such location where road stabilizers are required to provide and maintain the road network is Namibia, south west Africa. In Namibia road construction materials have always been scarce in the northern regions, where most development of new roads is focussed.

In recent years numerous vendors of road stabilizing agents have introduced a variety of proprietary products to both the Roads Authority and private developers throughout Namibia. These products present opportunities to address a number of challenges relating to both the provision of new roads and maintaining existing roads. However, before such products are submitted for trials, it would be helpful to ascertain what the potential environmental and health related impacts of such products could be and how to implement their use in a responsible manner.

Recognizing the need for investigating alternative methods that would enable cost effective construction of new roads, especially in rural areas the Roads Authority of Namibia commissioned SLR Environmental Consulting (Namibia) (Pty) Ltd, Colin Christian & Associates and specialist inputs on the chemistry of stabilizers from SLR UK, to ascertain the potential environmental and health related impacts of such products and how to apply their use in a responsible manner. This paper reports the outcome of the exercise.

II. SENSITIVE ENVIRONMENTS

The definition of a sensitive environment will depend on a number of factors. One such definition (Ref 1) states that: *If a habitat or species is very adversely affected by an external factor arising from human activities or natural events (killed/destroyed) and is expected to recover over a very long period of time, (10-20 years) then it would be considered to be highly sensitive.*

Sensitivity is dependent on the tolerance of a species or habitat to damage from an external factor, and the time taken for its subsequent recovery from damage sustained as a result of an external factor. Assessments of tolerance takes rarity into account, as the rarer a habitat is the more an external factor is likely to damage a significant proportion of the habitat and therefore it will have a lower tolerance rating.

On this basis the northern region of Namibia is considered to comprise a number of environmentally sensitive areas and determining the environmental impacts of any chemical compounds in such environments raises several challenges:

- chemical composition of the stabilizers must be known, including whether there are any impurities (unintended contents) and what the breakdown products are in the environment. The latter requires that one also needs to understand the chemical interactions with the soil;
- determination of what compounds and breakdown products should be looked for;
- ascertain what aspects of the receiving environment and what organisms may be affected;
- organisms may be affected in many ways that are non-lethal but can still pose a threat to a population. Persistent toxins i.e. those that don't break down rapidly, often accumulate in the food chain and may impact organisms at the end of the food chain. Such impacts may not kill organisms but may affect breeding success, or harm prey species, microorganisms, aquatic plants or any other living component of an ecosystem.

Attention has been drawn to aquatic ecosystems, as aquatic life is often sensitive to toxins and water can transport contaminants long distances. All areas producing runoff to surface water bodies should therefore be regarded as sensitive.

In summary:

- selection of road stabilizers must take into account whether they could pose any risk to aquatic ecosystems, and
- where there is a lack of knowledge about the chemical or physical impacts of stabilizers, or their breakdown products the Precautionary Principle should be applied. In practice this requires avoidance of situations where harmful substances could access water bodies, including both perennial and ephemeral water bodies. The following habitats could be at risk, even if they are seasonally inundated or remain dry for years at a time: -
  - perennial rivers;
  - floodplains;
  - lakes, pans, lagoons, backwaters etc;
  - reedbeds, papyrus, and *hygrophilous* (water loving) grasses;
  - *omurambas* and *oshanas* (dry watercourses);
  - salt pans;
  - springs and wetlands fed by groundwater;
  - karst areas, whether known to have cave lake fauna or not (normally *karst* areas will not require stabilizers, as they can provide conventional road building materials);
  - areas close to shallow wells (*omifima*), or where shallow groundwater exists that may be utilised by people and livestock.
- terrestrial plants may be less sensitive to low concentrations of chemicals that may be toxic to other organisms but in the context of Namibia:
  - 30 species of trees are known to be endemic to Namibia; and
  - 87 species are protected under various pieces of legislation or have conservation status in some form.

Figures 1- 6 illustrate both the types of underlying geology and the range of environmental settings found in Namibia.

Figure 1: Road upgrade Ohangwena Region

The road upgrade in Figure 1 required use of scarce calcrete and silcrete for layer works

Figure 2: Sand track Caprivi region

Materials for road making in sandy areas are scarce, hence the use of stabilizers would assist the development of road infrastructure in the region.

Figure 3: northern Kavango

The area of northern Kavango has sandy soils and no outcrops of rock or materials such as calcrete suitable for road making.

Figure 4: Ephemeral watercourse

Ephemeral watercourses in the western part of the Cuvelai system would be influenced by any releases from road stabilizers.

Figure 5: Agriculture and fishing

Dense rural settlements in the Cuvelai system are highly reliant on suitable agricultural soils and fish provided by the floodwaters; hence the environmental potential impact of stabilizer materials could be significant.

Figure 6: Ephemeral watercourse or "*omuramba*"

Figure 6 shows an ephemeral watercourse, or "*omuramba*", in Kavango that could be adversely impacted by the incorrect or inappropriate use of road stabilizers.

III. STABILIZER PRODUCTS

In order to provide a proper background to the use of stabilizers in road construction the following definitions are used:

- Soil: any combination of rock (crushed or uncrushed), gravel, sand, silt and clay;
- Stabilisation: treatment of soils by chemical or other means, in order to improve their engineering properties;
- Stabilising agent (stabilizer): chemical added to a soil to improve the engineering properties of the soil.
- Modification: improvement in properties obtained when a material is stabilized and there is not necessarily a development of a compressive or tensile strength. Modification is usually employed to reduce the Plasticity Index (PI) and to increase the California Bearing Ratio (CBR). The term "Modified Material" is also used.

It is further noted that cement or lime stabilization is a recognized engineering practise used extensively in Namibia and internationally. The environmental impacts of these methods are not considered. The study focused solely on the environmental impacts of patented/proprietary stabilizers.

Good quality road construction material is often unavailable in parts of Namibia. The transport costs of importing suitable materials have supported the development of stabilisation techniques able to utilise locally available resources. Often the required strengths can be obtained by altering the characteristics of locally available, sub-standard materials and stabilization is one such technique.

The objective of applying stabilizers is to bind the individual aggregate particles together, to increase strength and/or make the material more water-resistant. The addition of small amounts of stabilising agents, at a relatively low cost, can increase significantly the strength and water resistance characteristics of road construction materials.

Polymer stabilizers are of the order three times more expensive than Portland cement. Typical applications range between 1 to 2% (up to 6%) of the mass of the material being treated, with the main deciding factor usually being the cost of the stabilizers.

Commonly, utilization of polymer stabilizers is not cost effective for smaller projects, or projects that have sufficient suitable quality, road construction materials available. Another important cost factor is that specialized equipment is often required.

Conventional lime or cement stabilization is generally more cost effective, except in cases where the availability of construction material is very low.

It was expected that the use of stabilizers in Namibia by the Roads Authority would be for the following scenarios:

- rehabilitation of existing roads by recycling pavement layers and introducing stabilizing agents as part of major construction projects.
- new road construction projects in areas with insufficient road construction materials, where the requirement is to upgrade the engineering properties of in-situ, or substandard borrow materials, by addition of stabilising agents.
- ongoing maintenance requirements, where the base course of short sections of road are repaired.

Stabilizing agents are normally categorized as cementitious, bituminous, or chemical and are normally categorized according to its major constituent.

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Further subdivision of stabilizer categories used in this document are derived from AustRoads (Austroads Stabilising Binders, 2009).

Table 1 summarizes the main types of stabilizer and properties.

<u>Cementitious:</u> cement, lime, or a combination of either with milled granulated blast furnace slag (MGBS) or fly ash (FA):

- Lime (slaked or unslaked);
- Cement;
- Pozzolanic materials;
- MGBS, iron and steel slags;
- Fly ash, coal fired power stations

<u>Bituminous</u>:

- Bitumen emulsion;
- Foamed bitumen;
- Bitumen with secondary binders, such as mineral filler, rock dust and fly ash

<u>Chemical</u>:

- Synthetic polymer binders;
  - Insoluble dry powdered synthetic polymer (IDPSP)
  - Synthetic soluble polymers
- Organic;
- Ionic compounds;
- Salts;
- Enzymatic (not included in Austroads 2009) (Ref. 2)

Table 1: Stabilizer types and properties

No	TYPE		DESCRIPTION
1	Synthetic Polymer Binders		
1.1		Insoluble Dry Powdered Synthetic Polymer (IDPSP)	Water insoluble dry powder thermally bound to a fine carrier such as fly ash. Not to be confused with dust suppressants. Fine powdered product mixed with hydrated lime, flocculates and coats clay particles within the pavement material. Fly ash encapsulated by polymer is effectively inert and does not react in the stabilisation process. Its function is to facilitate distribution of polymer in the pavement material. IDPSP is used as powder and remains in a powder form during the pavement material mixing. Most insoluble synthetic polymers preserve the dry strength of pavement materials by creating a hydrophobic soil matrix, reducing permeability and minimising water absorption into the clayey fines. Three blends are commercially available and spread at a rate of 1% to 2% by dry mass of pavement material. The synthetic polymer thermally bonded to a fine powder carrier (i.e. fly ash): o blend 2:1 synthetic polymer-coated fly ash/ hydrated lime for medium plasticity materials (< 12); o blend of 1:1 synthetic polymer-coated fly ash/ hydrated lime for higher plasticity
1.2		Synthetic Soluble Polymers	Added to the compaction water to form a polymer chain which is an acrylimide or urethane copolymer. Products encapsulate soil particles with a thin film of polymer and, upon drying, create bonding and water insolubility is achieved.
2	Organic		By-product of the timber pulping industry (sulphonated lignin, tall oil pitch) or citrus industry (sulphonated di-limonene). Lignin sulphonates (sodium, calcium and ammonium lignin sulphonates) and di-limonene are by-products of the 'Kraft' pulping. Tall oil pitch usually converted into a water-based emulsion to facilitate handling and application. Tall oil pitch adheres the fine particles of the soil or pavement material; the glued matrix interlocks the larger aggregates. Hydrophobic property of tall oil pitch reduces water permeability of soils and pavement materials. Particle size distribution and plasticity influence the selection of material to be stabilised with organic binders. High plastic materials, with tall oil pitch, have demonstrated improved cohesion and neutralised clay reactivity.
3	Ionic		Mainly from sulphonated petroleum products and highly ionic. Electrochemical dust suppressants work by expelling adsorbed water from the soil that decreases air voids and increases compaction.
4	Salts		Largely waste products from the salt production or naturally-occurring in salt lakes. Magnesium chloride forms a large component of sea water. Salts suppress dust by attracting and trapping moisture from the air, keeping the road surface moist. When the atmospheric moisture falls below a certain level, these chemicals lose their effectiveness. Hygroscopic chlorides (sodium chloride) cease to function at below 70% relative humidity and deliquescent chlorides (calcium chloride and magnesium chloride) cease to function below 30 to 40% relative humidity, depending upon the ambient temperature. These types of binders are not suitable for use where a bituminous spray seal or asphalt may be incorporated, as the crystalline growth induces 'eruptions' in the seal caused by volume changes in the basecourse.

Combinations:

There is an increasing range of road stabilizing products being developed and patented that fall under the above categories or combinations thereof. The bulk of products introduced to the Roads Authority in recent years were either chemical, or a combination of the various categories indicated above.

Synthetic polymer binders/stabilizers consist primarily of either PVA, PVC or PAM (acrylamide) polymers, whereby the polymers bond fine particles and impart hydrophobic properties to the soil. They are generally effective in sandy soils, with lime added for application in clays.

This review does not include the environmental aspects of cementitious or bituminous stabilizers, as these have been in use for decades.

Synthetic polymers are either water soluble or water insoluble.

- Insoluble Dry Powdered Synthetic Polymer (IDPSP): dry powdered road stabilising binder consisting of an insoluble polymer thermally bound to a very fine carrier such as fly ash;
- Synthetic Soluble Polymers: polymer forming liquids that encapsulate and bind soil particles;
- Organic: generally a by-product of timber pulp or citrus industries, consisting of either sulphonated lignin, tall oil pitch, or sulphonated di-limonene;
- Ionic: highly ionic derivates of sulphonated petroleum products;
- Salts: salts can be used in areas where the atmospheric moisture falls below a certain level. Salts bind particles by attracting and trapping moisture from the air, keeping the road surface moist. Best suited to clay soils;
- Enzymatic: enzyme rich liquids that react with organic molecules in order to achieve an intermediary reactive that exchange ions with clayey structures. This effect generates a cemented bond, which stabilizes the soil structure and reduces its affinity for water.

Within the different categories, those based on cementitious, bituminous and enzymatic processes were excluded from the study at the request of the Client.

During any particular construction project, stabilising agents will be subjected to transportation, storage and application phases and any environmental assessment must consider the potential impacts of each stage.

A limited duration is generally allowed for mixing and setting processes during construction. Once the product is activated by addition of water and processing of the materials commences the chemical processes involved commence. Application of specialized stabilizers requires specialized supervision and strict control of the construction process. Most of the stabilizing process also involves use of specialized equipment, such as Recyclers or Rotovators.

Introduction of the stabilizer product into the pavement material is usually achieved as follows:

i. spreading or placing the stabilizing agent on the pavement material or spraying onto a windrow before processing commences;
ii. injection into the rotating drum chamber of a Recycling machine from a tanker during a recycling pass;
iii. premixing the stabilizing agent into the pavement material at a batch plant and subsequent importing the material onto the road section.

Standards for Contractors should make provision for spillages and remediation thereof and in particular, proper standards should be set for working with stabilizing agents that are potentially hazardous.

The range of the 20 stabilizer products considered are listed in the Appendix.

I. ENVIRONMENTAL REQUIREMENTS

The environmental requirements for a binder seeking approval for use relates to the potential for adverse impacts on the surrounding environment arising from its use, both during application and post-application (over time), due to wear and weathering.

Vendors wishing to sell their product into a market should be required to apply to be accepted onto an approved materials supplier list. To facilitate the review of available products, all information should be presented or made available in a summary sheet accompanying the information, including the following details:

- composition;
- testing certification;
- application;
- physical/chemical properties and hazards/toxicity;
- atmospheric concentrations;
- setting time;
- additional information

In terms of potential environmental effects, acceptance onto the list should be based a range of criteria, key amongst which is the product Material Safety Data Sheet (MSDS) and other chemical safety data as available. The MSDS data should provide a set of minimum requirements that provide sufficient data to allow an assessment of the potential environmental impacts arising from use of the substance in specific environmental settings.

Physical/chemical properties and hazards/toxicity factors to be considered when assessing a stabilizer should include:

- solubility;
- leachate;
- toxicity;
- carcinogenicity;
- corrosiveness;
- hazardous;
- acid forming potential

The UN document, *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)* Part 4 (Ref. 3), Environmental Hazards, aquatic environment, sets out the range of tests that can be applied to assess the potential impact of a chemical on the aquatic environment.

The necessary data to allow a decision on the suitability of a particular binder and its potential environmental impact is characteristically more extensive than that provided by the vendor.

The basic minimum information that each binder should have available is usually found in the MSDS, safety data sheet (SDS), or product safety data sheet (PSDS). Test data cited in these data sheets is based on the UN document but in a much-reduced form.

In addition to environmental data, other requirements needed for assessment and acceptance of an application should include the name of the vendor, name of the product, any patent information and a full product description.

The subsequent assessment of the potential impact of a stabilizer will depend not only on the properties of the stabilizer but also the particular environmental setting and how/when the binder is applied. In terms of 'application', this refers to both the initial stage involving placement of the stabilizer when spills can occur and once fully reacted and placed and its subsequent performance over the years.

Hence, while each application will be specific in terms of the combination of stabilizer and road materials used and the environmental setting, it is possible to set out general guidelines that will assist users make an appropriate, initial assessment of the suitability of a particular binder if used in a particular environmental setting.

Table 1 presents the data available for each of the 20 stabilizer products considered, which covers a range of factors, including the type/category of stabilizer, product description, MSDS environmental data, solubility, biodegradability, inertness and leachability. The 48h, mg/l, LC50 test is based on using *Daphnia*, upper 95% confidence level and the 72h, mg/l, EC50 test is the algal growth inhibition test.

Not all MSDS contain LC(50) and EC(50) data. Of the 20 stabilizer products considered, some toxicity information/data was provided by seven vendors but only one provided data for both toxicity tests.

II. BREAKDOWN PRODUCTS IN THE ENVIRONMENT

Key factors that may lead to releases into the environment are:

- inherent toxicity and/or harmful characteristics of pre-cursor substances (chemicals) used in road stabilisation and how they are stored and handled;
- the initial application stage and incorporation of the stabilizer with the road construction material, when an excessive amount may be applied or a spillage may occur;
- breakdown of the binder in the longer term leading to chronic environmental release.

In the case of the latter, important factors are the extent to which a product breaks down and the nature of the breakdown products arising. Standardised leaching tests are used to simulate the possible breakdown products generated and assess the effects of the products on the water environment. The UN document, *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)* Part 4 describes the terms that relate to the hazardous properties of chemicals and their impact on the aquatic environment.

The basic elements for use within the harmonised system are (Ref. 4):

- acute aquatic toxicity;
- potential for or actual bioaccumulation;
- degradation (biotic or abiotic) for organic chemicals; and
- chronic aquatic toxicity

While data from internationally harmonised test methods are preferred, in practice, data from national methods may also be used, where they are considered as equivalent. In general, it has been agreed that freshwater and marine species toxicity data can be considered as equivalent data; preferably derived using OECD Test Guidelines or equivalent. Where such data are not available, classification should be based on the best available data.

Two commonly referenced tests in relation to aquatic impacts are the 48h LC(50) and 72h EC(50) tests. In the LC(50) test fish (or aquatic organisms) are exposed to the test substance, preferably for a period of 96 hours. Mortalities are recorded at 24, 48, 72 and 96 hours and the concentrations that kill 50% of the organisms (LC50) are determined where possible.

The purpose of the EC(50) test is to determine the effects of a substance on the growth of fresh water microalgae (algae and cyanobacteria). Exponentially growing test algae are exposed to the test substance in batch cultures over a period, normally 72 hours. The test endpoint is inhibition of growth, expressed as logarithmic algal biomass increase (average growth rate) during the exposure period. From the average growth rates recorded in a series of test solutions and the concentration bringing about a specified X% inhibition of growth, usually 50%, is determined and expressed as the ECx e.g. EC50.

In simple terms the LC50 (mg/L) test results presented for a product can be interpreted as follows in Table 1.

Table 1: Toxicity tests

LC50 (mg/L)	Category Description
<0.1	Very highly toxic
0.1 – 1	Highly toxic
1 – 10	Moderately toxic
10 –100	Slightly toxic
>100	Practically non-toxic

Lignosulphonate products sold for road de-dusting are separated spent liquor (SSL) concentrates. When removing water in evaporators sulphur dioxide, acetic and formic acids are distilled off, leaving liquors that are less toxic than the raw material. Published information about various lignosulfonates are summarised in Table 2.

Table 2: Toxicity of water soluble materials on fish

Reference	Fish Species	Lignosulphonate Tested	LC50 – 96 hours mg solids/litre
Wilson	Rainbow Trout	Lignosol BD (Quebec)	3,700
Stapanian	Rainbow Trout	Lignosite (West Coast)	2,125
Wilson	Rainbow Trout	Lignosol XD	3,500

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Roald	Rainbow Trout	Purified Na Lignosulphonate	7,300
Canada	Various	Calcium Chloride	5,000
Jones	Various	Sodium Chloride	6,000
Jones	Fathead Minnows	Sodium Sulphate	9,000
Jones	Fathead Minnows	Tide Laundry Detergent	50
Jones	Fathead Minnows	Sodium Dodecylbenzene Sulphonate	4
Jones	Fathead Minnows	Sodium Lauryl Sulphate	5

Evaporating water and volatiles from dilute calcium and sodium SSL substantially reduces toxicity to the point where fish can tolerate 3,000 rather than 1,000 mg/l of solids. With purified lignosulphonates the tolerance is increased to 7,000 mg/l (Ref. 5). The common salts calcium chloride, sodium chloride and sodium sulphate have LC_{50} 96-hour values in the 5,000 – 10,000 range (Ref. 6). Other data references the cut-off point for LC_{50} 96-hour values as 1,000 mg/l. Compounds with values greater than this are given a value of >1,000 and are considered to have a low order of toxicity. Calcium and sodium lignosulfonates, calcium chloride, sodium chloride and sodium sulphate all are in this category. In contrast, a popular laundry detergent Tide and surfactants used in making these products are toxic toward fish (Ref. 7), with values ranging from 4 – 50mg/l reported for these materials.

III. POTENTIAL ENVIRONMENT IMPACTS OF STABILIZERS AND BREAKDOWN PRODUCTS

The potential environmental impact of stabilizers and their breakdown products is determined by both the chemical properties of the stabilizer/binder and its effective use and incorporation into the road materials.

Improper placement/incorporation of the stabilizers/binders is likely to result in greater environmental impacts than the resultant stabilised road structure. Poor storage, management, handling and application of the chemicals during application can result in spillages and release into the aquatic environment. Unless prompt remedial action is taken the impact of such spills is likely to far outweigh any long-term environmental impacts of the *in situ*, stabilised material.

Equally important is proper preparation of the road material(s) and adequate mixing/incorporation of the chemical into the road materials is important to reduce the quantity of any unreacted chemicals remaining and being released into the environment.

Data on the resultant breakdown products of the range of stabilizers/binders covered by the study is limited. A few vendors have provided useful data but most have not. In these latter cases reliance is left to any published information/data on the chemicals used, which is often quite generic and not targeted at the specific conditions experienced by a road i.e. intermittent flooding, cracking etc.

A. Acrylamide

Polyacrylamide or poly(1-carbamoylethylene)) is a polymer (-CH2CHCONH2-) formed from acrylamide subunits. While the main source of acrylamide in the environment is man-made, due primarily to the release of monomer residues from polyacrylamides used in water treatment and industry, acrylamide is also a naturally occurring by-product of the cooking food. Production of acrylamide occurs naturally in a wide variety of foods when they are heated or cooked, including coffee, chocolate, almonds, potato chips, cereal, bread and some fruits and vegetables.

Due to its highly solubility in water, acrylamide is extremely mobile in the aqueous environment and readily leachable in soil. In dilute aqueous solution applications, polyacrylamide polymers are susceptible to chemical, thermal, and mechanical degradation.

Chemical degradation occurs when the labile amine moiety hydrolyzes at elevated temperature or pH, resulting in evolution of ammonia and a remaining carboxyl group, increasing the degree of anionicity of the molecule. Thermal degradation of the vinyl backbone can occur through several possible radical mechanisms, including auto-oxidation of small amounts of iron and reactions between oxygen and residual impurities from polymerization at elevated temperature. Cross-linked variants of polyacrylamide have shown greater resistance to all these methods of degradation and proved more stable.

There are insufficient epidemiological data regarding occupational or environmental exposure to acrylamide to serve as a basis for a quantitative risk evaluation. Experimental animal data indicate that there are no major species differences among mammals with respect to acrylamide metabolism or sensitivity to its neurotoxic effects. Extrapolation from animal dose-effect data suggests that an absorbed dose of 0.12mg/kg body weight per day (derived from total dose to surface area data) could cause adverse neurological effects in man. As acrylamide is readily absorbed through the skin and by inhalation and ingestion, these effects are probably independent of the route of exposure. Applying a safety factor of 10 to the extrapolated minimum dose for neurological effects would indicate that an absorbed dose of 0.012mg/kg body weight per day should not be exceeded. Animal data are not sufficient to draw any conclusions concerning the carcinogenicity of acrylamide. Acrylamide is associated with adverse effects on testicular function in experimental animals. No data regarding these effects in human beings are available. Biodegradation is likely to occur, as a number of microbes possess the ability to degrade acrylamide. However, there is a latent period of several days before any significant degradation, so the residence period for acrylamide may be of the order of days, weeks, or months in rivers and coastal areas of low microbial activity. The half-life in aerobic soil is of the order of several days at 20°C, increasing with decreasing temperature. Concerns have been raised that polyacrylamide used in agriculture may contaminate food with the nerve toxin acrylamide.

While polyacrylamide itself is relatively non-toxic, it is known that commercially available polyacrylamide contains minute residual amounts of acrylamide remaining from its production, usually less than 0.05% w/w (Ref. 8).
There are concerns that polyacrylamide may de-polymerise to form acrylamide. In a study conducted in 2003 at the Central Science Laboratory in Sand Hutton, England, polyacrylamide was treated similarly as food during cooking. It was shown that these conditions do not cause polyacrylamide to de-polymerise significantly (Ref. 9). As of 2010, California requires products containing acrylamide as an ingredient to be labelled with a statement that it is "a chemical known to the State of California to cause cancer."

In a study conducted in 1997 the effect of environmental conditions on polyacrylamide were tested and it showed that degradation of polyacrylamide under certain conditions does in fact cause the release of acrylamide (Ref. 10). However, the experimental design of the study, as well as its results and interpretation, has been questioned (Refs. 11 and 12) and a 1999 study could not replicate the results (Ref. 13).

B. Hygroscopic and Deliquescent Chemicals

Deliquescent chemicals, such as calcium chloride and sodium chloride, attract water from the atmosphere, helping to maintain a moisture film around soil particles that binds particles together. Dust suppression using this method is therefore effective if the humidity of the air is high enough to provide the water.

Limited information is available on the environmental impact of hygroscopic and deliquescent chemicals when used as dust suppressant agents. Salts applied for dust suppression initially penetrate the road to a depth of several centimetres and then rise to the surface by capillarity action, making them susceptible to being washed off by rain. The environmental impact of the resulting runoff will be similar to that of the particular salt used and is dependent on the concentration of salt in this runoff.

C. Organic Binders/Lignosulphonates

Most organic binders used as dust suppressants are lignosulphonate compounds, water soluble liquid chemical by-products of the sulphite pulping process. There are five types of lignosulphonate compounds: crude lignosulphonate, calcium lignosulphonate; sodium lignosulphonate; magnesium lignosulphonate; and ammonium lignosulphonate.

Sugars and carbohydrates are easily fermented by many different microbes and with as much as 35% of these easily fermented substances present in lignosulphonate and few toxic materials around, partial decay occurs quickly (Ref. 14). Because of the wood sugars, lignosulphonates are not added to waterways containing fish and a marginal supply of dissolved oxygen, as the microbes will feed on the sugars and consume oxygen in the process.

Results of many tests on basic lignosulphonates indicate the five-day Biochemical Oxygen Demand (BOD_5) as 0.23kg/kg solids i.e. 45kg lignin mixed with 1,500m^3 water containing 11ppm dissolved oxygen, to end up after five days with water containing 4ppm dissolved oxygen. The concentration of 4ppm dissolved oxygen is where fish kill first appears. This means 30ppm SSL solids allows a safe level dissolved oxygen to be present. More complex lignosulphonates show even lower BOD_5 values.

During the 1960s attention was given to laundry detergents discharged to waterways that produced voluminous and persistent foam. The test developed for assessing the foaming ability of new surfactants for washing powders was applied also to examine the effects of lignosulphonates. Small amounts of lignosulphonates dissolved in aerated river water are held at room temperature for 33 days and samples removed periodically and tested for organic matter content, by oxidising with dichromate to determine the Chemical Oxygen Demand (COD). Data showed that Norlig A, a lignosulphonate road binder material, degraded 28% in five days and 43% in 33 days. This closely corresponds to the carbohydrate content of the product and indicates that pure lignin resists decay. The 54% material remaining after 33 days of incubation persisted as a road binder and shows as a natural lignin colour in waterways, similar to the situation of the brown colour imparted to streams and lakes by humus and humic acids produced by the decay of plants and trees.

The overall impact on the environment from applying lignosulphonates to roads is negligible. They are safer to use for stabilisation and dust control than any competing class of chemicals. The manufacture of lignin involves evaporation; the evaporation process drives off any volatile contaminants such as acetic acid. Corrosion and toxicity towards plants can be readily minimised by pH control and lignosulphonates are non-toxic to animals.

- no dioxins present;
- no other organics present at hazardous levels;
- toxic trace minerals are below EP Toxicity limits;
- low order of toxicity towards fish;
- non-toxic orally and non-irritating to the skin or eyes of animals;
- no human health problems attributed to exposure;
- very low toxicity towards plants;
- residuals are resistant to decay.

When spread on land there is no risk of contaminating ground water. Published data indicates that at <10kgs/m^2, no problems arise. This value is much above the 1kg/m^2 required for stabilisation and 0.3kg used typically for dust control.

D. Ionic Stabilizers

Investigations (Ref. 15) have shown that treatment with Sulphonated Petroleum Products (SPPs) can have a significant beneficial effect on the strength of certain soils. It has also shown that only some materials can be improved with SPP treatment and some SPP products only affect certain, mostly clayey soils.

Where the combination of soil and chemical is correct, strength increases of +100% can be achieved and even higher in practice. In many cases where SPPs are used, construction controls are reduced, or ignored. It is important that ongoing, rigorous quality control procedures are applied to the quantity of binder/stabilizer added and its proper incorporation into the soil, as assessed by materials control and density testing procedures.

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All SPP chemicals are classified as ionic soil stabilizers that rely on replacing/bonding with cations in the clays used. It is essential to evaluate any changes that may occur with both the stabilizer chemical used and clay soil applied to, as these can affect both the physical and environmental performance of the final product.

Aluminium oxide in 'unsuitable' lateritic soils (comprising mostly silica, aluminium oxide and ferric oxide) may react with the acidic ISS 2500 stabilizer during stabilization to form salts. "Salts" are formed when the H^+ ions of the acid are replaced by OH^- ions. Ferric oxide in unsuitable soils may react slowly with the acid of the ISS 2500 to form Fe^{+++} salts and may also react with the alkali to form ferrates. This may take place as a secondary effect after stabilization, as the action takes place slowly.

II. CLASSIFICATION AND RANKING OF STABILISATION PRODUCTS

A. Product types

The stabilizer products considered within this study are classified broadly as:

- Insoluble Dry Powdered Synthetic Polymers (IDPSP);
- Synthetic Soluble Polymers;
- Organic Lignosulphonates;
- Ionic Stabilizers; and
- Salts.

Within these broad classifications, products were subdivided as follows:

- ***Insoluble Dry Powdered Synthetic Polymers:*** products considered within this classification are subdivided in to those that contain lime and those that do not. Of the products considered within this classification, only one did not contain lime.
- ***Synthetic*** classification is subdivided in to bituminous products and non-bituminous products, mainly acrylamides, acrylates and vinyl polymers.
- ***Organic Lignosulphonates****:* there are no sub-divisions within this classification.
- ***Ionic Stabilizers****:* there were two products within this classification considered.
- ***Salts:*** there was only one product within this study that was a salt.

B. Ranking

Each of the products considered within the study are suitable for the purpose of road building. Consideration must be made of the area within which they are to be used and thus the classes of product are ranked with respect to the type of area within which they are to be used. The road stabilizer product classifications are considered both with respect to environmental impact as well as health and safety impacts.

Consideration was also made of potential impacts:

- on application (including on-site storage prior to use);
- when the road has been constructed; and
- on long terms degradation and decomposition.

The main areas for concern when using these products are application in and near to wetlands or water courses. Wetlands include areas where there are *omuramba*, permanent river systems (including their flood plains) and lakes, both permanent and ephemeral. However, even in areas considered as non-wetlands, care must be taken on application and on-site storage to prevent contamination of hand dug wells, or *omifima*.

Table 3 shows the ranking of the road stabilisation product types in terms of health and safety and environmental concerns only, where 1 produces the least impact. The civil engineering performance and structural stability of the products and their suitability for use with different soil types has not been considered within the scope of this study.

It is strongly recommended that a full, comprehensive testing programme to assess the structural performance of the soil/product mix is undertaken, both to ensure the necessary engineering performance is achieved and importantly, to confirm the correct mix proportions and placement conditions required.

The manufacturer's protocols for storage/handling/use should always be adhered to.

It should be noted that once the roads have been constructed the products used have negligible health and safety and environmental impacts. However, as with all the products, a precautionary approach must be taken to ensure that no contamination of the water environment occurs. This is particularly true in areas where ephemeral lakes and rivers occur, as it cannot be certain when these water bodies will be present.

IV. CONCLUSIONS

Road infrastructure is key for any country to enable its development, especially in developing countries such as those in Africa.

Natural road construction materials used historically can become depleted and increasing traffic loads produce higher road maintenance requirements. As a consequent research is ongoing to develop additives that can be used to enhance the engineering properties of the available soils.

Roads in rural areas must usually work with the available soils and make them suitable for use as a road bearing material, able to be used by large vehicles in all weathers. This process requires compaction and stabilisation of the soil, achieved by the combination of civil engineering measures to form the road surface and use of chemical additives or soil stabilizers to allow a compacted road surface to be formed.

Namibia, SW Africa, especially the northern region, has scarce road building materials and requires the use of road stabilizers to extend and maintain the road network. A number of stabilizer products are available and the choice of stabilizer must take into account both the specific properties of the stabilizer and sensitivity of the environment where the stabilizer is to be used, to ensure any potential adverse environmental impacts are avoided wherever possible or at least minimised;

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Recognising this need the Roads Authority of Namibia commissioned a review to ascertain the potential environmental and health related impacts of such products and how to apply their use in a responsible manner. The northern region of Namibia comprises an environment sensitive to the potential adverse impacts of materials that released into the environment, either during construction or subsequently as breakdown products. Much of the region contains aquatic ecosystems and as such, aquatic life is sensitive to toxins and water can transport contaminants long distances.

The main stabilizer types are cementitious, bituminous and chemical, with the latter broken down in a range of materials including synthetic polymer binders, organic and ionic compounds, salts, enzymatic products and combinations thereof.

Due to their long term, widespread use, cementitious and bituminous products are well characterised and excluded from the study.

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Table 3: Environmental ranking of stabilizer types

Stabilizer Class		Application (including storage on site)		In Use		Decomposition		Ranking
		H&S	Environment	H&S	Environment	H&S	Environment	
IDSPS	Lime	Potential to cause burns to skin and eyes. If inhaled may cause serious burns to lungs and nasal passages	If lime gets into the water environment it will raise the pH and react exothermically. It has the potential to cause significant, short term environmental harm. However, if these products enter an *omuramba* /ephemeral water body the environmental consequences could be longer term and more significant.	Durability of the road surface is unknown, but erosion and abrasion may give rise to particulate matter. If PM_{10} are produced this may have concern if inhaled. However, dust particulates will be naturally generated through wind action and thus the impact on H&S from is minimal in comparison.	Once set the leachability is low and thus unlikely to cause any contamination of water bodies. If the product has been badly mixed there may be a surfeit of lime, which may leach into water bodies, thus significant care must be given to preparation and application to prevent future harm once the road has been constructed.	Not considered significant	Not considered significant	2
	No Lime	Negligible	Negligible, although care should be taken to prevent contamination of drinking water.	Negligible	Negligible	Not considered significant	Not considered significant	1
Synthetic Soluble Polymers	Bituminous	Bitumen contains carcinogenic substances, and although not classified as a carcinogen, care must be taken when using these products, based upon the precautionary principle	Although not considered toxic to aquatic organisms since these products are liquids, care should be taken in storage and application to ensure they do not enter water courses to ensure contamination of drinking water does not occur.	Essentially non-hazardous once cured.	Essentially non-hazardous once cured	Not considered significant	Not considered significant	2
	Non-bituminous	Considered non-hazardous	Considered non-hazardous but as these products are liquid, care must be taken in storage and use to ensure they do not enter water courses to prevent contamination of drinking water occurring.	Negligible	Negligible	Not considered significant	Not considered significant	1
Organic Lignosulphonates		Essentially non-hazardous	Essentially non-hazardous, although care should be taken to ensure they do not enter water courses to prevent contamination of drinking water.	Negligible	Negligible	Not considered significant	Not considered significant	1
Ionic Stabilizers		Can be acidic and thus may cause burns to skin and eyes. If inhaled significant burns may occur to lungs and nasal passages	Claims to be environmentally safe but if acidic, may cause deleterious effects if entering water bodies. Care must be taken to ensure pollution of water courses does not take place during storage and handling.	Essentially non-hazardous once cured.	Essentially non-hazardous once cured	Not considered significant	Not considered significant	2
Salts		Considered non-hazardous	Care must be taken during storage and application, to prevent contamination of water bodies.	Essentially non-hazardous once cured.	Essentially non-hazardous once cured	Not considered significant	Not considered significant	1

In terms of testing the UN document, "*Globally Harmonized System of Classification and Labelling of Chemicals (GHS) Part 4, Environmental Hazards, aquatic environment*", sets out the range of tests that can be applied to assess the potential impact of a chemical on the aquatic environment. Tests include product description, MSDS environmental data, solubility, biodegradability, inertness and leachability, with the 48h, mg/l, LC50 test based on using *Daphnia*, upper 95% confidence level and 72h, mg/l, EC50 test is an algal growth inhibition test.

A total of 20 stabilizer products were reviewed in terms of the above criteria but only general findings for the main product types are reported in this paper. All road binders and soil stabilizer products reviewed are in widespread use across the world in different climates and underlying geology. Despite the apparent lack of documented supporting material for some products, it is was assumed the products were accepted or authorised by the appropriate road authority for use in those countries.

In general terms the environmental impact of stabilizers and any breakdown products is determined by the chemical properties of the stabilizer/binder and its effective use and incorporation into the road materials.

Factors such as poor storage, management, handling and application of the chemicals during application can result in spillages and release into the aquatic environment and unless prompt remedial action is taken the impact of such spills is likely to far outweigh any long-term environmental impacts of the *in situ* stabilised material.

The most significant problems are likely to arise from poor construction practices associated with the transport, storage, handling and disposal of the drums and containers used, combined with inadequate mixing and poor placement practices i.e. insufficient/too much water or product, poor compaction, insufficient curing/reaction time etc. Some stabilizer products can be harmful and/or toxic to the surrounding environment and human health, prior to being mixed and reacted fully. If incorrectly applied the stabilised road base may have the potential to release substances in the short/medium term due to overuse of one or more of the chemicals involved etc.

In terms of the overall ranking of the environmental impact of stabilizer types, much depends on the specific setting and product used. In general, product types with the highest i.e. best, environmental ranking are: no lime IDPSP, non-bituminous synthetic soluble polymers, organic lignosulphonates and salts;

Road stabilizers play an important role in providing transport infrastructure in developing countries but when used in sensitive environments, especially aquatic settings, full account of the material properties, including any breakdown products, need to be taken into account.

When the stabilizers have been mixed correctly and applied properly, they create a stable, relatively inert matrix with the soil. The main conclusion of the review is that with proper handling and application, most if not all stabilizers, pose few, long-term, toxicity effects.

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APPENDIX: STABILIZERS REVIEWED

No.	Product Name	Product Use	Stabilizer Category	Product Description	Upper 95% confidence level, 48h, mg/l, LC_{50}	Algal growth inhibition test 72h, mg/l, EC_{50}	Solubility	Biodegradability	Inertness	Leachability	Raw Materials	Handling Precautions
1	ANSS- Anyway Soil Stabilizer	Soil stabilizer	IDPSP	Inorganic hydration activated powders composed of a specific type of cement, a lime, several pozzolans, rate governing additives, and a unique polypropylene fibre. Heavy metals - natural in origin nothing added even if present then stabilised at high pH.	1.62	10-25	Low	Material is not expected to significantly bioaccumulate	No data available	Low. Concentration of transition elements in leachate is below primary drinking water standards, while Co and Pb are only slightly above. Non-toxicity recognised by Green Label award, Ministry of the Environment and the Standards Institute, Israel.	Main components are a series of inorganic hydration activated powders. It is composed of a specific type of cement, a lime, several pozzolans, rate governing additives, and polypropylene fibre.	Use gloves, shoes and protective clothing to prevent skin contact. Contaminated clothing should be removed and the skin washed with soap and water or an appropriate skin cleanser

2	Polyroad	Stabilising binder for rehabilitation of granular pavements and new pavement construction	IDPSP	Polyroad is a dry, powdered polymer, mixed with hydrated lime. Three Polyroad products identified: Polyroad PR100; Polyroad PR11L; and, Polyroad PR21L. Polyroad PR11L and Polyroad PR21L contain hydrated lime, whereas Polyroad 100 does not and can be used alone, or to form the base of the other two Polyroad Products. Lime will react with water and raise the pH, which may have a deleterious effect on freshwater organisms.	No Data Available	No data Available	Polymer is insoluble but lime is soluble in water and raises pH	Persistent but bioaccumulation considered low	Polymer considered inert once fully reacted but will have a raised pH while setting.	Polyroad is hydrophobic and repels water. Until reacted the presence of lime may give rise to moderate/severe irritation or burns. In water, lime will raise pH and may have a deleterious effect on freshwater organisms until reacted fully.	Polymer, hydrated lime and typically flyash, including aluminium oxide and amorphous crystalline silica. Polymer encapsulates flyash, making it inert and not reacting chemically in the stabilisation process. Hydrated lime is added to the polymer-coated carrier to flocculate and prepare clay particles for adhesion to the polymer	Polymer is considered inert but the presence of lime gives rise to safety concerns when handling and PPE must be worn. Avoid contact with skin and eyes.

3	Ecobond	Used beneath blacktop / bituminous seal to improve bearing capacity of base course and lower layers. Improves bitumen performance. Can be used as wearing course for light loads.	Synthetic soluble polymer. Synthetic resin reinforced bitumen emulsion (anionic)	Four component mixture, comprising an anionic bitumen emulsion (EB4) reinforced with Urea (EB1), UFC (EB2) and a proprietary activator (EB3.) The chemicals form a cross linked resin that forms polymer fibres, together with bitumen/soil etc. to bind aggregates in heavy to light duty roads. Product is both sufficiently strong and water resistant to be used with/without a bitumen seal	No Data Available	No data Available	Does not leach out into the environment, as it is water insoluble but remains porous and is mostly bound to other particles.	Will revert back to carbon, oxygen, hydrogen and nitrogen after centuries.	Chemically inert, once fully reacted and will not react easily with any other substances in the soil to form toxic substances.	Low when reacted. Claims to be insoluble and mostly bound to other particles	Limestone, lime and cationic polymer	EB2 component (urea formaldehyde pre-condensate) is largely pre-reacted (for safety) but does contain some free formaldehyde. Formaldehyde emissions have a strong, pungent odour that can cause eye and respiratory irritation in high concentrations. EB3 activator is a weak organic acid. EB4 is a bitumen emulsion (anionic stable grade), containing 60% bitumen particles suspended in 40% water by an emulsion (like soap bubbles) with alkaline pH 11.
4	Polyroads_SoilTech Polymers	Road stabilization of base and sub-base strength and dust suppression. Suitable for light top course use.	IDPSP	Three-part mix comprising limestone, hydrated lime and non-hazardous, cationic polymer. Appearance is a light grey, fine grained, powdery solid mixture, negligible solubility in water and contains respirable fines <7 microns diameter.	>100mg/l trout. >1000mg/l daphnia	No data available	Resistant	Yes. Stated as low level of bioaccumulation	No Data Available	SoilTech Mk III has no hazard classification according to 88/379/EEC.	Three-part mix, comprising limestone, hydrated lime and a non-hazardous, cationic polymer.	Reacts with aluminium / zinc producing flammable, explosive hydrogen gas. Avoid strong acids, acid chlorides, acid anhydrides and chloroformates. Causes burns., risk of serious damage to eyes and do not breathe dust.

5	Renolith WSS	Used on gravel roads and stabilised in-situ road layers with a sand seal or heavier surfacing.	Synthetic soluble polymer	Applied as a liquid. When mixed with cement and local soils, will form a stable concrete.	No Data Available	No data available	insoluble once set/reacted	No data available. Letter from Dr James Rowe, Scientific Director of Technical Consultancy Services Ltd (Australia) March 2000 confirms the MSDS has been reviewed and Renolith is considered non-toxic to the environment.	Chemically inert once reacted. While unreacted, not to be discharge to sewer or waterways, as it increases the hardness of water. Although inorganic chloride ions are not normally considered toxic, they can exist in effluents at acutely toxic levels (chloride >3000 mg/l). Resulting salinity can exceed the tolerances of most freshwater organisms.	Low. Claimed that hydrated calcium chloride chemically binds with cement and soils to perform a stable compound and leachability considered low. Due to calcium chloride, may harm local water courses and lead to adverse effects on aquatic organisms at high concentrations in fresh water. The toxicity of chloride salts depends on the counter-ion (cation) present; that of chloride itself is unknown. A harmful effect of aquatic organisms is only to be expected at high concentrations. [Merck]	Little data available but the bioaccumulation potential is considered low, based upon the presence of hydrated calcium chloride. Contains acrylic resin <5%; calcium salt <8%; mineral oil <1%, "cellulose" <2%; water to 100%. Alternatively, composition given as calcium chloride, hydrated 10-30%; acrylic co-polymer latex 10-30%; water 30-60%	Standard health and hygiene measures. Incidental exposure to inorganic chloride may occur in occupational settings where chemicals management policies are improperly applied. Chloride toxicity has not been observed in humans except in the special case of impaired sodium.
6	DirtGlue industrial polymer (Dgip)	Stabilisation of high plasticity soils	Synthetic soluble polymer	May be mixed with PolyCure/TerraDry. PolyCure is an anhydrous mix of inorganic mineral compounds and acrylate-based, fine, granular powdered polymers.	No Data Available. Not considered to have a toxicological impact on plants or animals.	No data available	Soluble if entering the water environment before setting/curing TerraDry may have a short-term deleterious effect.	Unknown. DirtGlue Polymer, DirtGlue Industrial Polymer and PolyCure are not considered harmful to the environment.	Chemically inert, once reacted. Non-toxic and approved under international recognised materials environmental authority standards and/or registration. Has no Hazchem or UN number.	Unknown. MSDS for DirtGlue polymer emulsion and DirtGlue Industrial Polymer indicates no significant environmental hazards.	Water-based, heavy duty acrylic powder formulation	

7	DirtGlue: TerraDura and TerraDry	Road base stabilizer, subgrade waterproofing agent and polymer pavement additive to increase bond and water resistance in the surface layer.	Synthetic soluble polymer	Liquid polymer concentrates. Polymers are non-toxic, non-flammable, non-carcinogenic and use no solvents to contaminate land and water.	No data available	No data available	Soluble in water. Non-hazardous to plant, animal and marine life and impervious to water after curing.	No data available. Essentially non-hazardous once cured.	Formaldehyde generated under acidic conditions. Thermal decomposition may result in acrylic monomers.	Low. Once cured no chemical, surface wash-off or toxicity threat to land or adjacent waterways. In initial liquid form, care must be given when applying in wetlands or near surface water as it will raise the pH and may have deleterious effect on fresh water organisms. Care must be taken on application to ensure non product enters the water environment, especially, when using TerraDry.	TerraDry is an organo-silane, blend of sodium siliconate and potassium siliconate in water.	TerraDry is a corrosive substance and will cause caustic burns.
8	Silt Stop 700 Series	Dust suppression and erosion control	Synthetic soluble polymer	Anionic polyacrylamide co-polymer emulsion binding agent, comprising a range of anionic, water-soluble co-polymer gels and anionic, water-soluble, co-polymer powders.	Generally >420ppm.	Generally >500ppm	Soluble as gel and powder until cured	Both gels and the powders are not readily biodegradable and will not readily bioaccumulate. Essentially non-hazardous.	Stable. Review of the MSDS for gels and powders indicates they are non-toxic and non-reactive.	Low once product has set. Care should be given on application in wetlands or near water to prevent the unreacted product entering water courses.	Polyacrylamide co-polymer, water soluble gels or anionic, water-soluble co-polymer powders.	Prevent inhalation of the powder, use adequate dust mask
9	SoilTac	Dust suppression and erosion control	Synthetic soluble polymer	Vinyl co-polymer emulsion, designed to penetrate the soil / aggregate layer and bind together the soil / aggregate particles. Applied as liquid emulsion.	96-hour LC50 >1,000mg/l	96-hour LC50 >1,000mg/l	Emulsion	Biodegradable. Essentially non-hazardous.	Stable	Low - designed to penetrate surface layers and bind to soil particles. Once cured no leaching should occur. Care required when applying in wetlands and near surface waters.	Vinyl co-polymer emulsion	Use only in well-ventilated areas. Avoid contact with eyes., breathing vapours and avoid prolonged or repeated contact with skin. Wash hands thoroughly after handling and before eating or drinking

10	Soil Sement	Dust and erosion control and sub-grade soil stabilization	Synthetic soluble polymer	Acrylic vinyl acetate polymer emulsion that binds soil/aggregate particles together with a molecular mesh.	3,483ppm	>1,000	Forms emulsion	Not known. Product is stable and non-hazardous.	Stable	Not known.	Aqueous acrylic vinyl acetate polymer emulsion. Does not contain any detectable polycyclic organic matter (POM), including polynuclear aromatic hydrocarbons (PAH).	Standard eye protection
11	Sasbind	Suitable for binding/stabilisation of layers in all types of road construction.	Synthetic soluble polymer	Provides strong gluing and waterproofing action on soil particles and is suitable for application to a wide variety of soil types, improving the wet weather performance of soils and gravel roads	No Data Available	No Data Available	Not known.	Stated as having no long-term adverse impact on the environment, is non-toxic and non-hazardous and is safe to handle. Company not contactable for MSDS.	No Data Available	Not known.	Water based, acrylic polymer emulsion	Nothing specific
12	PennzSuppress D	Used as dust suppressant and soil stabilizer	Synthetic soluble polymer	Concentrated paraffin resin solution with ionic and non-ionic surfactants. Diluted with water until required concentration produced.	No Data Available	>510mg/l Fathead minnow; 913mg/l Rainbow trout	Forms emulsion. When still a liquid product, should be used with care near wetlands or surface waters.	Not known. Classified as “non-hazardous,” “non-toxic,” and “non-carcinogenic” by Federal US guidelines and is considered non-toxic to aquatic life.	Stable under normal conditions, but avoid strong acids and strong oxidising materials	Low once product has cured. Care needed on application in wetlands or near watercourses, due to potential to cause oil-like pollution in surface waters.	Paraffin resin in solution with water soluble, anionic and non-ionic surfactants.	Nothing specific
13	Tembind Lignosulfonate Grade A-002	Used as dust suppressant and road stabilizer	Organic. Lignosulphonate	Lignosulphonate polymer that acts as a binding agent for soil/aggregate particles to ensure better compaction and stabilisation of road surfaces.	No Data Available	No Data Available	Not soluble but an emulsion	Biodegradable over time. Essentially non-hazardous.	No Data Available	No leaching problems once set. Poor application in wetlands/near surface waters may cause contamination of water courses and short-term elevated BOD /COD but no permanent effect.	Ammonium lignosulphonate	Standard PPE for eye protection and gloves for skin contact

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14	Dustex	Used as dust suppressant for road surfaces.	Organic. Lignosulphonate	Calcium lignosulphonate liquid, act as binding agent for soil and aggregate particles.	According to OECD Method No. 203 this product is classified as not fish toxic.	No Data Available	Soluble	According to OECD Method No. 302B, this product classified as inherently biodegradable and non-hazardous	No Data Available	Low once cured, becoming impermeable. As a liquid care must be given when applying in wetlands or near surface waters.	Calcium lignosulphonate	Standard PPE for eye protection and gloves for skin contact. Dustex is slightly acidic with pH of 5.4 ± 3.0.
15	LFPP Spent Liquor 2	Stabilisation of road surfaces and used as a dust suppressant for road surfaces	Organic. Lignosulphonate	Lignosulphonates act as binding agents to bind soil and aggregate particles together to ensure better compaction and become impermeable after curing.		No Data Available	Not soluble but an emulsion	Biodegradable over time. Essentially non-hazardous	No Data Available	Once set should have no leaching problems. Poor application in wetlands or near surface waters may produce contamination of water courses. If this occurs may give rise to short-term elevated BOD or COD but no permanent effect.		Standard PPE for eye protection and gloves for skin contact
16	ENTAC	Road dust suppressant	Synthetic soluble polymer	Tall Oil Pitch (T.O.P) is a pitch-in-water emulsion	Non-lethal to aquatic organisms, Daphnia Magna, Rainbow Trout.	No Data Available	Once applied and cured unlikely to cause any leaching or environmental concerns.	Natural decomposition occurs over a long time (>60% biodegradation in 28days. Degradation products CO, CO_2 and water	No Data Available	Insoluble in water and extremely viscous in its natural state. Stated as having "no negative environmental impacts".	Pitch-in-water emulsion. Must be emulsified to facilitate its handling and usage.	Nothing specific

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17	Earthbind 100	Road dust suppressant	Synthetic soluble polymer	Bituminous modified, bitumen/water emulsion. Product contains 40 -60% bitumen as an emulsion.	Rainbow trout >5,000 ppm	No Data Available	Once applied and cured unlikely to cause any leaching or environmental concerns.	Persistent. Website claims it is non-flammable and a non-hazardous waste, not considered harmful to aquatic and mammal life or carcinogenic. Bitumen contains carcinogenic components and the dermal carcinogenicity of testing bitumen on mice showed tumours arising with a frequency significantly different from the control study. No data for teratological potential.	No data available. Bitumen has given negative or marginally positive findings in most mutagenicity assays conducted.	Once set should not have leachability problems. Claims it is not considered harmful to aquatic and mammal life and claims not considered to be carcinogenic. Care must be taken when applying the liquid emulsion in wetland/water rich areas to ensure contamination of water does not occur.	40% and 60% bitumen emulsion.	Nothing specific
18	Iss2500	Suitable for construction of sealed pavement structures and improvement in performance of un-surfaced roadways	Ionic. Oily, dark-coloured liquid, miscible with water	Electrochemical clay soil stabilizer suitable for improving marginal or substandard materials or soils for use in the construction of roads. .	Once pH adjusted to the range of 7-8, all bar one test sample had 100% survival for *D. pulex* and *P. reticulata*, indicating the chemical constituents are not toxic	No Data Available	Soluble	Unknown. Product test data claims it is environmentally safe and if handled properly should not pose any adverse impact on the environment	Once cured, inert	Low, once cured. Care must be given when applying in wetlands or near surface water due to its acidic nature, will lower pH in freshwater. Will have temporary ecological harm but no permanent effect.	Hazardous. Sulphonated petroleum products, derived from combined organic sulphur and buffered acids combined as bisulphates	pH <2 and can cause acid burns.
19	Con-Aid/CBR PLUS	Helps reduce pavement thickness and is suitable for light traffic use	Ionic	Water-soluble, anionic compound with surface-active properties, from a blend of synthetic chemical products, comprising surfactant and sulphonic acid derivatives, as an organic acid solution in water. Chemical Formula: R – SO3H, where R = hydrocarbon.	No Data Available	Not toxic at 1-3mg/l	Soluble	Yes. Claimed non-toxic and environmentally friendly	No Data Available	Leaching treated soil samples showed no toxicity to Rainbow trout, *Daphnia Magna* & *Microtox* at the concentration of CBR PLUS (normal dilution for application of 1.5 to 3mg/L) to be used in the field.	Main active ingredient organic sulphonic acid derivatives	Stable but care needed when handling, basic PPE required. (see above).

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20	Trisal	Used for stabilizing granular base materials	Salts	Blending into road base provides stabilization similar to chlorides but with no cure time required.	No Data Available	No Data Available	Soluble	No, inert	No Data Available	May be harmful to freshwater aquatic species and to plants not saline tolerant.	Typically, $MgCl_2$ in aqueous solution	Nothing specific

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