EVALUATION OF THE SUSTAINABILITY OF LOW VOLUME ROADS STABILIZED WITH NON-TRADITIONAL STABILIZERS

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ABSTRACT

Stabilization of unpaved (mostly low volume) roads using non-traditional stabilizers has received attention over the last number of years as various types of these stabilizers are developed and become available. Evaluation of the sustainability of various infrastructure actions, including the provision and maintenance of roads, is becoming more relevant as the effects of actions taken in the natural environment on the natural and human environment are evaluated and understood in more detail. Greenroads offer a method for evaluation of the sustainability of the design, construction and maintenance of roads. It was developed with a focus on surfaced higher volume roads. In this paper, the potential applicability of Greenroads for the evaluation of the sustainability of unsurfaced low volume roads is investigated, based on two case studies of experiments where unpaved low volume test sections were stabilized using various types of traditional and non-traditional material stabilizers. Appropriate parameters were selected from the general Greenroads metric to ensure that those parameters that will affect unpaved low volume roads will be evaluated (e.g. Runoff quality and use of Regional materials) while parameters such as Paving emission reduction were excluded from the analysis. The assumption was made that all the compulsory Project Requirements will be adhered to by each of the options evaluated. It was concluded that the Greenroads metric can be used to evaluate the potential sustainability of unpaved low volume roads stabilized using non-traditional stabilizers, and that the metric provide insight into the potential effect of various parameters on the sustainability of the various stabilization options.

INTRODUCTION

South Africa has in excess of 500 000 km of unpaved roads. The treatment of these roads to decrease the amount of material lost through dust and to improve the bearing capacity of the materials, especially during wet periods, is vital for sustainable transport in areas that are serviced by these roads. Stabilization of unpaved (mostly low volume) roads using non-traditional stabilizers has received attention over the last number of years as various types of these stabilizers are developed and become available (Jones, 2001; Thompson and Visser, 2002, Jones and Ventura, 2004; Van Veelen and Visser, 2007; Moloisane, 2009). Although the functionality and performance of these non-traditional stabilizers vary, dependent on factors such as the properties of the material being treated, the type of stabilizer and the environment, many of them offer good alternatives to traditional stabilizers when used in the correct location (Tingle et al, 2007; Visser, 2007). In this paper traditional stabilizers are defined as materials such as lime, cement and bitumen emulsion, while non-traditional stabilizers are defined as all those additives used as either dust palliatives or compaction aids and stabilizers (Jones and Ventura, 2004).

Typically the performance of roads stabilized with non-traditional stabilizers are compared to that of roads being stabilized with traditional stabilizers as well as control sections, based mainly on the strength of the various layers before and after stabilization. Although layer strength is vital for good pavement performance, factors such as the dustiness, effect on the environment and maintainability are also important to determine the performance of the stabilized materials. The sustainability of the finished road is thus becoming a major feature on which the evaluation of the performance of a specific road is being based. Greenroads defines sustainability as a system characteristic that reflects the system's capacity to support natural laws and human values (Muench et al, 2010). This is not only valid for traditional paved roads, but also unpaved and low volume roads.

Various systems have been developed for the evaluation of the sustainability of engineering infrastructure, including roads (Mills et al, 2007; Lopez, 2003; Colbert, 2003). One system that specifically focuses on the design, construction and maintenance of roads is the Greenroads system (Muench et al, 2010).

The objective of this paper is to evaluate the potential applicability of using Greenroads for the evaluation of the sustainability of unpaved roads stabilized with non-traditional stabilizers. It falls outside the scope of this paper to evaluate the effect on sustainability when surfacing unpaved roads. The paper is based on experiments that were planned and conducted before the Greenroads system became available, and thus, the objectives of the various experiments did not necessarily require measurement or observation of all the parameters deemed important from a sustainability viewpoint. There are thus parameters that were not specifically evaluated during the experiments used, which may be important for the Greenroads metric. Reasonable assumptions, based on a current evaluation of the condition and performance of the test sections were made (and ar indicated as such) in these cases.

In the paper background is provided on the Greenroads system, and adaptations suggested to ensure that objective evaluations for low volume unpaved roads can be made. The suggested system is then evaluated using data from experiments conducted over a number of years in South Africa, and conclusions and recommendations for the further use of the system provided.

SUSTAINABILITY EVALUATION SYSTEM

Greenroads concept

Greenroads is a sustainability performance metric for roads that is used to award points on an objective scale for sustainable practices to roads. Through this process the sustainability of various road designs, construction methods and maintenance methods can be evaluated, and a specific roads project can therefore be measured and rated against known standards. It was developed at the University of Washington for use on mainly paved roads (Muench et al, 2010).

Greenroads focuses on the evaluation of the following seven components in road designs, construction and maintenance: ecology, equity, economy, extent, expectations, experience and exposure. The core understanding is that materials (specifically natural materials) should not be used in such a way that it can be depleted and that the waste caused by road building actions becomes a major problem to the environment (natural and human). In this regard activities such as regravelling of and dust loss from unpaved roads obviously become an unsustainable practice.

The metric consists of the evaluation of a set of compulsory Project Requirements (PR) and a set of Voluntary Credits (VC) against which the whole project is evaluated. If a specific requirement is met, the project is credited with the points in the category. A certain threshold of points is required to attain any of the four defined levels of achievement / certification (i.e. Greenroads, Silver, Gold and Evergreen). The PR and VC categories are listed in Table 1. The aim of Greenroads is not to disqualify specific stabilizer options but to assist in rating the most sustainable option and therefore ensure that whichever of the various types of stabilizer is used on an unpaved road will provide the most sustainable solution to the specific road.

A number of requirements and credits are highlighted in **bold** in Table 1, while others are not. Those requirements and credits that are not highlighted are deemed by the authors to be insensitive to the use or not of non-traditional stabilizers as compared to the use of traditional stabilizers or no stabilizers for the type of low volume unpaved roads evaluated in this paper. Those detailed descriptions that are highlighted are those for which the authors are of the opinion that they may be directly affected by the use of non-traditional stabilizers for unpaved roads, and these form the focus of the evaluations and discussions.

Evaluation of components

Those components not highlighted in Table 1 are deemed not to be affected by the decision of whether or not to stabilize the road material at all, or the type of product that is used in the stabilization process. These include requirements such as the need for an environmental review process, a waste management plan and a pavement management plan (it is assumed that all Project Requirements will be covered when evaluating a project regarding its potential sustainability). Similarly, Voluntary Credit (VC) components such as the environmental training, stormwater cost analysis and pedestrian access will not be affected by the type of stabilization selected, while aspects such as the paving emission reduction, warm mix asphalt and quiet pavement are likewise not affected as only unpaved roads are included in this evaluation. Some of these components (such as pedestrian and bicycle access) focus specifically on the provision of dedicated facilities within the project Right-of-Way and will thus not be affected by the choice of stabilizer. Further, Voluntary Credits (VC) such as the Road Safety Audits (RSA) are scored based on the fact that the audit is conducted and not based on any improvements in road safety by using a specific product or method (Muench et al, 2010). The selection of stabilizer will thus not affect this score (although it can reasonably be expected that a stabilizer producing a slippery surface will be perceived negatively during the RSA). It should be clearly stated that the surfacing of unpaved roads obviously is one of the methods that can be used very effectively to improve the sustainability of unpaved roads substantially, however, this is not always possible from a direct economic viewpoint and often the traffic levels on these roads do not support such an alternative. It thus falls outside the scope of this paper to compare the various types of stabilization (on unpaved roads) with the option of surfacing the road.

The process followed in the evaluation in this paper is thus to accept that those components that will not differ between the different types of stabilization efforts are ignored for the comparison, and the focus is only on those where different stabilizers will potentially cause a difference in the outcome of the credit or requirement.

The eleven credits identified to be affected by the different stabilizers in Table 1 are Runoff quality, Context sensitive solutions, Traffic emissions reduction, Fossil fuel reduction, Equipment emission reduction, Water use tracking, Pavement reuse, Earthwork balance, Recycled materials, Regional materials and Custom designed credits. The expected effects that different types of stabilizers (traditional and non-traditional) may have on each of these credits are as follows (potential points are shown in brackets):

- Runoff quality (3 points)

The potential for leaching of various non-traditional stabilizers differ and can be evaluated using standard tests (Jones and Ventura, 2004). Although leachate may not always be hazardous to humans and the environment, those options where leaching is minimized should be deemed more sustainable. Evaluation of sediment load should also be evaluated, as stabilizers that leave a layer of loose material on the surface will not only increase dustiness under dry conditions, but will also quality of stormwater runoff.

- Context sensitive solutions (5 points)

Most unpaved low volume roads runs through small and informal communities, affecting their lives both positively (access to transport routes and the broader economy) and negatively (traffic through the community, dust and mud to name a few). Different types of stabilizers may affect the number of labor opportunities created through use of local labor, and may also affect the medium to long-term potential of upgrading the specific road to a paved standard. Stakeholder inputs and understanding in all decisions regarding different options should thus be evaluated.

- Traffic emissions reduction (5 points)

This credit typically focuses on the greenhouse gas emissions. Although this may be relevant where construction equipment is used, the credit can for unpaved roads rather focus on dust generation from the road. Different stabilizers affect the generation of dust on specific road-building materials differently, and therefore an evaluation of the amount of dust generated at typical speeds during the various seasons should be evaluated. The baseline for evaluations in this case will typically be the un-stabilized material. Where no measurement of dust generation is measured on the finished road, the material classification proposed by Paige-Green in TRH20 (TRH20, 2010) can be used to provide an indication of the potential for dust after stabilization.

- Fossil fuel reduction (2 points)

Fossil fuel reduction on the stabilization process will be affected by the type of equipment required to prepare the road for stabilization, the equipment required during stabilization and equipment required during any maintenance actions (i.e. reblading or regravelling). Where stabilization can be conducted using labor-intensive process, this may have a major beneficial effect on the credit, however, the fuel usage of a number of small plant running should be compared to that of one efficient machine that can replace these smaller plant.

- Equipment emission reduction (2 points)

Equipment emission reduction on the stabilization process will be affected by the same factors as for the Fossil fuel reduction credit. It can generally be accepted that reduction in consumption of fossil fuels will lead to reduction in equipment emissions, if all equipment are similar.

- Water use tracking (2 points)

The total water requirement during stabilization of unpaved roads can be substantial, depending on the type of stabilizer. Water sources and quality requirements should also be incorporated into this credit, as long distances from a water source will add to the fossil fuel consumption while the production of high quality water in often rural areas can also add a major energy cost to the overall construction process. The cultural effect of using potable water for road construction in an area where potable water may not be abundantly available for human consumption, may also negatively affect the use of a specific stabilizer in an area. Development of boreholes in the area will probably be a positive credit in terms of sustainability if these boreholes can be used by the local community after construction.

- Pavement reuse (5 points)

The objective of many non-traditional stabilizers is to make use of in situ materials for constructing the layerwork of the road. This is often one of the main marketing focus areas for many products, and unfortunately not always practically applicable where local materials may not be reacting positively to the specific stabilizer evaluated. Detailed laboratory evaluation of in situ material properties and the reaction of the material to stabilization using the specific stabilizers should form part of this credit evaluation.

- Earthwork balance (1 points)

This credit links to the pavement reuse for unpaved stabilized pavement layers as the objective is to keep the majority of the in situ material within the road itself. Where material properties vary along the length of the road and a specific stabilizer may not be applicable everywhere, or where much higher quantities of the same stabilizer may be required to attain the same level of quality for the road, this credit may favor stabilizers that are effective in a wider range of source materials.

- Recycled materials (5 points)

Use of in situ materials for construction of layerwork is equivalent to use of recycled materials, as the existing materials are reused. Care should be taken in areas where the road may have been stabilized before using a different type of stabilizer and where the use of another stabilizer (or addition of more of the same stabilizer) may negatively affect the performance of the final road or increase leaching from the layerwork.

- Regional materials (5 points)

Where in situ material may not be suitable for stabilization, the requirement to haul material from sources will affect the sustainability of the project. A balance should be obtained between using the in situ material and providing an inferior (but acceptable) road quality and using imported material with another stabilizer and improved (and therefore longer expected life) road quality.

- Custom designed credits (10 points)

These credits are left open for the user of the system to define project specific credits that may be used in addition to those already mentioned that can improve the sustainability value of the specific road. The following credits are suggested for low volume unpaved roads in this regard:

  - Development of skills in the community to be used on similar projects not related to the roads project (i.e. stabilization of materials for manufacturing bricks for housing);
  - Use of labor during construction to alleviate unemployment in the surrounding community (human sustainability), and
  - Relative costs of the various stabilizers (economic sustainability).

In the next section selected case studies of the application of different types of traditional and non-traditional stabilizers are discussed to indicate where the type of credits discussed can be used to indicate whether one type of stabilizer can be more sustainable than another under specific circumstances. It is important to realize that if a specific stabilizer is deemed to be the most sustainable in a specific project, it does not mean that this stabilizer will always be more sustainable than other stabilizers evaluated. Availability and type of materials, availability of labor resources and the geographical location of the specific project will directly influence the outcome of the evaluation. Further, it is assumed in these evaluations that all those aspects not addressed (i.e. those not highlighted in Table 1) are similar between the different stabilizer applications and will thus not affect the outcome of the comparison between different stabilizers. Lastly, the Greenroads rating is typically performed before a project is started, and thus long-term performance of the road is not incorporated in the rating, although expected performance should be part of criteria such as the Pavement management system and the Lifecycle assessment.

LOW VOLUME ROADS STABILISED WITH NON-TRADITIONAL STABILIZERS

Non-traditional stabilizers are typically added to road construction material through dilution in the compaction water, except in cases where the products are non-soluble in water and where the product is directly mixed with the source material (i.e. some bitumen-based and wax-based stabilizers). This evaluation process for establishing the suitability of a specific stabilizer to be used on the road typically include a suite of laboratory tests where the source material is treated using a range of application rates and the optimal application rate for the specific requirement (i.e. dust palliation or stabilization or a combination) is selected. Guidelines such as those prescribed by Agrément SA (Jones and Ventura, 2004) require a comparison with a control section (no stabilizer) as well as a section where the source material is treated using a traditional stabilizer to ensure that the benefit of the non-traditional stabilizer is real and effective. Similar processes should be followed to ensure that the use of non-traditional stabilizers in unsurfaced roads is sustainable and effective.

The sections used in this paper to demonstrate the application of the Greenroads metric to non-traditional stabilizers for unpaved roads are summarized in Table 2 (Van Veelen and Visser, 2007; Moloisane, 2009), indicating the basic material description and properties. It contains five different materials in one region where various experiments have been conducted over a number of years, using various types of stabilizers. The objective of these tests was typically focused on strength gain in the materials, and therefore all the required input data for the Greenroads evaluation may not always be available. The generic stabilizers used for the various sections are also shown in Table 2. In the sustainability evaluation the different stabilizers used for each of the 5 materials are evaluated to determine the most sustainable option for the specific material. The effects of different stabilizers on different materials are thus not compared, as the assumption is made that the evaluation of the use of a specific stabilizer for a road will be conducted only on the materials directly available in the area.

In order to provide an indication of the comparison of the sustainability rating with the traditional strength rating for each of the road sections, the evaluation as done originally for each of the sections is also shown in Table 2. This is based on the maximum in situ soaked Dynamic Cone Penetrometer (DCP) measurement attained within 8 months of construction (Van Veelen and Visser, 2007; Moloisane, 2009). Analysis of the traditional strength evaluation and the Greenroads-based sustainability evaluation is provided later in this paper.

EVALUATION OF SUSTAINABILITY

Based on the Greenroads criteria and the information available for the various test sections, the evaluation of the sustainability of the various projects are summarized in Table 3. The current evaluation is partly subjective as

Greenroads was not initially developed for application in unpaved roads specifically, and the decision as to the number of points awarded to a specific application for a specific credit may not necessarily reflect the sustainability accurately. However, it is provided as a first attempt in applying the metric and therefore open for further refinement and development.

The evaluation has been conducted by rating each of the different stabilizers from most sustainable (full score) down to least sustainable (0 points) for the specific application. It is possible in the rating that a type of stabilizer may get a high score for one project and a low score for another, based on factors such as the source material treated. The brand names of the various stabilizers are not provided in the paper, and only generic descriptions are used, as per the definition in Jones and Ventura (2004).

Some of the credits are difficult to rate for the specific projects selected, as the specific parameter may not have been measured or evaluated explicitly in the original project, and thus no information is available for the rating. The following methodology has been used for the rating of the 11 credits identified:

- Runoff quality

  No specific leaching results were available, but the assumption was made that more permeable materials would have a higher potential for water to dissolve materials from the stabilized layer and carry it into the surrounding environment.

- Context sensitive solutions

  The relative compaction achieved during construction was used as an indication of the ease of construction and therefore the applicability to possibly construct the sections in a rural area with higher labor content. The sections with highest relative compaction achieved were viewed as the best in terms of this credit.

- Traffic emissions reduction

  No specific evaluation was conducted on dust emissions after stabilization. A possible route to follow is to use the indication based on material properties developed by Paige-Green (TRH20, 2010) to test the material in the laboratory after stabilization to determine propensity to be dusty, or the Abrasion resistance and Erosion resistance tests recommended by Ventura and Jones (2004). This was not done in these cases and all options were deemed equal in this regard. Recent visual evaluations of the conditions did not show significant differences in dust generation. This was however during the wet season and potential differences could be masked by environmental conditions as well as the relatively light traffic volumes on the sections.

- Fossil fuel reduction

  A distinction was made between those stabilizers where the stabilizer is merely added to the compaction water and sprayed onto the material, and those where dry material had to be mixed in with the source material as a separate action to adding the compaction water with the first deemed to require less energy input than the second. Addition of emulsion was rated between these two options.

- Equipment emission reduction

  As it was indicated that the fossil fuel reduction and equipment emission reduction credits will be affected by similar parameters, the same credits were given to this credit than for the fossil fuel reduction credit.

- Water use tracking

  The required moisture content of the material for stabilization using the specific product was used as an indication of the relative amount of water that will be needed to ensure effective stabilization.

- Pavement reuse

  All sections were conducted with the same material that is found in situ in the region, and therefore all options were deemed equal in this regard.

- Earthwork balance

  Similar to Pavement reuse and therefore all options were deemed equal in this regard.

- Recycled materials

  Similar to Pavement reuse and therefore all options were deemed equal in this regard.

- Regional materials
  Similar to Pavement reuse and therefore all options were deemed equal in this regard.

- Custom designed credits
  - o Development of skills in the community – not evaluated as no data were available.
  - o Use of labor during construction to alleviate unemployment in the surrounding community – not evaluated as no data were available.
  - o Relative costs of the various stabilizers comparative cost for the stabilizer required as per dosage used – due to the experiments used for this paper being experimental sections, the relative costs of the various products did not offer a suitable platform to base a comparison of relative costs on.

In order to provide an indication of the expected level of sustainability attained by each of the stabilizer / material combinations, the same guide as have been used in the full Greenroads guideline has been followed, where all Project Requirements need to be met and a minimum of 30 per cent of the total Voluntary Credits (VC) is required for a Greenroads certificate, 40 per cent for a Silver certificate, 50 per cent for a Gold certificate and 60 per cent for an Evergreen certificate. As the total number of potential points that the unpaved roads can score is much lower than that required for the full evaluation (refer to Table 1 and the subsequent discussion), the required scores for these four levels of sustainability has been calculated as 13.5 (Greenroads) 18.0 (Silver), 22.5 (Gold) and 27.0 (Evergreen). For the calculation of the score for each of the sections 50 per cent of those points for which data were not available (Table 3) have been allocated for each section (assuming that all the sections would rate at least acceptable for each of these criteria) and this score was added to the actual points as based on the ranking of the various options (Table 3).

The overall outcome of the evaluation is presented in Table 4, showing the Strength rating (based on soaked DCP data), the Greenroads rating (based on the specific aspects rated as indicated in Table 3) and the overall Greenroads certification.

OUTCOMES OF THE ANALYSES

Analysis of the data presented in Tables 3 and 4 provides an indication of the potential applicability of using Greenroads for evaluating the potential sustainability of various types of traditional and non-traditional stabilizers for unpaved roads. A direct evaluation of the total score attained by each of the options indicates that the same stabilizer is not providing the highest potential sustainability for all materials (Table 4 – bold Greenroads scores). This is acceptable when remembering that all stabilizers do not perform equally well on all materials. This is well-known and one of the fundamental reasons why the performance of all stabilizers should first be evaluated for the specific material where it is to be used before bulk stabilization is attempted.

Further analysis indicates that the best strength rating does not necessarily provide the best sustainability rating in all cases. Again, this is acceptable as the sustainability evaluation incorporate effects that may not necessarily directly attribute to increased strength of a layer, such as the Runoff quality, Fossil fuel reduction and Custom designed credits. In some cases (i.e. material P) the Greenroads rating indicate the control section as having the highest potential sustainability. It is interesting to note that in this case the control section also provided the highest strength (based on the strength parameter used) and it may thus provide a suggestion as to cases where stabilization of the in situ material may not necessarily be the optimum solution. Application of this process in practice is easy – the strength parameters may be determined on small test panels as described by Visser (2007), and the balance is determined from visual inspection on previously stabilized roads or expected performance.

The perceived lack of sensitivity of the application of the Greenroads metric for parameters such as road safety (skid resistance and dust generation) can be addressed through the inclusion of dedicated Custom Credits that are linked not only to the measurement or lack thereof of these parameters, but also a required minimum standard to be attained for the credit. However, the sustainability evaluation should not stand alone in the evaluation of stabilization evaluation of potential road projects, and common sense and standard engineering evaluation of the outcome of standard laboratory tests on the potential stabilized materials should still play a major role in the final decision regarding the optimum stabilizer to be used for specific circumstances.

CONCLUSIONS

Based on the information provided in this paper the following conclusions are drawn:

- The Greenroads metric can be used to evaluate the potential sustainability of unpaved low volume roads stabilized using non-traditional stabilizers, and
- The metric provide insight into the potential effect of various parameters on the sustainability of the various stabilization options.

RECOMMENDATIONS

Based on the analyses contained in this paper it is recommended that the proposed adaptations to the Greenroads metric be evaluated further for application in unpaved roads with stabilized layers to ensure that the system can provide objective ratings of the sustainability of these roads. The analysis of paving the road as an option would provide an interesting further dimension to the analysis. Development of a specific version for use on unpaved roads may be considered, as the majority of roads in developing countries are unpaved and thus in dire need of an objective method to evaluate the sustainability while improving the condition of the network.

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TABLE 1 Summary of Project Requirements (PR) and Voluntary Credits (VC) for Greenroads (Muench et al, 2010).

METRIC	**EXAMPLE OF DETAILS**	**AVAILABLE CREDITS**
Project Requirements (PR)	Environmental review process Lifecycle cost analysis Lifecycle inventory Quality control plan Noise mitigation plan Waste management plan Pollution prevention plan Low-impact development Pavement management system Site maintenance plan Educational outreach	11
Voluntary Credits (VC)		
Environment and water (EW)	Environmental management system, Runoff flow control, **Runoff quality**, Stormwater cost analysis, Site vegetation, Habitat restoration, Ecological connectivity, Light pollution	21
Access and Equity (AE)	Safety audit, Intelligent transportation systems, **Context sensitive solutions**, **Traffic emissions reduction**, Pedestrian access, Bicycle access, Transit and HOV access, Scenic views, Cultural outreach	30
Construction Activities (CA)	Quality management system, Environmental training, Site recycling plan, **Fossil fuel reduction**, **Equipment emission reduction**, Paving emission reduction, **Water use tracking**, Contractor warranty	14
Materials and Resources (MR)	Lifecycle assessment, **Pavement reuse**, **Earthwork balance**, **Recycled materials**, **Regional materials**, Energy efficiency	23
Pavement Technologies (PT)	Long-life pavement, Permeable pavement, Warm mix asphalt, Cool pavement, Quiet pavement, Pavement performance tracking	20
Custom Credits (CC)	**Custom designed credits**	10
Greenroads total		118

TABLE 2 Summary of sections evaluated using Greenroads for stabilized unpaved roads.

SECTION NUMBER	SECTION IDENTIFICATION & MATERIAL DESCRIPTION	TYPE OF STABILIZER	STRENGTH RATING
1	P Ferricrete; Grading modulus – 2.01; CBR at 95% mod AASHTO – 7.6; PI – 10; AASHTO A-2-4	Synthetic Polymer Emulsion A (SPEA)	2
2		Synthetic Polymer Emulsion B (SPEB)	2
3		Enzyme (E)	3
4		Sulphonated Oil (SO)	3
5		Control	1 (best)
6	D Windblown sand; Grading modulus – 0.85;CBR at 95% mod AASHTO – 20; PI – 4; AASHTO A-4	Synthetic Polymer Emulsion A (SPEA)	2
7		Synthetic Polymer Emulsion B (SPEB)	3
8		Enzyme (E)	3
9		Sulphonated Oil (SO)	4
10		Control	1 (best)
11	B Weathered Dolerite; Grading modulus – 1.65;CBR at 95% mod AASHTO – 10; PI – 11; AASHTO A-2-6	Synthetic Polymer Emulsion A (SPEA)	3
12		Synthetic Polymer Emulsion B (SPEB)	1 (best)
13		Enzyme (E)	5
14		Sulphonated Oil (SO)	2
15		Control	4
16	Q Gravel; Grading modulus – 1.95;CBR at 95% mod AASHTO – 24; PI – 12; AASHTO A-2-6	Synthetic Polymer Emulsion A (SPEA)	1 (best)
17		Synthetic Polymer Emulsion B (SPEB)	2
18		Enzyme (E)	5
19		Sulphonated Oil (SO)	4
20		Control	3
21	X Dark reddish brown gravel; Grading modulus – 1.25; CBR at 95% Mod AASHTO - 19; PI - 10; AASHTO A-2-4	Cement (C)	2
22		Enzyme (E)	10
23		Cement catalyst (CC)	1 (best)
24		Organic non-petroleum (ONP)	8
25		Organic non-petroleum (ONP)	6
26		Sulphonated Oil (SO)	11
27		Enzyme (E)	9
28		Polymer (P)	5
29		Cement (C)	3
30		Organic petroleum (OP)	4
31		Control	7

Grading modulus = [300 – (sum of percentage passing 2.00, 0.425 and 0.075mm sieves)]/100

TABLE 3 Summary of sustainability evaluation of sections.

CREDIT (maximum points)	SECTION IDENTIFICATION	RATING PER GREENROADS GUIDELINES Section number for Highest to Lowest ranking, values in brackets are equal
Runoff quality (3)	P D B Q X	2, 1, 5, 3, 4 10, 8, 9, 7, 6 (12, 14), 11, 15, 13 18, 16, 19, 20, 17 22, 26, (23, 30), 31, 21, 27, 29, 28, (24, 25)
Context sensitive solutions (5)	P D B Q X	5, 4, 3, 2, 1 9, 7, (6, 8), 10 14, 13, 11, 15, 12 17, 18, (16, 20), 19 22, 24, 27, 29, 28, (23, 25, 30), 26, 31, 21
Traffic emissions reduction (5)	P D B Q X	No measurements taken in this study and therefore all options equal
Fossil fuel reduction (2)	P D B Q X	All equal for P, D, B and Q All equal for P, D, B and Q All equal for P, D, B and Q All equal for P, D, B and Q 31, (22, 26, 27), 28, 30, 24, (21, 25, 29), 23
Equipment emission reduction (2)	Same as for Fossil fuel reduction	
Water use tracking (2)	P D B Q X	All equal for P, D, B and Q All equal for P, D, B and Q All equal for P, D, B and Q All equal for P, D, B and Q 31, (22, 26, 27), 30, 28, 24, (21, 25, 29), 23
Pavement reuse (5) Earthwork balance (1) Recycled materials (5) Regional materials (5)	P D B Q X	All sections deemed equal for this evaluation – refer to text
Custom designed credits (10) - Only evaluated for relative costs	P D B Q X	Not rated for paper – cost basis for experimental section made this inaccurate for a realistic comparison in this case

TABLE 4 Strength rating, Greenroads rating and Greenroads certificate for all sections.

SECTION NUMBER	SECTION DESIGNATION	TYPE OF STABILIZER	STRENGTH RATING	GREENROADS RATING	GREENROADS CERTIFICATE
1	P AASHTO A-2-4	SPEA	2	6.8	Silver
2		SPEB	2	8.3	Gold
3		Enzyme (E)	3	6.8	Silver
4		Sulphonated Oil (SO)	3	6.8	Silver
5		Control	1 (best)	**9.0**	Gold
6	D AASHTO A-4	SPEA	2	5.6	Silver
7		SPEB	3	7.5	Gold
8		Enzyme (E)	3	7.9	Gold
9		Sulphonated Oil (SO)	4	**9.0**	Gold
10		Control	1 (best)	7.5	Gold
11	B AASHTO A-2-6	SPEA	3	8.3	Gold
12		SPEB	1 (best)	7.1	Gold
13		Enzyme (E)	5	6.8	Silver
14		Sulphonated Oil (SO)	2	**10.1**	Gold
15		Control	4	6.0	Silver
16	Q AASHTO A-2-6	SPEA	1 (best)	7.9	Gold
17		SPEB	2	7.5	Gold
18		Enzyme (E)	5	**9.8**	Gold
19		Sulphonated Oil (SO)	4	6.0	Silver
20		Control	3	6.4	Silver
21	X AASHTO A-2-4	Cement (C)	2	4.8	Silver
22		Enzyme (E)	10	**13.2**	Evergreen
23		Cement catalyst (CC)	1 (best)	5.4	Silver
24		Organic non-petroleum (ONP)	8	6.6	Silver
25		Organic non-petroleum (ONP)	6	5.3	Silver
26		Sulphonated Oil (SO)	11	11.1	Gold
27		Enzyme (E)	9	10.8	Gold
28		Polymer (P)	5	7.5	Gold
29		Cement (C)	3	5.7	Silver
30		Organic petroleum (OP)	4	9.3	Gold
31		Control	7	11.7	Evergreen