USING A MOBILE DUST MONITOR TO MEASURE DUST CONTROL EFFICIENCY FOR COMPARISON OF DUST SUPPRESSION PALLIATIVES

by

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WEB EDITION

This web edition leaves out the cover, which carries the student number, the two signed declarations, the plagiarism declaration and the acknowledgements. Names that would identify a mine are left out: the two coal mines of appendix A are called coal mine A and coal mine B, and a mine named in a cited figure is not named. Every other page is as submitted.

ABSTRACT

In South Africa, regulatory authorities often indict mines with *Section 54* penalties due to conditions threatening health and safety of workers and near by communities because of too much dust. Unfortunately, this assessment of what is considered *too much* dust is subjective. There is no explicit guideline to measure against and no available tool in South Africa to produce repeatable and reliable results.

Further the assessment of many available dust palliatives is also subjective leaving a lack of clarity as too which products are effective and by how much.

This dissertation successfully presents the use of a road emissions monitor (REM) that is light duty vehicle (LDV) mounted to develop a dust-scale and methodology to measure haul road emission dust lift off.

This methodology was used to compare *water-only* dust suppression to a polymer dust suppressant available on the market on a site in North West Province, South Africa.

The results of REM were then compared to known subjective approaches of dust palliative efficacy assessment for validation and accuracy. Both REM and the subjective approaches, both supported the same conclusion.

In 2013, the Environmental Protection Agency in New South Wales, Australia legislated the measure of active haul road emissions to a level of *control efficiency 80%*. The use of a dust palliative other than water was also recommended to control emissions.

This dissertation serves to bring forward the need and benefit for a similar approach to active haul roads and dust emissions in South Africa.

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LIST OF SYMBOLS AND ABBREVIATIONS

DCE	Dust Control Efficiency
LDV	Light Duty Vehicle
GPS	Global Positioning System
PM10	Particulate Matter 10micron
REM	Road Emissions Monitor
TAS	Time After Spraying

1. INTRODUCTION

1.1. BACKGROUND

It is well known and accepted that dust emitted from haul roads within opencast mines generated from haul truck traffic results in significant health, safety, social and environmental risks. All of which are damaging to the stakeholders associated with the mine - including the local communities, employees, suppliers, contractors and shareholders.

The traditional and most common method of dust suppression on mine haul roads is spraying water by means of a water truck. Spraying *water-only* doesn't necessarily provide the highest dust mitigation performance and may not be most cost effective method. (Thompson, 2014)

Many technologies such as natural polymers (Lignosulphonates), synthetic polymers (Styrene Acrylics), Bitumens, Sugars and Salts have been introduced to improve the time of efficacy and overall performance of dust suppression. These various dust suppression products are known as palliatives and all have a specific method of application and associated maintenance procedures.

The broad purpose although is focused on suppressing haul road dust, these palliatives may be best selected based on soil types, annual precipitation, availability of water and application method. (Kissell, 2003)

The industry for dust suppressant technologies has grown significantly with rising concern for the environment, the safety of workers and nearby communities as well as a scarce water resource in many of the mining areas. This has led to a significant increase in demand by the industry for cost-effective high performance, environmentally friendly dust suppression products. Many private companies have developed proprietary formulations to offer uniqueness and meet this demand. Unfortunately, there hasn't been an objective tool available to clients and regulators to assess the real benefits of such palliatives in South Africa

The dissertation was titled: *Using a mobile dust monitor to measure dust control efficiency for comparison of dust suppression palliatives*

Although there are various dust suppressants available, this dissertation focussed on comparing a *water-only* application to a polymer technology known as *Hydrogel,* manufactured by global total dust management company, 88CHEMCO. The product is designed to extend and enhance water's ability to suppress dust in a topical application i.e. the product is a *water-extender*.

Hydrogel was selected as the focus of this dissertation due to it's application method which consists of:

- Dosing the water bowser at 1:1000 ratio
- Topically applying within the normal watering practise

Many alternate products require establishment, which includes breaking the road surface and blending the product with the material. This requires an upfront investment from the client, a significant time before the road is ready for use and an obligation to maintain the newly created road surface. These products are typically only applicable to permanent roads.

Hydrogel may immediately be applied with the purpose of optimising the existing watering practise on site, reducing the haul road dust emission impact contribution.

An open-cast coal mine in South Africa typically has up to 93.3% dust emission contribution from haul roads, which consist of permanent and non-permanent roads (Thompson & Visser, 2001)

As determined through discussions with Manager's on numerous mines in South Africa and neighbouring countries, it was discovered that an objective method for dust suppression product comparison and control efficiency was required in order to audit suppliers, demonstrate compliance to regulatory bodies and further to develop an internal reporting measure for road dust emissions to ensure safe working conditions.

It is also a legislative requirement for mines to maintain safe operating conditions. The Inspector may issue a Section 54 Indictment due to dangerous conditions, resulting in a suspension or halting of activities. (Mine Health and Safety Act,1996).

It is often a long-term financial commitment to engage in the use of dust palliatives giving strong reasoning for a mobile dust monitor that provides an objective performance measure with methodology that is repeatable and reliable. The mobile dust monitor will herein be referred to as REM.

1.2. OBJECTIVES OF THE DISSERTATION

The objectives of this dissertation were:

- To understand the need for an objective measurement tool for comparing the performance of various dust palliatives.
- To develop a concept mobile dust monitor (REM) to compare and measure results on a water-only treated surface to a Hydrogel treated surface.
- To use the REM to determine Dust Control Efficiency.

- To statistically validate results for time effectiveness of dust suppression based on a subjective visual scale as compared to the quantitative mobile dust monitor measurement scale.
- To prove the usefulness and applicability of REM.

Further, the presentation of the dissertation needs to provide applicable and meaningful information to all stakeholders, who include:

- Those responsible for *procurement, accounting and cost management* due to the validated performance relating to cost benefit of product claims for factors directly affecting business profitability.
- *On the mine members*; in terms of road performance, dust mitigation and Health and Safety. Understanding quantitatively the areas of concern, direct measurable action can be taken.
- *The community*; as reduced haul road dust reduces the dust impact contribution at the mine boundary which is further dispersed into near-by communities. Objective evidence of trouble areas assists in mitigating root causes for dust.

1.3. SCOPE OF THE DISSERTATION

The scope of the dissertation is to use the Road Emission Monitor (REM, Mobile Dust Monitor) developed by South African company 88CHEMCO to audit the performance of haul road dust palliatives and determine Dust Control Efficiency on active haul roads.

Real data was collected from a mine in South Africa's North West Province.

Other data from various sites around the world will be included for performance comparison purposes only.

1.4. METHODOLOGY OF DATA COLLECTION AND ANALYSIS

To validate the results from REM, the evaluation method will be a combination of *Dust Degree Defect Score, empirical Dust Control Efficiency,* and comparison to other *Mobile Dust Monitoring* results.

1.4.1. Analysis Type for Dissertation

This dissertation is purely data driven for comparison and validation purposes.

This is due to there being limited literature available on the use of mobile dust monitors, with few available reports only illustrating results. This dissertation will use subjective and empirical standard industry evaluation techniques to validate the results of REM. The methodology that REM will use to acquire results will be similar to the available commercial systems in Australia.

1.4.2. Dust Degree Defect Score

The Thompson & Visser (2001) *Dust Degree Defect Score* was used to determine the *time of efficacy* for dust suppression. This dissertation defines a limit of effectiveness as: A *topically applied palliative, is only effective until a Dust Defect Degree 3 is exceeded.*

The time to exceed a *Dust Defect Degree 3* for both water-only and Hydrogel was recorded for comparison.

Table IV

Classification of the degree of haul road dust defect

Typical dust defect photograph showing haul truck travelling past monitor point at 40 km/h descriptions	Dust defect degree and associated Hund peak dust levels (approx. mg/m³ for 10 µm dust per haul truck pass)	Qualitative dust defect degree descriptions
	Degree 1: <3,50	Minimal dustiness
	Degree 2: 3,51 to 23,50	Dust just visible behind vehicle
	Degree 3: 23,51 to 45,00	Dust visible, no oncoming vehicle driver discomfort, good visibility.
	Degree 4: 45,01 to 57,50	Notable amount of dust, windows closed in oncoming vehicle, visibility just acceptable, overtaking hazardous.
	Degree 5: >57,51	Significant amount of dust, window closed in oncoming vehicle, visibility poor and hazardous, overtaking not possible.

Figure 1: Dust Defect Degree Score

Source: Thomspon & Visser, (2001)

1.4.3. Empirical Dust Control Efficiency

Cowherd et al (1988) *Dust Control Efficiency Score* is a measure defined by:

$$C = 100 - \frac{0.8p.d.t}{i}$$

where: C = Average dust control efficiency (%)

p = Potential average hourly daytime evaporation rate (mm/h)

d = Average hourly daytime traffic rate (h^{-1})

i = Application intensity (L/m^2)

t = Time between applications (h)

This equation is empirical and allows for effective comparison of topically applied dust suppressants, where effectiveness is a function of time, meteorological conditions, application intensity and traffic rates.

1.4.4. Static Road Dust Monitor

The static road dust monitors were setup on the side of the road for both water-only and Hydrogel treated roads on similar traffic and soil composition for a minimum data gathering period of one (1) month.

The static road side dust monitors were a combination of light scattering devices and dust deposition bowls.

1.4.5. Road Emissions Monitor – (REM)

The Road Emissions Monitor (REM) is a light scattering device that has been modified to fit on the back of an LDV. Dust measurements are GPS recorded at an operating speed of 40 km/h.

The collected data is then calibrated for various dust emissions and are colour coded to plot on a map of the site. This provides an indication of dynamic monitoring specific to road dust impact contribution.

This method provides opportunity for further development in future studies as it presents an abundance of road dust evaluation methods.

The mobile dust monitor is known as REM, manufactured by 88CHEMCO for the purpose of this concept dissertation.



Figure 2: Light Scattering Dust Monitor

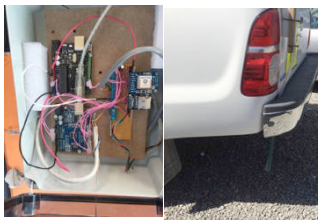


Figure 3: Backend Processors



Figure 4: Sample Point

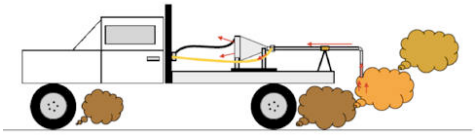


Figure 5: Schematic of Mobile Dust Monitor

1.4.6. Calibration testing

A calibration testing circuit should be completed. Calibration testing should include the full range of dust conditions:

- No dust – freshly watered,
- Extreme dust – requires urgent watering.

1.4.7. Dust Control Efficiency for REM

Dust Control Efficiency for an active haul road will be determined relative to the site under the definition of a *controlled* haul road relative to an *uncontrolled* measurement. This is in accordance with EPA-NSW (2014) requirements as outlined in the literature review.

2. CHAPTER 2 –ABOUT THE DISSERTATION

2.1. INTRODUCTION

This dissertation has made use of existing data accumulated from sites around the world where Hydrogel technology (or similar) was used to confirm an outperform relative to *water-only* treatment. A variety of methods were used to compare *water-only* to *Hydrogel* technology. These methods differ from site to site, however are related and were the following:

- Dust Degree Defect Score,
- Photo Comparison,
- Dust Control Efficiency,
- Static Roadside Dust Monitor,
- Mobile Dust Monitor.

The requirement for this validation is to provide evidence that readings for dust levels acquired from REM should support lowered dust levels on *Hydrogel* treated roads as opposed to *water-only* treated roads.

Specifically, for the purpose of this dissertation, a new comparison between *water-only* and *Hydrogel* was made at a mine site in South Africa's North West Province.

This test included:

- The subjective visual *Dust Degree Defect Score* as presented by Thompson & Visser (2001),
- *Dust Control Efficiency* as provided by Cowherd et al (1988),
- *P*hotographic comparison and,
- The newly developed quantitative dust scale as determined by 88CHEMCO's REM as a proof of concept.

2.1.1. Geographical locations where tests occurred

These are the geographical locations where tests were conducted using *Hydrogel* technology. The table below indicates the data that was collected for each location. Appendix A – *Hydrogel Test Results*, details all past results excluding the REM test performed for this dissertation and other mobile monitoring studies performed.

Table 1: Hydrogel technology test locations and collected data

	Dust Degree Defect Score	Photo Comparison	Dust Control Efficiency (Old method)	Static Roadside Dust Monitor	Mobile Dust Monitor (REM/similar to get DCE – New method)
South Africa – Coal mine A	✔	✔			
South Africa – Coal mine B	✔	✔	✔		
South Africa – Northern Cape	✔	✔			
South Africa - Another site					✔
Botswana	✔	✔	✔		
Australia – Western Australia	✔		✔	✔	
Australia – New South Wales	✔			✔	
Australia – New South Wales					✔✔
South Africa - North West*	✔	✔	✔		✔

* This case study was performed specifically for this dissertation.

2.2. HYDROGEL – WATER EXTENDER

Hydrogel is a topical dust suppressant used on all roads. H*ydrogel* is dosed into the Water Bowser at 1:1000 and applied onto roads. Literature from the supplier states that *Hydrogel* lasts at least twice as long as water in reducing dust after application.

It is stated that this product increases waters ability to suppress dust by over 100%.

The figure below illustrates the mechanism that Hygrogel uses to agglomerate dust particles.

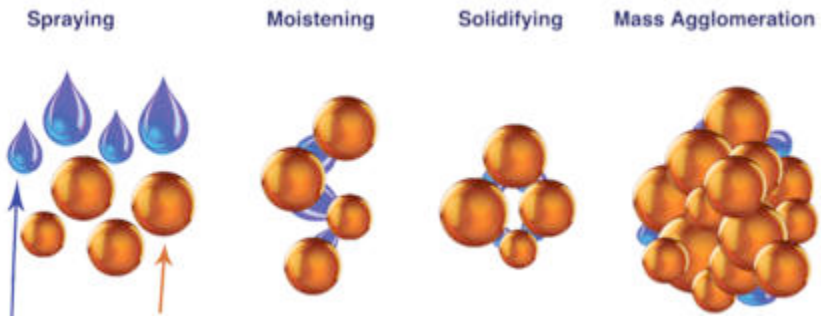


Figure 6: Hydrogel in water agglomerating dust particles

2.2.1. Research Questions Investigated

The questions investigated in this dissertation were as stated below and were in a prescribed sequence to reach a logical and statistically significant conclusion.

This dissertation evaluated the available literature surrounding mobile dust monitors to develop a concept model called REM and validate that a methodology for haul road dust palliative assessment can objectively be made. Further review of results validating *Hydrogel* as a dust palliative performing better than water, was reviewed and determined.

Finally, a methodology for REM concept proof on real time case study application, at a mine in South Africa's North West Province was implemented as below:

1. On the selected mine site, the times of dust mitigation efficacy for both *water-only* and *Hydrogel* applications for a time to reach *Dust Degree Defect Score* of 3 was determined (with photographic evidence).
2. The empirical *Dust Control Efficiency* for both *water-only* and *Hydrogel* applications were determined.
3. REM data was collected from *Hydrogel* and *water-only* applications on active haul roads at a case study application in South Africa's North West Province.

3. LITERATURE REVIEW

3.1. PRELIMINARY OVERVIEW OF LITERATURE WITH ANALYSIS OF THEORIES FOR DUST PALLIATIVE ASSESSMENT

Dust palliatives have been studied in depth, in terms of selection criteria and long-term performance. However, analysis has had a strong focus on use in the civil industry where the service life of roads are far greater than that of an average mine haul road. However, the fundamental contributors to dust generation from an unsealed road surface remained universal:

- Vehicle Speed
- Number of wheels per vehicle
- Number of vehicles
- Vehicle weight
- Particle size distribution of surface material
- Restraint of the surface fines (compaction, cohesiveness/bonding, durability)
- Surface moisture (humidity, amount of precipitation, amount of evaporation)

(Bolander & Yamada, 1999)

Through observation, Kaufman & Ault (1977) recognised that many open-cast mining operations gave little consideration to these contributors in particular to the construction practice and methodology of haul road surfaces. Further, these roads were often subjected to heavy wetting (over-watering) in an attempt to suppress dust. These roads become ‘slick and severely defaced by erosion.’

‘Adhesion of the road surface’ by means of wetting improves the haul road running surface, reducing wear and tear on vehicles and fuel consumption, but is the most significant contributor to the mitigating dust emissions.

The loose fines when agitated by traffic and wind turbulence result in unwanted fugitive emissions of which wetting agglomerates, keeping fine particles within the road surface. However, in excessive persistence for this effect, over watering/wetting may occur, which is an attempt to bind the surface fines by means of excessive moisture.

This may have the opposite effect - damaging the road; increasing the resistance to haul truck motion (rolling resistance) and further causing an increase in resources consumed during

hauling - though dust suppression is achieved it is at significant detriment to resource consumption and the primary mining purpose of production. (Tannant & Regensburg, 2001)

In a mining environment, it isn't always possible to select the optimum material to construct a road surface as optimum material may not be available and the life of the road may not warrant the investment.

Roads are broken down into the following: *Permanent Haul Roads*, *Semi-Permanent Haul Roads* and *Temporary Haul Roads.* All of which have varying factors that contribute to their life cycle cost.

Tannant & Regensburg (2001) recommends that when considering the quality requirement of a road, the factors for consideration are:

- Life of road
- Use of road (amount of production over the road)
- Location of road (is it permanent or will it be removed)

This analysis forms part of the strategies for haul road asset management. Many haul roads, should they be permanent, will economically support proper initial construction. However they will still require either water or another dust palliative to reduce fugitive emissions.

Haul Roads are exposed to mining haul trucks that are capable of payloads in excess of 290 tons operating at speeds of up to 60km/hour. This constant traffic in most weather conditions results in surface damage and the requirement for ongoing maintenance. (Thompson & Visser, 2000)

Figure 7 illustrates dust plume density readings for the size fraction below 10**µm** for a Komatsu 730E haul truck at various speeds. This evidently confirms that dust emissions increase with vehicle speed.

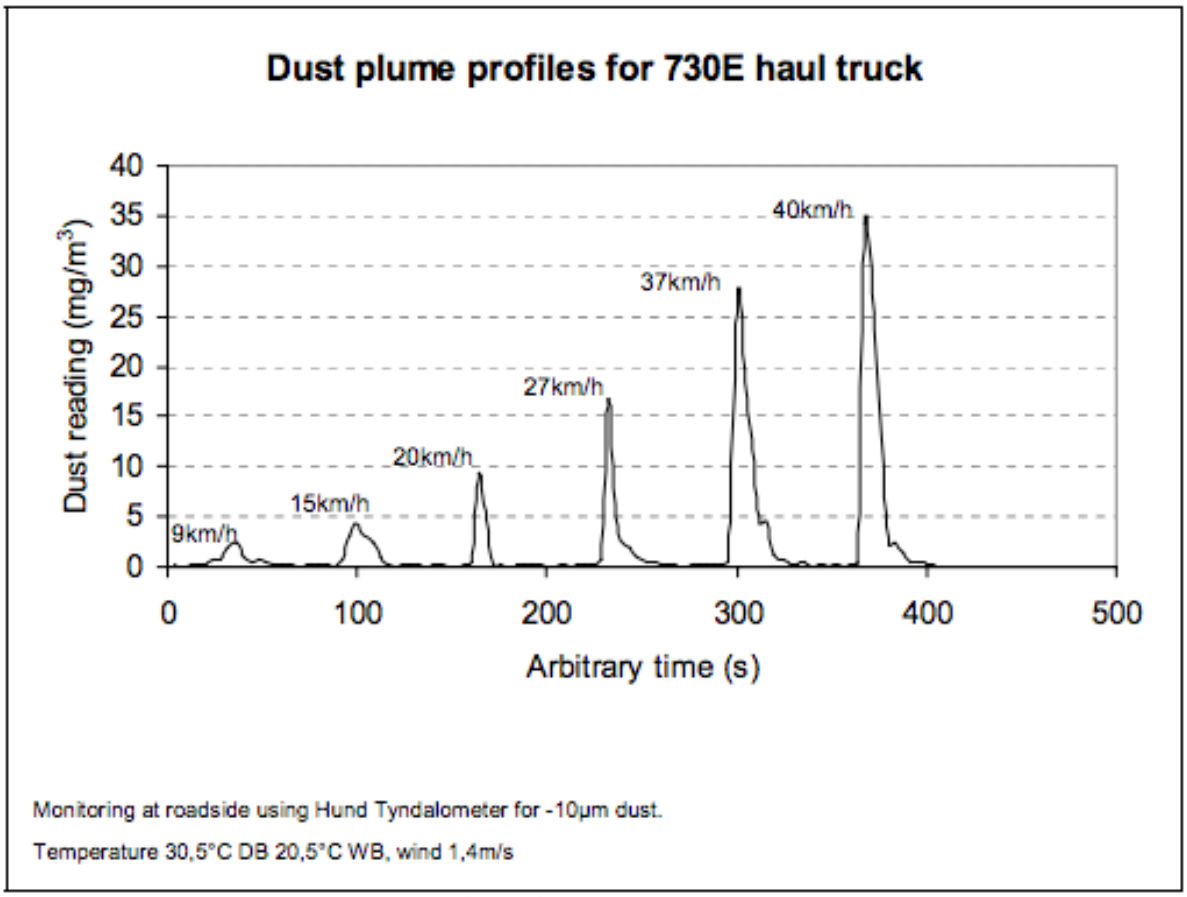


Figure 7: Dust Plume Profiles for 730E Haul Truck

Source: Thompson & Visser, (2001)

These findings allowed for the determination of a *Dust Degeneration Profile* chart to be used when assessing the Degree of Haul Road Dust Degree Defect as illustrated in figure 2 and classified in table 1.

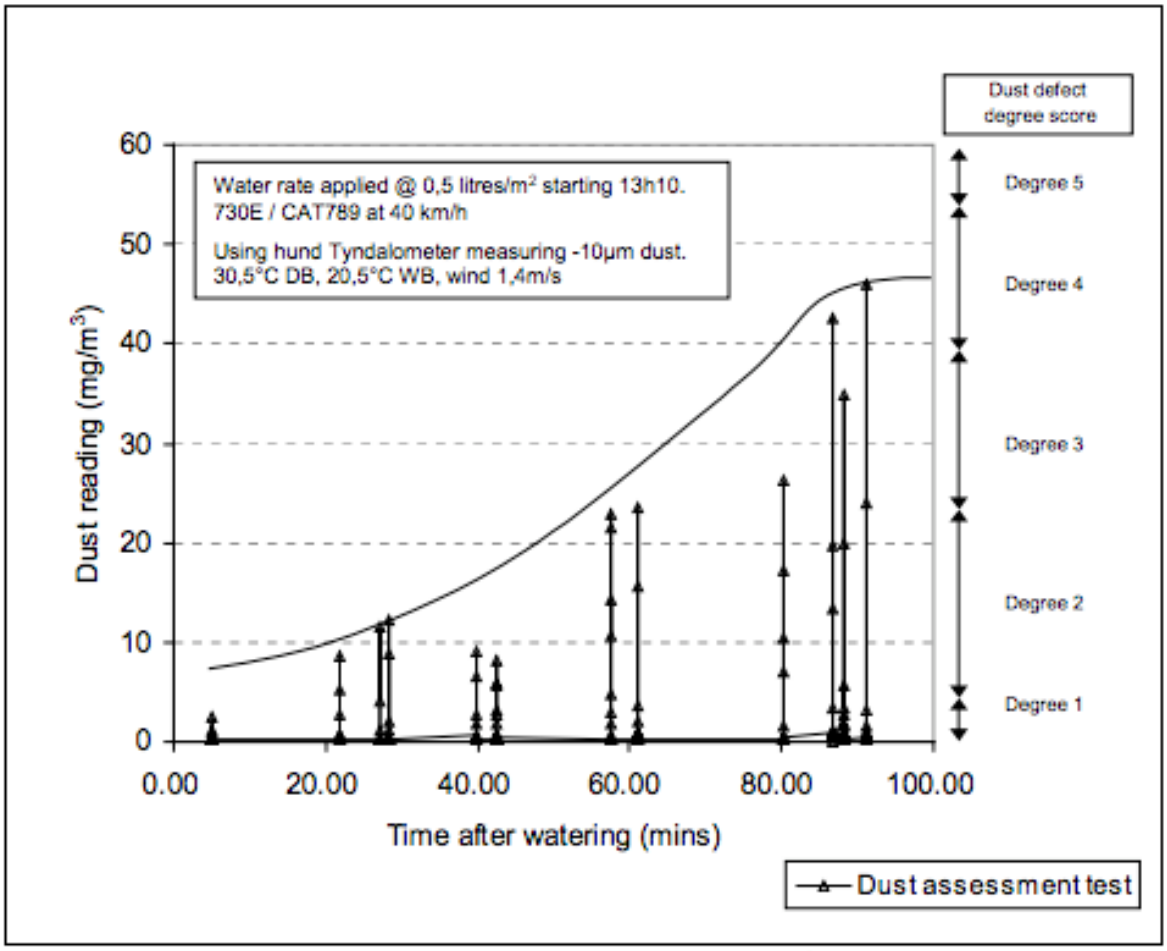


Figure 8: Dust Defect Degree Score Profile

Source: Thompson & Visser, (2001)

The *dust defect degree* profile illustrates the rate of dust generation as the influencing factors vary i.e. traffic volumes, vehicle weight, vehicle speeds, material silt content. This profile is specific to the conditions prescribed on the chart, however, the dust degree levels will remain as defined i.e. Degree 1 to Degree 5 by means of quantitative dust density measurement and qualitative visual scale.

This indicates that as contributors to dust generation vary so will the times of palliative efficacy per degree band after application.

Table 2 Dust Defect Degree Descriptions

Dust defect degree descriptions and associated Hund peak dust levels (approx. mg/m^3 for -10µm dust per haul truck pass at 40 km/h)				
Degree 1 <3,50	Degree 2 3,51 to 23,50	Degree 3 23,51 to 45,00	Degree 4 45,01 to 57,50	Degree 5 >57,51
Minimal dustiness	Dust just visible behind vehicle.	Dust visible, no oncoming vehicle driver discomfort, good visibility.	Notable amount of dust, windows closed in oncoming vehicle, visibility just acceptable, overtaking difficult.	Significant amount of dust, window closed in oncoming vehicle, visibility poor and hazardous, overtaking not possible.

Source: Thompson & Visser, (2001)

Thompson & Visser (2001) state that, 'Although watering itself is often seen as a cheap and simple approach to dust suppression, equipment and operating costs often escalate the cost of suppression'

It has been determined that the consensus is to provide remedial dust suppression action once a *Degree 2* is exceeded. This is determined from the point of view of a haul truck travelling at 40km/h and is primarily based on driver discomfort and road safety. (Thompson & Visser, 2001).

This research study however, will set the benchmark for ineffective suppression at *Degree 3* to accommodate cost of practice whist still maintaining safe operating conditions.

These methods by Thompson & Visser (2001) provide an adequate measurement of time of effectiveness and comparison at varying haul truck speeds.

However, Cowherd et al. (1988) developed an empirical method to determine the dust control efficiency of surface treatments. This method allows for benchmarking to be achieved under various meteorological, traffic, palliative application intensities and time efficacy conditions.

Equation 1, presented below determines the performance of a surface treatment i.e. watering only or watering inclusive of an additive.

$$C = 100 - \frac{0.8p.d.t}{i}$$

where: C = Average dust control efficiency (%)

p = Potential average hourly daytime evaporation rate (mm/h)

d = Average hourly daytime traffic rate (h^{-1})

i = Application intensity (L/m^2)

t = Time between applications (h)

Through the use of Thompson & Visser's (2001) *Dust Degree Defect Score* (will be referred to as Dust Degree) to determine required *(t) Time between applications* as Dust Degree 3 is exceeded so to can the *Dust Control Efficiency* be determined using the Cowherd et al (1988) empirical method (will be referred to as *Dust Control Efficiency*).

This combination of methodologies presents the opportunity to understand how effective the surface treatment is in suppressing dust i.e. Dust Control Efficiency, whilst staying within a defined dust level parameter for safe operating conditions i.e. Dust Degree 3.

The Dust Control Efficiency, although empirical, offers a method for benchmarking and comparison of palliative performance inclusive of traffic and meteorological variables. This encompasses many of the variables impacting evaluation, making it possible to compare palliative performance under varying conditions.

There is a need for new and improved theory as products evolve and haul trucks increase in size. However, for the purpose of surface treatment comparisons, the existing theory does allow for a performance evaluation to be completed. This is cumbersome, static, subjective and empirical. This further presents the premise to have an automated assessment by means of a 'mobile' road emissions monitor such as REM.

3.2. EMISSIONS MONITORING METHODS FOR HAUL ROADS (NOT MOBILE)

Prior to the development of mobile dust monitors, the most effective way to measure haul road dust and expected improvements from dust palliative use was to perform plume profiling and analysis.

This included placing a tower immediately downwind of the road edge and one upwind of the road edge as per the following figure:

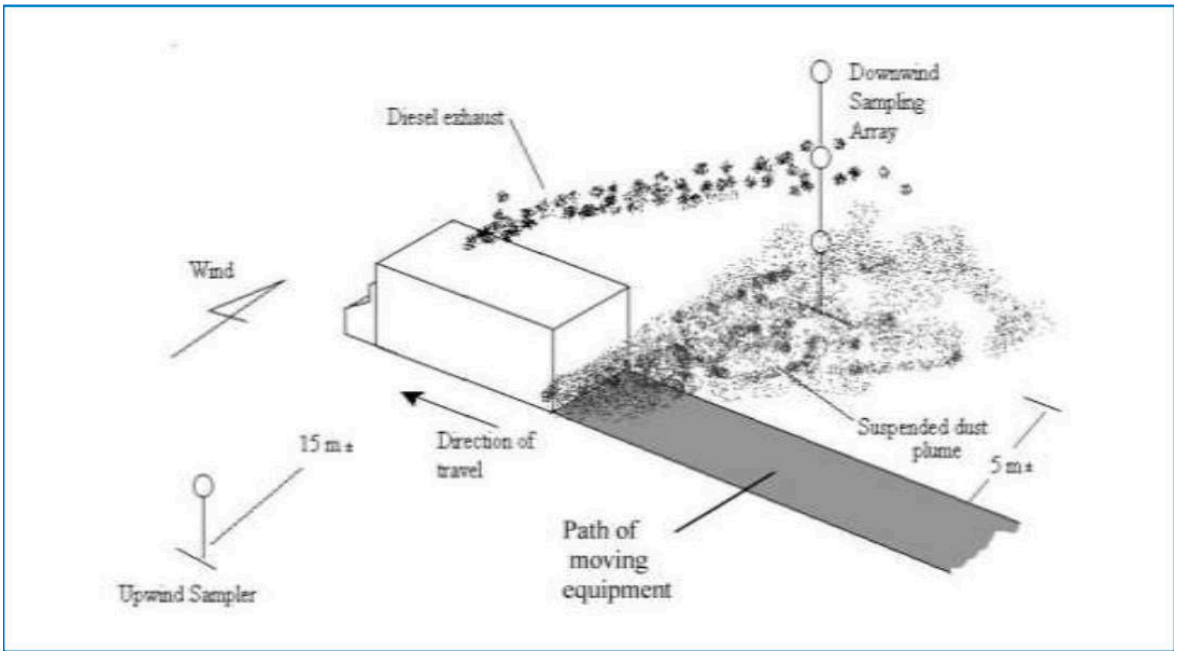


Figure 9: Plume Profiling for Haul Road Dust Analysis

Source: Cox (2013)

This method offers some level of reliability of measurement however possesses many disadvantages such as:

- High cost and labour requirement
- Measurements need to be repeatedly taken to ensure statistical significance
- Set up of equipment is difficult and finding a road with perpendicular wind can be challenging
- Can only measure one small road section at a time

These challenges have led to considering alternate methods to calculate haul road dust control efficiency that considers all active haul roads and a method that has little constraints.

The current industry, particularly in New South Wales (NSW), Australia has had both private and government input into development of mobile monitoring tools for dust control efficiency calculation and compliance by Mine Licensees.

3.3. NEW APPROACH TO DUST CONTROL EFFICIENCY USING MOBILE MONITORING METHODS

Cox and Laing (2014), approach the concept of *control* efficiency in terms of a percentage of *uncontrolled emissions.* A procedure to determine the *control efficiency* was developed using a PM10 mobile dust monitor and since formed part of *Section 55* in the *Protection of the*

Environment Operations Act 1997, Released by Australia's, New South Wales, Environmental Protection Agency (EPA, 2014) and mandated as *Environmental Protection Licence = 1376.*

The particular section is titled: *U1 The Particulate Matter Control Best Practice Implementation – Wheel Generated* where all the parameters for compliance in measuring wheel generated dust are set out.

The definition of *control efficiency (CE)* is set out as follows with a defined requirement to the licensee.

" The Licensee must achieve and maintain a dust control efficiency of 80% or more on

all active haul roads"

Control efficiency is calculated as:

$$CE = \frac{E(\text{uncontrolled}) - E(\text{controlled})}{E(\text{uncontrolled})} \times 100$$

Where E = the emission rate of the activity

Condition U1 requires that to assess compliance a mine must:

- Measure uncontrolled and controlled haul road emissions on at least 2 occasions using a mobile dust monitor.
- Measure 'additional site data' including:
    - Vehicle kilometres travelled
    - Meteorological conditions
    - Water use for dust suppression
- Undertake silt content and soil moisture sampling during sampling events.
- Determine if a site specific relationship may be derived between the measured control efficiency, additional site data, water use, meteorological data and the soil moisture and silt content levels.

The measurement of uncontrolled and controlled haul road PM10 emissions should be undertaken under varying meteorological conditions, including at those times when analysis of meteorological data indicates that elevated levels of dust are most likely at the Premises. EPA-NSW(2014)

Pacific Environmental Limited, an Australian company that developed a mobile dust monitor known as REX presented three (3) ways to analyse road emissions. These were:

- Various colours for percentage ranges of CE with uncontrolled indicated as a grey, as illustrated below.

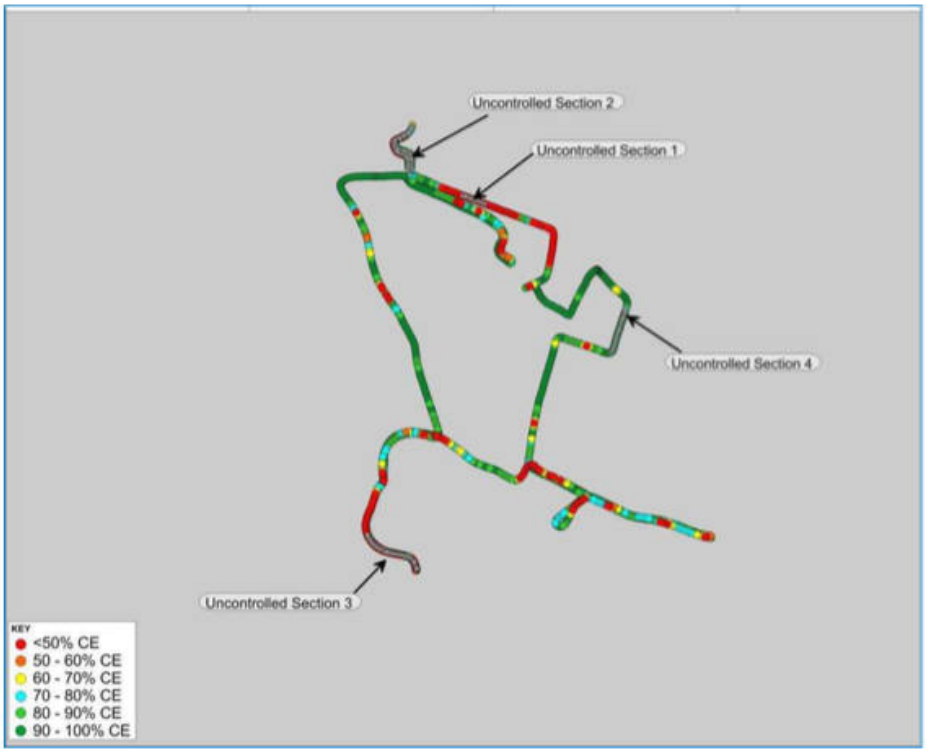


Figure 10: Colour Range Expression for Control Efficiency

Source: Cox and Laing (2014),

This method was further adopted by Australian company, Proof Engineers.



Figure 11: Mine Road Emission Monitor Example

Source: Proof Engineers (2016)

This method although providing more detailed information is simplified by defining what is a *controlled* section of road and what is *uncontrolled* section of road.

- Cox and Laing (2014), state that many factors such a seasonal changes in meteorology, road building techniques and management impact the efficiency of controls applied to haul roads. Subsequently and for the purposes of determination of *CE*, it has been accepted that *uncontrolled* haul roads are defined as:

"A section of at least 150 m of an active haul road where no water has been applied for at least 12 hours prior to monitoring and hasn't been treated with chemical suppressant. Less than 0.3mm of precipitation has been recorded at the closest meteorological station in the preceding 12 hours and ambient conditions during monitoring do not act to suppress dust (rainfall, fog, mist, high humidity, low evaporation, low wind speeds)". Cox and Laing (2014)

Using this definition, the insitu *uncontrolled* haul road state may be measured to determine the PM10 reading. This then forms the baseline for determining the *CE*. By setting the *CE* to the minimum allowable value, i.e. 80% as defined by the EPA-NSW(2014), *E(Controlled)* can be determined. All active haul roads above the solved *E(controlled)* are then coloured green and anything exceeding this PM10 value are coloured red as per the illustration of test results at a coal mine in NSW, Australia.

What is concluded is that *controlled* emissions from haul roads are a relative measure to *uncontrolled* emissions from haul roads. This is not an explicit PM10 reading that can be applied universally, but rather one that is site specific and meteorologically specific to meet the *uncontrolled* definition.

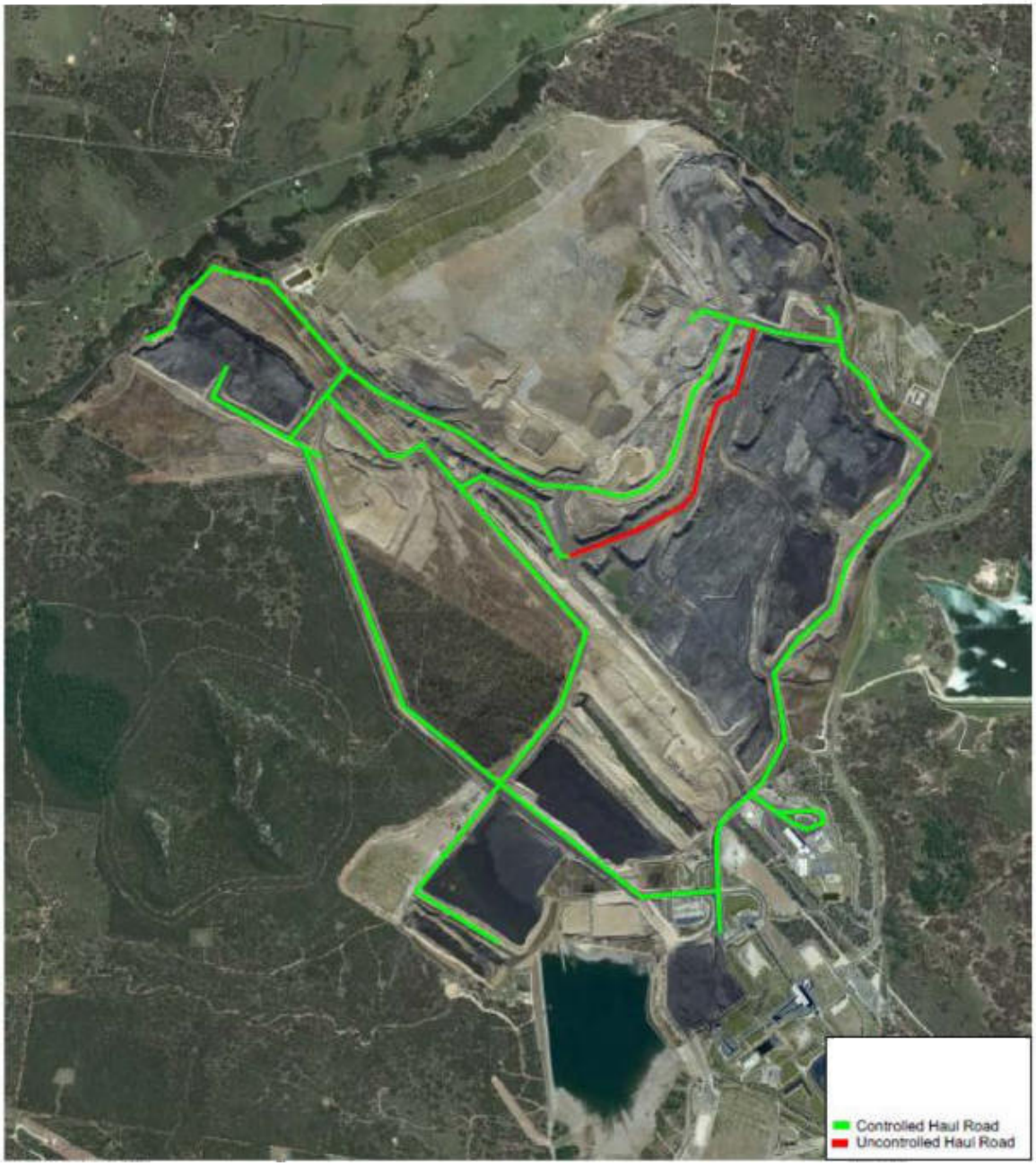


Figure 12: Controlled vs Uncontrolled Haul Roads at a Coal Mine

Source: Cox and Laing (2014)

- Pacific Environmental Limited also use the mobile dust monitor for *Hotspot Identification*. This allows miners to better understand their operation in terms of haul road dust emissions and action controls to better prevent unnecessary emissions.

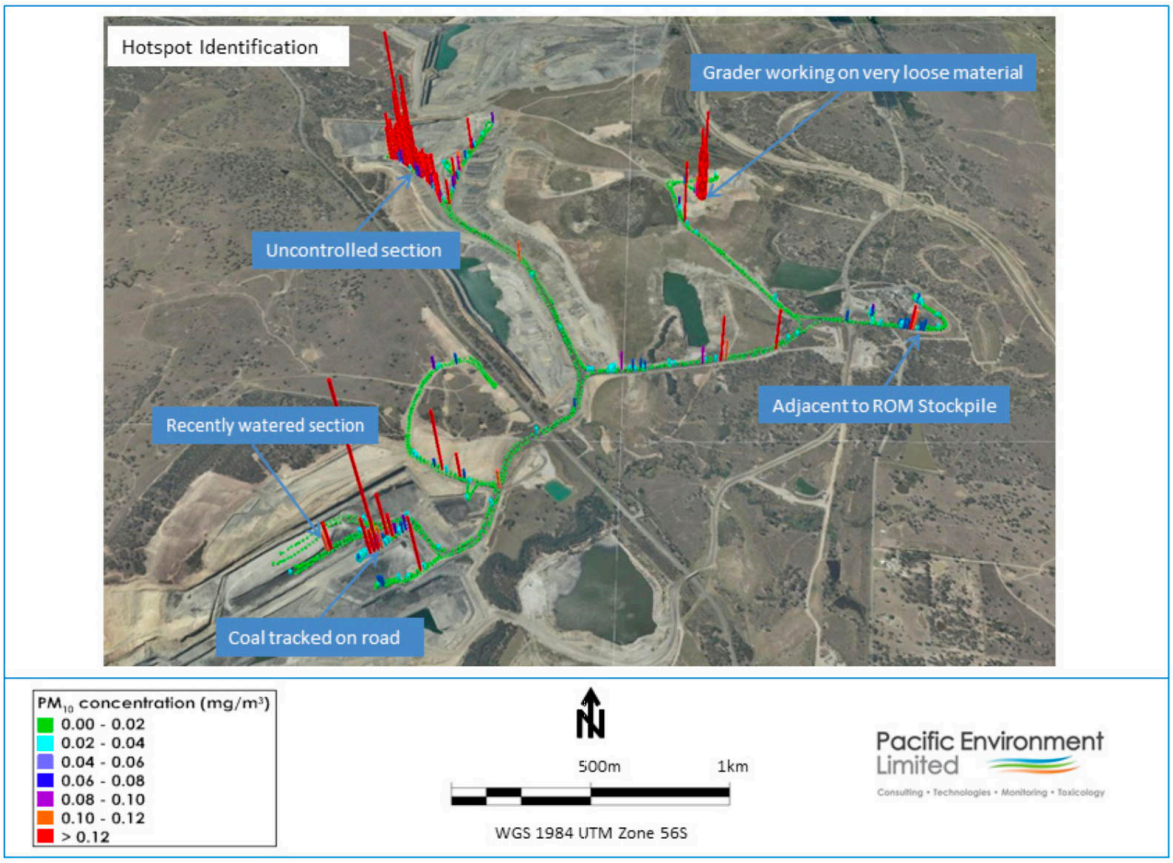


Figure 13: Hotspot Identification

Source: Anon. (2015)

4. GLOBAL AVAILABLE MOBILE DUST MONITORS

Cox (2013) identified the following available mobile dust monitors including the monitors developed by Pacific Environmental Limited (company of employment) and Proof Engineers mobile monitor. The table below illustrates the available monitors:

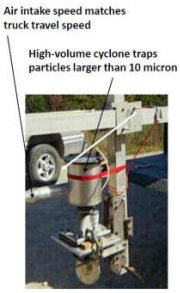
Company:	CSU Dustometer	UAF-DUSTM	MRIGlobal – Rear Mounted
Image:			  Close-up view of sampling system
Company:	MRIGlobal – Side Intake	Proof Engineers - Dustective	Pacific Environmental Limited - REX
Image:			

Figure 14: Available Road Dust Monitors

Source: Cox (2013)

All of these monitors, although mobile, act as a fixed unit built onto a utility vehicle. This study presents 88CHEMCO's REM that may be fitted to any utility vehicle. The results presented in the next section demonstrate that a retro-fitted mobile monitor may provide results consistent with the previous subjective methods. This provides justification for further development and study.

5. PROOF ENGINEERS STUDY

In 2013, Conducted conducted a study for a coal mine in New South Wales, Australia.

The purpose of this study was to:

- Estimate baseline emissions and determine a scale for haul road dust emission based on acceptability,
- Determine the insitu test state of active haul roads,
- Compare a *water-only* treated haul road surface to a palliative (similar to *Hydrogel*) treated haul road surface.

A scale for acceptable, cautionary and unacceptable dust levels was determined and is illustrated below:

Colour	Scale (mg/m^3)	Associated PDM Picture	Comments
	0.00 – 0.50		- No visible dust produced by haul truck - Just watered - Operable
	0.50 – 1.25		- Low levels of visible dust produced by haul truck - Does not require watering - Operable
	1.25 – 1.56		- Medium levels of visible dust produced by haul truck - Requires immediate watering
	1.56 – 3.25		80% Dust Control Efficiency Reached
	> 3.25		- Extreme levels of visible dust produced by haul truck - Inoperable and highly unsafe

Figure 15: Dust Scale for NSW Coal Mine

Source: Retief et al, (2013)

After implementing the mobile dust monitor, the following result were observed for the *water-only* and *palliative* treated surfaces.

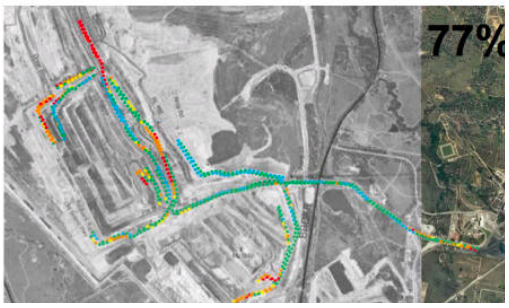


Figure 16: *Water-only* Treated, CE =77%



Figure 17: *Palliative* Treated, CE=90%

Source: Retief et al, (2013)

These test results demonstrated that using a mobile dust monitor may quickly determine and present a visual representation of active haul roads and the dustiness conditions. This allows the industry to objectively understand performance differences with confidence.

6. PLATINUM MINE, NORTH WEST, SOUTH AFRICA CASE STUDY

This case study was purpose performed for this dissertation and forms the primary data source for analysis of *Using a mobile dust monitor to measure dust control efficiency for comparison of dust suppression palliatives.*

Hydrogel was implemented on site to reduce water used in dust suppression on haul roads and as a prevention for section 54 indictment. A section 54 indictment is a health and safety shut down due to unsafe working conditions which is commonly issued as a result of too much dust. The site was tested with *water-only* conditions and again once treated with *Hydrogel.*

The purpose of this study was to demonstrate that 88CHEMCO's REM will produce results aligned with all the subjective measures, for or against the performance of *Hydrogel.*

6.1. TEST METRICS

This site had all the metrics for measuring effectiveness of Hydrogel including:

- Dust degree defect score comparison
- Dust Control Efficiency comparison
- Mobile Dust Monitor comparison

6.2. METHOD FOR DATA COLLECTION

The table below outlines the collection method to attain the defined key performance indicators (KPI).

Table 3: KPI and Test Method for Comparative Evaluation

KPI	Collection Method
Time of efficacy	The recorded time with photographic evidence to exceed a *Dust Defect Degree Score* of 3
Expected water truck cycles/day shift	Based on *Time of Efficacy,* divided by day shift hours, divided by total treated area
Expected water usage/m^2/day shift	Expected *water truck cycles* multiplied by litre capacity, divided by total treated area
Water cart minutes per m^2 per shift	Total water truck operating time divided by total treated area
Dust Control Efficiency*	Collected inputs for Cowherd et al (1988) DCE equation
Road Dust Monitor Scale	Photographic evidence of *dust defect degree score* with road dust monitor reading

* The Dust Control Efficiency (DCE) of both *water*-only and *Hydrogel* may be obtained from the meteorological, traffic and application intensity data. Dust Control Efficiency refers to how efficiently a particular palliative may suppress dust under specific conditions.

Inputs for calculating the DCE for *water-only* and *Hydrogel* included:

- Evaporation rate
- Traffic rate
- Time before required re-application
- Application Intensity

All KPI are determined in the unit measure of m^2 in order for results to be extrapolated to haul roads of various total areas.

6.3. METHOD OF HYDROGEL APPLICATION

Hydrogel was dosed into the Water Truck by means of a pump and nipple connection. Dosing was to a ratio of 1:1000 with water and applied onto haul roads following the standard watering practise.

Once dust levels exceeded a *Dust Defect Degree Score* of 3, a further application was required.



Figure 18: Hydrogel Dosage Setup

6.4. DATA ANALYSIS

6.4.1. Dust Degree Defect Score with Photo Comparison

Below is photographic evidence of *Dust Degree Defect Score* with time.

Water-Only Application



Figure 19: 1 hour after water-only application, Degree 4



Figure 20: 45 minutes after water-only application, Degree 4

Hydrogel Application



Figure 21: 2 hours after Hydrogel application, Degree 2



Figure 22: 3 hours after Hydrogel application, Degree 3

As illustrated, *water-only* application lasts between forty-five (45) minutes and one (1) hour before the *Dust Degree Defect Score* of 3 is exceeded, deeming it ineffective beyond this time point.

However, when *Hydrogel* was added to the Water bowser, the *Dust Degree Defect Score* of 3 was maintained to a *time of efficacy* of three (3) hours.

6.4.2. Dust Control Efficiency Comparison and Expected Water Savings

Over a three month period i.e. May, June, July data inputs required for the Cowherd et al (1988) DCE equation were collected and averaged.

All meterological information was sourced from local weather sources for 2016 to date and for the second half of 2015 (August to December) to build an annual model.

Watering cycles per day shift when using *water-only* were nine (9) cycles per day shift as collected when operating on site before *Hydrogel* application.

After introducing *Hydrogel*, these cycles reduced to three (3) cycles per day shift.

The inputs of:

- Traffic rate
- Application intensity

Remained constant in the DCE comparison. However, inputs regarding:

- Meteorological information
- Applications/day shift

Varied, based on conditions at the time of collection.

The most significant difference in input value affecting the DCE calculation comparison was the *applications/day shift* for *water-only* and for *Hydrogel*, which were nine (9) and three (3) respectively.

Table 4: Annual average DCE comparison for water-only to Hydrogel applications

Annual Average DCE Water-Only (%)	Annual Average DCE Hydrogel (%)	Percent Improvement (%)
36.40 %	109.21 %	300 %

The table above indicates that when using *water-only,* the DCE at the platinum mine in the North West Province of South Africa has an annual average of 36.40% effectiveness. This means that under the environmental, application and traffic conditions, *water-only* offers an efficacy for dust control to a score of 36.40%.

Alternatively, by using *Hydrogel*, under the same conditions, with altered application rate per day shift resulted in a DCE of 109.21%. This exceeds what would be considered a benchmark 100% efficiency level. This indicates that implementation of *Hydrogel* is three (3) times more efficient than using *water-only* to suppress dust on the sites haul roads.

In order to determine annual expected water savings, a relationship between DCE and watering cycles was required. This was defined as the *Hydrogel DCE Ratio* and the *Water DCE Ratio*.

DCE data for the three (3) months of data collected onsite was compared to the calculated DCE for that month. A ratio of DCE to Water bowser cycle was then calculated and averaged over the three (3) months to determine a ratio that can be used to predict application cycles required in months where DCE data was not collected.

This although based on a limited amount of data allows for indication of expected cycles of *water-only* to expected cycles of *Hydrogel* to achieve a certain DCE.

The table below indicates the required watering cycles annually for both *water-only* and *Hydrogel*. The Water bowser capacity is 80,000L and therefore is the amount of water used in one (1) cycle.

Table 5: Annual average DCE comparison for water-only to Hydrogel applications

Annual Average Water-Only Usage (L)	Annual Average Water Usage with Hydrogel (L)	Percent Improvement (%)
3,681 cycles = 294,471,500L	1,227 cycles = 98,157,167L	67%

The table above indicates that when using *water-only,* 3,681 cycles of the 80,000L Water bowser (294,471,500L) are expected to be used annually to suppress dust. However, when using *Hydrogel* in the Water Bowser, a 67% improvement is expected. This reduces the cycles to 1,227 (98,157,167L) saving a total of 196,314,334L of water annually.

The above subjective study demonstrates a significant dust suppression outperform on *Hydrogel* treated roads as opposed to *water-only* treated roads.

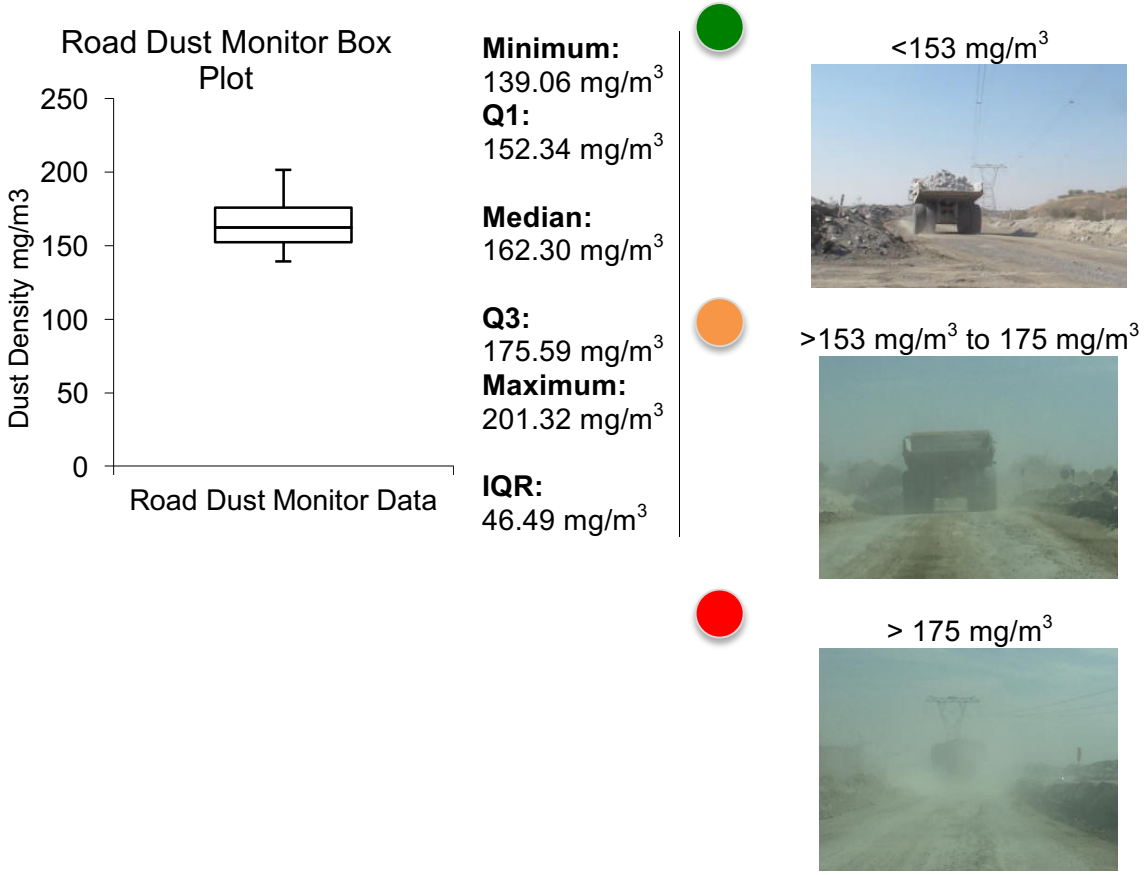
6.5. ROAD EMISSIONS MONITOR - REM

REM was developed to create a convenient quantitative method of determining the *Dust Defect* and *Control Efficiency* without the need for subjective decision making.

The road dust monitor scale was developed by relating dust imagery to a quantitative dust reading.

The scale for dustiness below illustrates the levels of dust density that are considered to be *controlled* and *uncontrolled*. Once the *orange* level is exceeded the level of dust is deemed *uncontrolled* and is then considered a *red* state.

Table 6: Road Dust Monitor Scale for Dustiness



The figure below is a map of the mine with the colours from the dustiness scale plotted. In the case of all the data for the testing days, the mines roads were considered acceptable.

All of these roads were treated with Hydrogel and remained out of the *red* category as an overall average.



Figure 23: REM Output

REM is a powerful tool to demonstrate road dustiness. The data is quick to process and may be used on a daily basis to collate an archive of road dust levels. Unfortunately, access to the site for further data collection was restricted. However, results for emissions didn't reach an *uncontrolled state* as dust was supressed for a period greater than forty-five (45) minutes, which was the limit of *water-only* in regards to performance. This demonstrated congruent results with the subjectively collected data, illustrating a qualitative measure with visual representation of *Hydrogel* treatment as compared to haul roads treated with *water-only* for dust suppression.

The purpose of producing results and a scale of dust emission lead to DEM concept validation.

It is recommended that each site have a scale developed due to the differences in road material composition. Once this scale is developed and calibrated for the site, use for reporting may continue.

It was not possible to determine a factor of improvement for *Hydrogel* compared to *water-only* using the road dust monitor as all roads were treated and the unit was not available during baseline data collection.

7. CONCLUSION

Suppression of dust on active haul roads is an important component of most mines environmental management plan and health and safety plan. This is a considerable expense for the mines, often with little objective and measurable evidence of effectiveness that may be related to costs. This is of importance when comparing the large array of dust suppression products from various suppliers on the market, compared to using *water-only.*

This dissertation effectively demonstrated the proof of concept of an LDV mounted road emissions monitor that may be used as a tool to measure dust palliative efficacy and determine the dustiness state of which a haul road is, in terms of *controlled* and *uncontrolled* levels.

The method measures the PM10 emission over time in relation to the *controlled* and *uncontrolled* state, plotting the condition as a colour scale on the site map.

88CHEMCO's REM was used in this dissertation to demonstrate replication of available mobile dust monitors in Australia, however with the point of difference being that it is not fixed to a single LDV.

In South Africa, there is no tool available at present to objectively compare haul road dust palliatives, nor is there a tool to demonstrate compliance of haul road dust emissions to a set standard.

This dissertation demonstrates that with appropriate effort from industry and regulators, as in Australia, a system using a mobile road emissions monitor could exist.

8. SUGGESTIONS FOR FURTHER WORK

This dissertation serves as a proof of concept in terms of:

- The mobile emissions monitor,
- Development of an objective methodology for testing haul road dust conditions
- Development of an objective methodology for dust palliative comparison

It is recommended that further study be conducted specifically in the following two (2) areas:

- Development of a robust mobile emissions monitor
- Development of an objective methodology to measure haul road dust conditions for compliance. This would require input from both industry and Government.

It is recommended that the further study include:

- Testing at various sites around South Africa
- Testing on various materials (compare silt loadings)
- Testing in various meteorological conditions (seasons, rain, sunshine)

This would develop an understanding of what is accepted as *controlled* and *uncontrolled* haul road emissions as realistically possible in the varying conditions.

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1. APPENDIX A: CASE STUDIES PROVING HYDROGEL OUTPERFORMS WATER

Prior to attempting to prove the concept of the quantitative and accurate nature of a mobile emissions monitor in roads palliative assessment; Hydrogel needs to be proven to outperform water. This section provides a summary of results for the case studies identified in the main body of the report.

1.1. COAL MINE A, SOUTH AFRICA

Summary of Results achieved with Hydrogel implementation:

KPI	Water Only	Hydrogel
Water used per m^2 per shift	3.68L/m^2/shift	0.61L/m^2/shift
Expected water cart cycles/12hours	8cycles	2 cycles
Water bowser minutes per m^2 per shift	0.0033min/m^2/shift	0.0005min/m^2/shift

An 83.4% performance optimisation was achieved on current practice.

Further dust densities for Hydrogel treated roads were also observably favourable when compared to 'water only' treated roads.



Figure 24: 1hr after 'water only' treatment, Dust Degree 4



Figure 25: 3hrs 42mins after Hydrogel treatment, Dust Degree 3

TAS = Time after spraying, Data collected as possible and available

Day	Dust Defect Degree/Time after treatment/ Picture	Dust Defect Degree/Time after treatment/ Picture	Dust Defect Degree/Time after treatment/ Picture	Dust Defect Degree/Time after treatment/ Picture
Baseline (Water only) Monday, Day 1	12:11 on 16/02/2015 TAS: 1hr, ***Degree 5*** 	12:12 on 16/02/2015 TAS: 1hr, ***Degree 5*** 	09:34 on 20/01/2015 TAS: 1hr, ***Degree 4*** 	
Wednesday Day 1 Hydrogel	09:00 on 18/02/2015 TAS: ca. 24hr (prev.day) ***Degree 4*** 	10:30 on 18/02/2015 TAS: 1hr ***Degree 3*** 	11:59 on 18/02/2015 TAS: 2hr 29min ***Degree 3*** 	13:12 on 18/02/2015 TAS: 3hr 42min ***Degree 3*** 
Thursday Day 2 Hydrogel	10:30 on 19/02/2015 TAS: 1hr 20min ***Degree 2*** 	11:21 on 19/02/2015 TAS: 2hr 11min ***Degree 4*** 	12:04 on 19/02/2015 TAS: 2hr 54min ***Degree 4*** 	
Friday Day 3 Hydrogel	09:35 on 20/02/2015 TAS: 1hr 15min ***Degree 2*** 	09:35 on 20/02/2015 TAS: 1hr 15min ***Degree 2*** 		

Through familiarization of the site and processing of data measured and calculated, a performance evaluation of Hydrogel may be confidently made.

Picture evidence of *dust defect degree* of baseline roads compared to the Hydrogel treated road is in favour that Hydrogel is up to four (4) times more effective than water for dust suppression.

This is also confirmed through operator feedback that water only lasts for approximately fourty-five (45) minutes before roads need re-watering. This is further supported by the standard water cart cycles claimed by the operators to be between eight (8) and ten (10) cycles per shift for an active area.

Effective dust suppression on the low-wall road (allocated trial road) was achieved within the Hydrogel dosage budget and with an average of two (2) water bowser cycles per shift.

The most important KPI that relates to direct cost savings is the *water bowser minutes per m^2 per shift* which is an indication of water bowser resource time spent per shift to mitigated dust on a particular area of road.

This KPI was improved by 83.4% on the low-wall road, freeing up the water bowser resource significantly to attend to other areas. The business case for Hydrogel use is most affected by the offset of the savings achieved within this KPI.

The *dust defect degree*, demonstrated the prolonged effectiveness of Hydrogel. This score was superior in comparison to the 'water only' treated area. When reviewing the pictures the difference in level of dust cloud density behind the passing vehicles is clearly evident.

1.2. COAL MINE B, SOUTH AFRICA

Summary of Results achieved with Hydrogel implementation:

KPI	Current	Achieved
Expected water bowser cycles/12hours	12 (application every hour)	3.4 (average of Thursday's and Friday's results. ({3+4}/2)
Water bowser minutes per m^2 per shift	71% reduction in time spent mitigating dust per m^2 /shift ({{12-3.4}/12} x 100)	
Water used per m^2 per shift	71% reduction in water used mitigating dust per m^2 /shift ({{12-3.4}/12} x 100)	

A 72% performance optimisation was achieved on current practice.

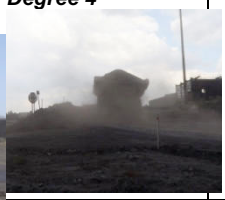
Water only treatment for dust suppression is 243% more resource intensive to maintain *Dust defect degree* less than 4 when in comparison to using Hydrogel.



Figure 26: 1hr after 'water only' treatment



Figure 27: 4hrs after Hydrogel treatment

Day	Dust Defect Degree	Dust Defect Degree	Dust Defect Degree	Dust Defect Degree	Dust Defect Degree
Baseline (Water only) Monday 11/05/2015, Day 1,	Immediately after water application ***Degree 1*** 	1 hour after water application ***Degree 4*** 	n/a	n/a	n/a
Thursday, 14/05/2015 Day 1 Hydrogel	Before Hydrogel application. Last water during night shift ***Degree 3*** 	1hr after Hydrogel application ***Degree 1*** 	2hr after Hydrogel application ***Degree 1*** 	3hr after Hydrogel application ***Degree 2*** 	4hr after Hydrogel application ***Degree 4*** 
Friday, 15/05/2015 Day 2 Hydrogel	Immediately after Hydrogel application. ***Degree 1*** 	1hr after Hydrogel application. ***Degree 1*** 	2hr after Hydrogel application. ***Degree 2*** 	3hr after Hydrogel application. ***Degree 4*** 	

It was concluded that the use of Hydrogel resulted in an average required application of three and a half (3.4) times per twelve-hour period as opposed to water's required twelve (12) applications. This results in a 71% reduction in time spent per m^2 and water used per m^2 for mitigation of dust.

This indicates that using water only for dust suppression is ca. 243% more resource intensive as opposed to using Hydrogel.

Applying Cowherd et al (1988) *Dust Control Efficiency Equation* the following plot was produced. By day 2 of testing, Hydrogel is approximately seven (7) times more efficient in controlling dust as opposed to water-only.

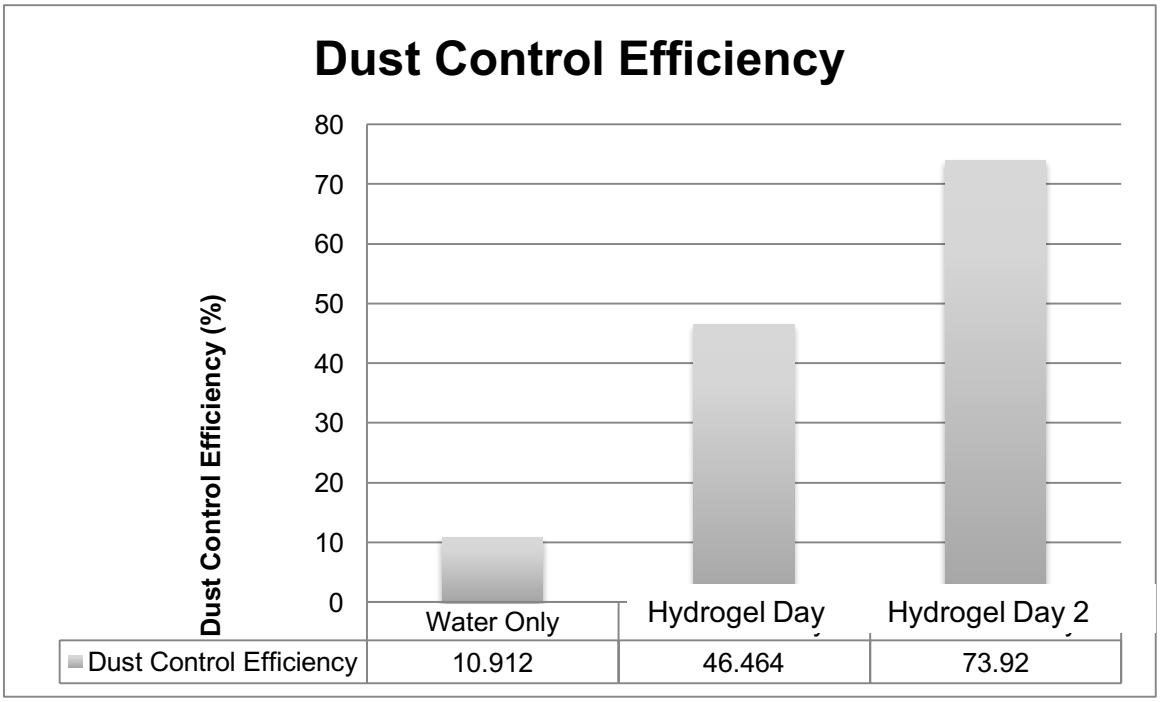


Figure 28: Dust Control Efficieny of Hydrogel comapred to Water-only

Table 7: DCE inputs

Palliative| Element	Evaporation Rate (mm/h)	Traffic Rate (veh/h)	Time Between Application (hour)	Application Intensity (L/m^2)
Water Only	0.31	22	1	0.5
Hydrogel Day1	0.33	22	4	0.5
Hydrogel Day2	0.7	22	3	0.5

1.3. LIME QUARRY, SOUTH AFRICA, NORTHERN CAPE

Hydrogel was compared to water-only application for dust suppression at a lime quarry in South Africa's Northern Cape. The purpose was purley to test for time of efficacy.



Figure 29: 6 minutes after water-only, Dust Degree 4



Figure 30: 50 minutes after Hydrogel, Dust Degree 1

Figure 31: Total cost of ownership compared to a water-only approach

1.4. DIAMOND MINE, BOTSWANA

Hydrogel was used in Botswana for the primary purpose of saving water. In order to achieve



Figure 32: 34 minutes after water-only, Dust Degree 4



Figure 33: 2.25hours after Hydrogel, Dust Degree 2

this, water's ability to suppress dust for longer than typical was required. By adding Hydrogel to the Water bowsers at 1:1000, the following results were observed.

Analysis for Hydrogel application compared to water-only applications were made to determine the reduced Water bowser cycles required to suppress dust effectively and determine the water savings that may be achieved through use of Hydrogel.

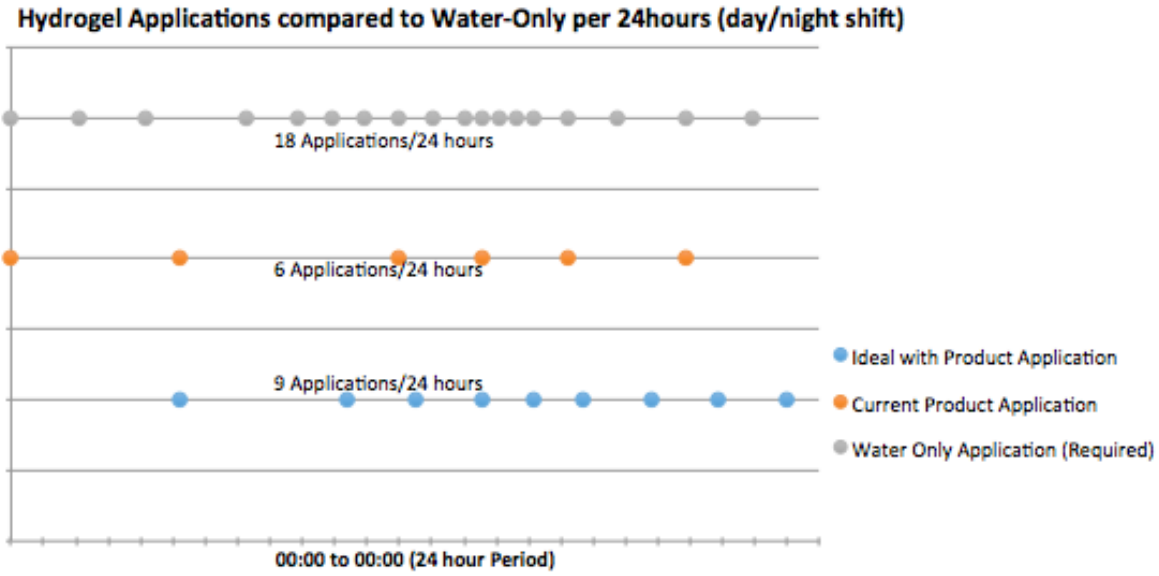
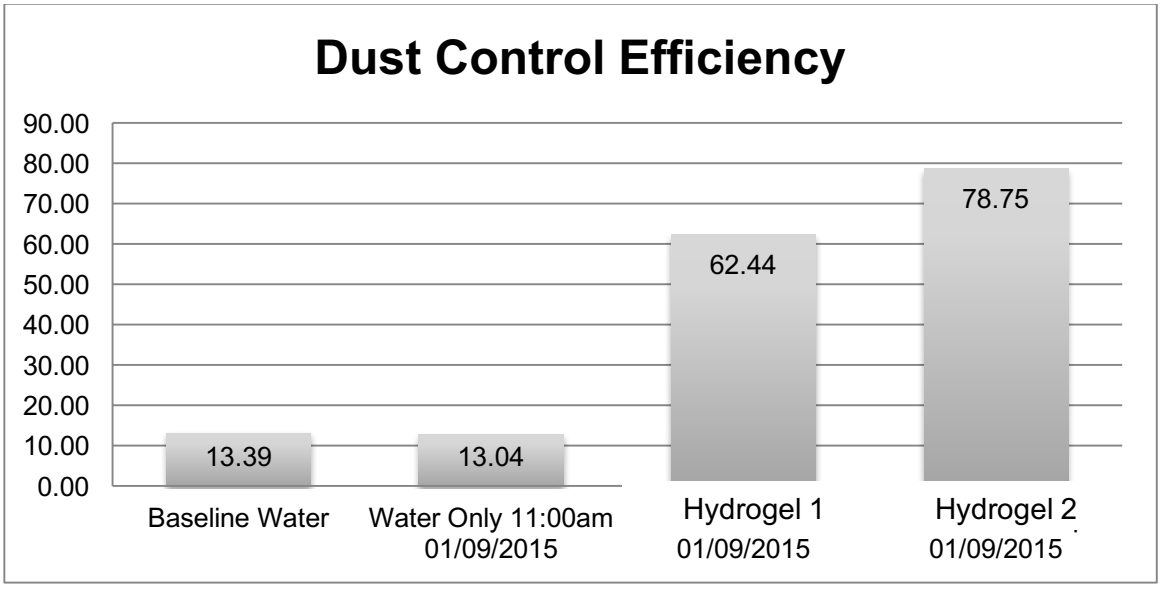


Figure 34: Hydrogel Applications Compared to Water-Only Applications per 24hours



Use of Hydrogel compared to water demonstrated a minimum of a 50% reduction in Wate bowser cycles per 24hours. This indicates that through addition of Hydrogel, water is at least 100% more effective in suppressing dust.

1.5. IRON ORE MINE, WESTERN AUSTRALIA, AUSTRALIA

Static road side dust monitors were set up on a Hydrogel technology treated road and on a water-only treated road to measure PM10 dust emissions. This was for comparison purposes to determine the reduced dust levels from a Hydrogel technology treated road.

The mine was seeking dust emission reduction at the best cost of ownership with little concern for water consumption.

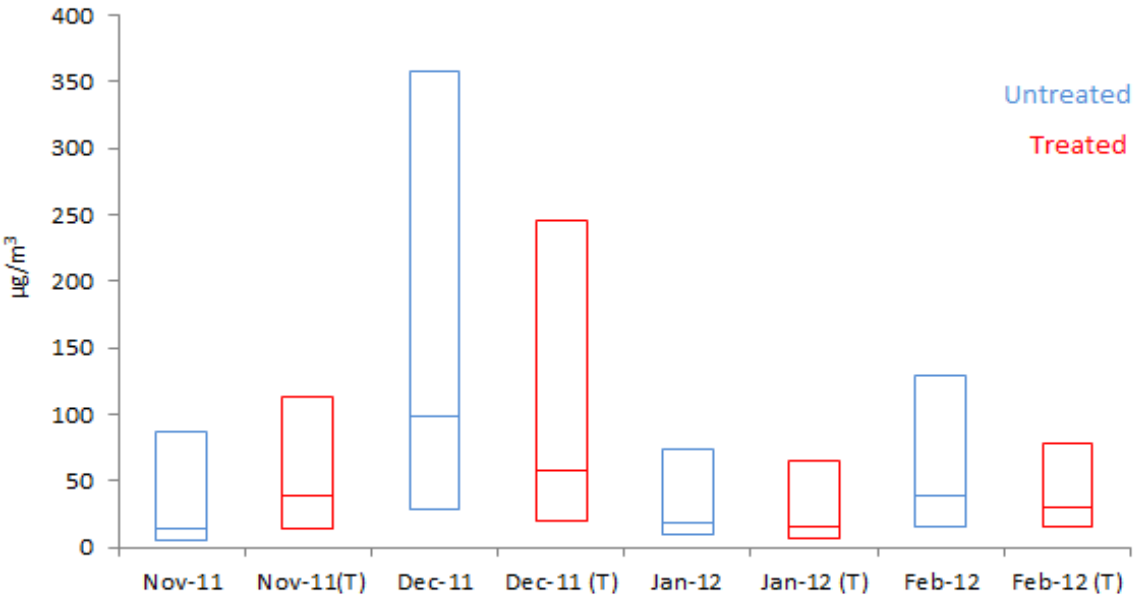


Figure 35: Box Plots of Treated and Untreated Dust Monitoring Data

Table 8: DCE Inputs

Measure	November (baseline), Water Only	December, Hydrogel Technology	January, Hydrogel Technology	February, Hydrogel Technology
Evaporation rate, (mm/hr)	0.4	0.4	0.4	0.3
Traffic/hr, estimate	25	25	25	25
Water usage L/m2 (GPS)	0.45	0.39	0.38	0.34
Time to empty water cart (mins)	14.7	16.6	23.2	21.2
Dust Control Efficiency	5.33%	30.77%	31.58%	26.47%

Two areas: untreated (water only) and treated (Hydrogel technology) where simultaneously monitored for dust levels over three months. The material was Maramamba, which is an extremely fine and dusty material found in Western Australia.

Results:

- 24% reduction in water/m^2
- 44% improvement in water cart usage per fill

- Significant decrease in Min/Max dust range
- 555% improvement in Dust Control Efficiency

1.6. COAL MINE, NEW SOUTH WALES, AUSTRALIA

Static road side dust monitors were set up on a Hydrogel technology treated road and on a water-only treated road to measure PM10 dust emissions. This was for comparison purposes to determine the reduced dust levels from a Hydrogel technology treated road.

The mine was seeking dust emission reduction at the best cost of ownership with little concern for water consumption.

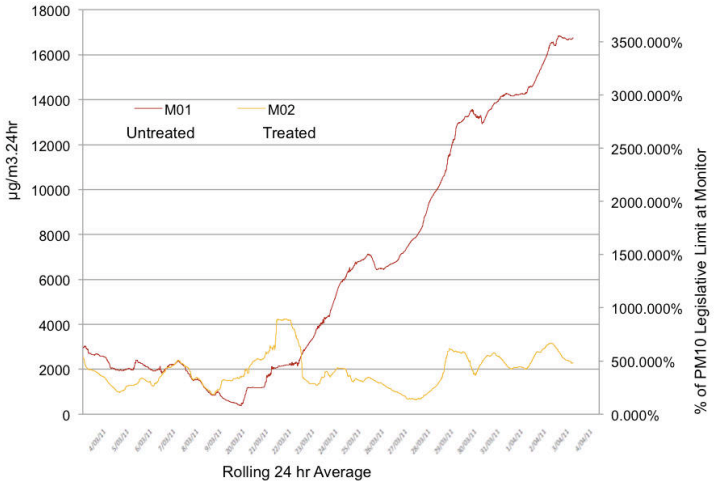


Figure 36: Plot of Raw Dust Data

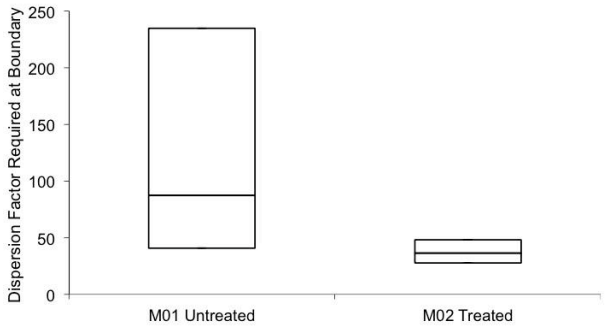


Figure 37: Box Plot of Comparative Data

Labels	M01 Untreated	M02 Treated	Difference in Dispersion Multiple
Q_1	40.8496	27.7156	13.13
Median	87.2256	36.3352	50.89
Q_3	234.85	48.1888	186.66
IQR	194.0004	20.4732	173.53

Table 9: Coal Mine, NSW, Australia Hydrogel Technology Results

Measure	Water-Only	Hydrogel Technology	Percentage saving/improvement
Water applied L/m2	0.46	0.21	54%
Distance per water truck load km)	11.6	37.0	218%
Dust Level Average Water-Only vs Hydrogel Technology (ug/m3.24hr)	87.2	36.3	58.7%

Hydrogel technology increased Water-Bowser performance and decreased water usage whilst mitigating dust levels by 58.7% as a cumulative dust density.

2. APPENDIX B:

2.1. HYDROGEL PERFORMANCE FACTOR

Through analysis of all the available data, a factor of performance for Hydrogel compared to water-only was determined. The scoring matrix takes into account factors of comparison for:

- Dust Degree Defect Score
- Dust Control Efficiency
- Static Roadside Dust Levels

All elements were assigned equal weighting when determining the performance factor.

Table 10: Hydrogel Performance Factor Matrix

Site	Dust Degree Defect Score Ratio	Dust Control Efficiency Ratio	Static Roadside Dust Monitor Ratio	Water Ratio	AVERAGE COMBINATION FACTOR
South Africa - Coal mine A	3.42			4.00	3.71
South Africa - Coal mine B	4.00	7.39		3.53	4.97
South Africa - Northern Cape	10.00				10.00
South Africa - North West	3.43	3.00		3.00	3.14
Botswana	3.97	5.88		2.00	3.95
Australia- Western Australia		5.55	1.32	1.22	2.70
Australia - New South Wales			2.40	2.19	
AVERAGE FACTOR	4.96	5.46	1.86	2.66	3.75
PERFORMANCE FACTOR					**4.75**

The performance factor is the multiple by which Hyrdrogel outperforms water-only for haul road dust suppression.

Should individual comparisons i.e. water usage, average dust density etc be required, the average factor from the matrix may be used as the multiple of performance.