Wet Weather High Visibility Linemarking Trial

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ABSTRACT
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Visibility of conventional pavement markings in wet conditions is often significantly reduced as the coating of water which covers traditional glass beads in markings during times of heavy rainfall has the effect of an optical lens which changes the refraction of light so that it is no longer returned to the driver. This reduced visibility causes the driving task to be more difficult because drivers have less tracking information and guidance along the roadway.

The importance of the issue is supported by crash data analysis, which showed that 20% of the total crashes on Queensland's state-controlled roads in the last five years occurred on sealed wet roads. 16% of crashes occurred when it was raining and 9% during dark conditions.

The Queensland Road Safety Action Plan 2013-15 included a priority action to 'identify and trial innovative safety engineering treatments to further increase visibility of road markings in heavy rain'. To meet this action and find an effective solution to this ongoing road safety problem, Queensland's Department of Transport and Main Roads (TMR) has undertaken a Wet Weather High Visibility Pavement Marking Trial. The project aims to improve the availability of proven and effective road-marking systems in wet weather.

This paper describes the selection, implementation and evaluation of several innovative pavement marking products used in the trial. The trial was undertaken at sites that had experienced a high rate of out-of-control, run-off-road and head-on wet weather crashes. Performance measures including wet retroreflectivity have been monitored and evaluated. Products are also being monitored and evaluated on their road safety benefits, with wet-weather-related crash rates analysed and compared before and after the installation of the new pavement markings.

INTRODUCTION

The Queensland Government has endorsed the National Road Safety Strategy 2011-2020 which includes a target of a reduction of at least 30% in the number of fatalities and serious injuries by 2020.

As part of Queensland's continuing and evolving efforts to improve road safety, Queensland has adopted the Safe System approach to road safety which, while promoting alert and compliant drivers, also aims to reduce the severity of crashes through infrastructure improvements, speed management and enforcement.

The Queensland Government's Targeted Road Safety Program aims to address known and potential crash sites on state-controlled roads by providing cost effective, high-benefit treatments such as providing better linemarking, signage etc.

The Queensland Road Safety Action Plan 2013-15 included a priority action to "identify and trial innovative safety engineering treatments to further increase visibility of road markings in heavy rain". To meet this action and find an effective solution to this ongoing road safety problem, the Department of Transport and Main Roads (TMR) has undertaken a trial of several linemarking products that have increased visibility in wet conditions.

Background

TMR has several linemarking products that have been applied on the state-controlled road network over time. These products range from waterborne paint to thermoplastic paint and standard beads to large beads. Nevertheless, it has been acknowledged that there exists a significant risk to drivers during wet weather on Queensland roads and an opportunity to further investigate other superior retroreflective road markings for wet conditions.

The importance of the issue is supported by crash data analysis which shows that 20% of the total crashes that occurred in Queensland in the last five years occurred on sealed wet roads. 16% of crashes occurred when it was raining and 9% during dark conditions.

Funding of $500,000 was allocated for engineering trials. The project involved the supply and installation of linemarking products that provide high visibility on wet pavements at high-risk locations on the state-controlled road network.

TMR engaged ARRB Group (ARRB) to develop a wet linemarking reflectivity testing method and undertake periodic readings of the reflectivity of two linemarking products. The data from the readings shows the reflectivity performance of each product when it is dry and wet, identifying the reflectivity deterioration when wet. Over time, the data will show the rate of deterioration of reflectivity for each product.

Methodology

Trial site selection

The sites for the trial were based on a crash analysis, and then ranking of each site for suitability.

A crash analysis of Definition for Coding Accidents (DCA) groups 2 (head-on) and 15 to 20 (off carriageway on straight/curve, out of control on straight/curve) on state-controlled roads during wet weather was undertaken to identify potential trial sites. They were required to meet the following criteria:

- higher than average rate of wet weather crashes (state average = 20%)
- a minimum of two wet weather injury crashes in the last five years.

The potential trial sites were then ranked based on the following criteria:

- Sites with immediate upstream or downstream section/s that have also experienced high crash rates were given high priority.
- Sites identified under other programs such as wide centreline treatment were excluded due to inaccuracy in evaluating crash performance.
- Sites with very high annual average daily traffic (AADT) such as motorways were given low priority due to potential high traffic management costs.
- Sites were checked for issues such as the existence of current linemarking and if the marking was warranted as per the Manual of Uniform Traffic Control Devices.

Initial investigation of rainfall data and the distance of the rainfall station from identified wet weather crash sites was carried out to consider in the prioritisation of trial sites. However, due to time limitations this work was not completed and hence not incorporated in the final ranking.

Six sites were selected for the installation of wet weather high visibility linemarkings. These are listed in Table 1.

Table 1: Wet weather linemarking trial sites in Queensland

Site	Road/site	AADT	Maximum posted speed limit	Minimum posted speed limit
1	Caboolture-Bribie Island Road	19,500	100	60
2	Samford Sub-arterial Road	33,000	60	60
3	Beaudesert-Beenleigh Road	7000	80	80
4	Nambour-Mapleton Road	5000	100	60
5	Samford Road	12,700	70	60
6	Landsborough-Maleny Road	7000	80	80

Control sites

In addition to the trial sites for new products, three control sites were selected within 2 km of the trial sites as shown in Table 2. The control sites had waterborne paint with Type D-HR glass beads.

Table 2: Wet weather linemarking control sites in Queensland

Site	Road/site	AADT	Posted speed limit
Control Site A	Landsborough-Maleny Road	7000	80
Control Site B	Caboolture-Bribie Island Road	19,500	100
Control Site C	Beaudesert-Beenleigh Road	7000	100

Product selection

Through consultation with industry, TMR sought advice from multiple companies that potentially had capability to undertake the trial works. The initial procurement process (multi-invitation process) was conducted from 2013 to mid-2014, seeking potential suppliers across the state.

Of the five companies shortlisted, one was selected for supply and install linemarking in accordance with TMR technical specifications (Department of Transport and Main Roads 2012).

The linemarking products selected for trial were RainLine (RL) and cold applied plastic (CAP). These products have Type D-HR W glass beads and will provide the levels of reflectivity required as per TMR technical specifications (Department of Transport and Main Roads 2012) and Australian standards (Standards Australia 2009, Standards Australia 2005a and Standards Australia 2005b).

It was recognised these products have been tested worldwide and received good initial trial results.

TMR also considered a third product or system – retroreflective raised pavement markers (RRPMs) with shorter spacing (12m) than currently prescribed by the TMR standard (Department of Transport and Main Roads 2008). This was based on internal feedback suggesting a benefit in reducing RRPM spacing in terms of the reduction in encroachment into other lanes in wet weather.

RRPMs at reduced frequency

RRPMs generally provide more effective and durable pavement markings than painted lines because:

- They are not generally obscured at night under wet conditions.
- They provide an audible and tactile signal when traversed by vehicle wheels.
- They are conspicuous in all conditions.

RRPMs are generally located in gaps in the painted broken lines. For applications with continuous lines such as barrier lines, RRPMs are placed 25 mm to 50 mm from the line. On sharp curves RRPMs are oriented in the direction of approaching traffic rather than tangentially to the curve.

The normal spacing between RRPMs for unlit roads is 24 m. The arrangements installed at two sites selected for the trial are as per Table 3. Figure 1 shows the RRPMs with shorter spacing at Sites 1 and 2.

Table 3: RRPM trial installation arrangements

Site	Road Name	Current RRPM arrangements	Trial RRPM arrangements
1	Caboolture-Bribie Island Road	White RRPMs on lane lines with 24 m spacing.	Install additional white RRPMs on lane line to ensure the spacing of 12 m; new edge RRPMS at 12 m spacing.
2	Samford Sub-arterial Road	White RRPMs on lane lines with 24 m spacing; yellow RRPMs on dividing lines with the spacing greater than 12 m.	Install additional yellow RRPMs on lane lines to ensure the spacing of 12 m; additional RRPMs at 12 m spacing.

Figure 1: RRPMs at reduced frequency at Caboolture-Bribie Island Road and Samford Sub-arterial Road

Cold applied plastic

Cold applied plastic (CAP) linemarking is a cold-hardening, two-component, methyl methacrylate (MMA) resin compound. The technical name of the product was Sprayable Degadur SP2.

CAP is a fast curing, highly durable product and formulated to create an unbreakable bond between itself and the substrate. In addition to long-term material presence, it is designed to provide a high wear resistance and an optimum retroreflectivity. These factors in combination with the use of large glass beads, which allow the water to drain off more quickly than smaller beads, help achieve wet night visibility in a sustainable way.

CAP is catalysed by dibenzoyl peroxide, which is organic peroxide (Type D), 50% powder with silica. It is a free-flowing white powder, used as an initiator for cold applied plastic products.

Type D-HR W glass beads are applied to the surface of the marking to provide initial retroreflectivity (Figure 2).

CAP has been extensively used throughout Europe and New Zealand but is less commonly used in Australia for long, flat lines or structured markings.

Figure 2: Cold applied plastic at Beaudesert-Beenleigh Road and Nambour-Mapleton Road

RainLine

RainLine (RL) linemarking is a thermoplastic low-profile marking with grooves or channels marked into the hot material as it is applied to increase the speed at which the rain water runs off the line. This gives improved time retroreflectivity during wet road conditions and visibility by allowing rain water to run between raised sections of thermoplastic. Figure 3 shows the application of RL at sites 5 and 6.

Glass beads were applied at the time of application to provide acceptable levels of retroreflectivity before traffic wear exposes the embedded glass beads.

RL has been used extensively in the UK. The feedback received from UK's Highway Agency to TMR was that it is a very useful product where there are occurrences of wet night crashes with no street lighting and locations where the road is very flat and rainwater sits on the carriageway covering the lane lines, which then gives poor lane delineation and can be a factor in side-swipe crashes.

Figure 3: RainLine at Samford Road and Landsborough-Maleny Road

Testing and evaluation proposal

ARRB prepared a proposal for the testing and evaluation of wet weather linemarking products. Initially, ARRB provided a cost to undertake handheld retroreflective measurements using handheld equipment. However, it was found the cost of using handheld equipment would be prohibitive and therefore an alternative methodology of using Delta LTL-M mobile measurement equipment was developed. It was proposed that both wet and dry retroreflectivity data be collected from both the trial and control sites during night-time.

Product evaluation

The performance of each product will be monitored over two years. This will be undertaken by measuring the reflectivity of each product at the trial and control sites to provide comparative data.

The installation cost will be compared with the lifespan of the linemarking. The three products will be compared to each other and also to 'standard waterborne' linemarking paint. The reflectivity thresholds are given in Table 4.

Table 4: Linemarking reflectivity thresholds

Traffic volume (AADT)	< 250	250 - 1500	1500 - 5000	5000 +
Dry conditions, minimum retroreflectivity	50	70	100	150
Wet conditions, minimum retroreflectivity	25	35	50	50 +

Source: Guidelines for Performance of New Zealand Markings (Dravitzki et al. 2003)
Note: Reflectivity units in millilux (mcd/lx/m^2).

Reflectivity data collection

ARRB developed a wet weather linemarking reflectivity testing method for the project. The method allowed the linemarking reflectivity to be tested in dry and wet conditions. The Delta LTL-M retroreflectometer was integrated with ARRB's Hawkeye system on a Network Survey Vehicle (NSV) (Figure 4). This also enabled video capture of the site, mapping, accurate road gazetted chainages and, if required, overlays of other Hawkeye datasets such as Gipsitrac, cracking, roughness, pavement strength etc.

Figure 4: LTL-M integrated with Hawkeye

A simulated water-flow rate of approximately 6 mm per hour was selected. This was the rate at which the road remained visibly wet and left a film of water over the road (Figure 5) while the NSV collected the data.

Figure 5: Wetting the road

Several pilot data collections were undertaken to evaluate the consistency of the readings during the day and night, and in dry and wet conditions. The readings from the pilot were consistent in all conditions (Figure 6). This provided the confidence that the data could be collected during the day or night.

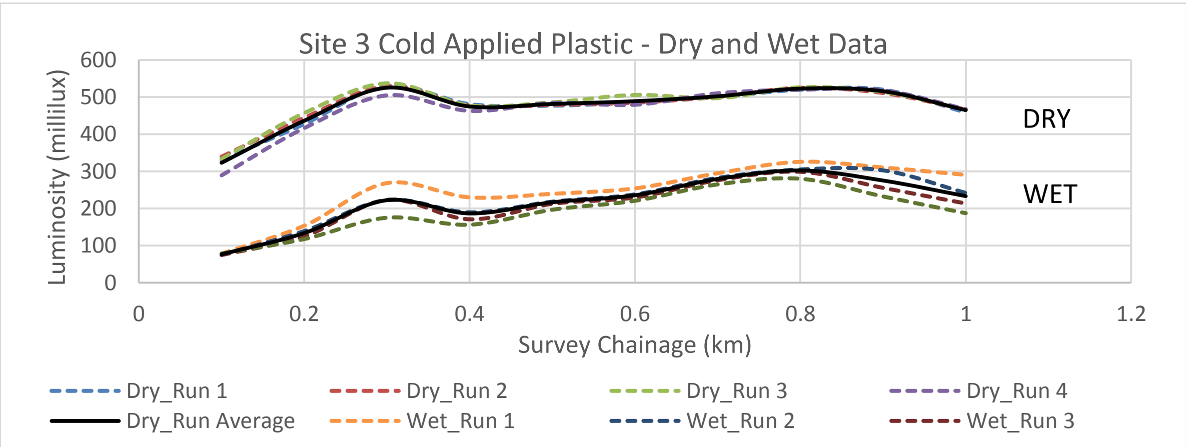


Figure 6: Consistent reflectivity data, four runs of data

Reflectivity data results – Year 1

To date, data has been collected twice at each of the trial and control sites; there was a three-month interval between the first and second data collections. A 1 km section of each site where the road geometry was reasonably flat and straight was selected. This was to ensure that any influence that grade and curvature may have on the readings is reduced, providing a reasonable level of consistency between the data collection sites.

The data demonstrated a clear reduction in reflectivity when the road is wet. This was evident for traditional waterborne paint with Type D-HR glass beads, and CAP and RL with D-HR W glass beads. The reflectivity readings for the RRPMs at reduced spacings were not consistent and not considered reliable to show a comparison between dry and wet readings.

A visual comparison of the dry and wet reflectivity readings for each trial site is shown in Figure 7 to Figure 9.

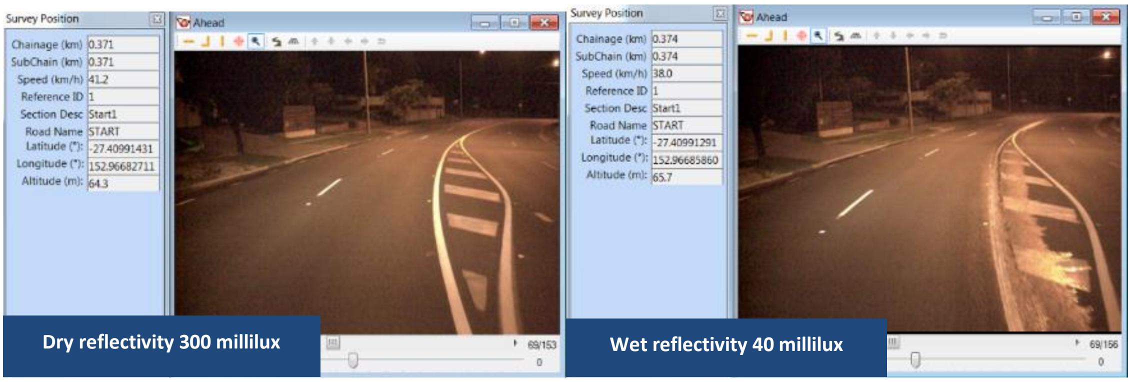


Figure 7: RRPMs and waterborne paint, site 3 dry and wet reflectivity

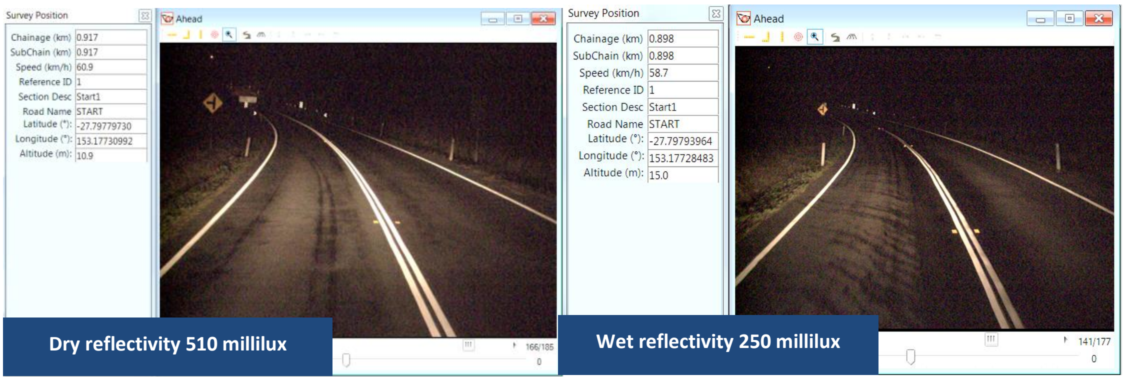


Figure 8: CAP, site 3 dry and wet reflectivity

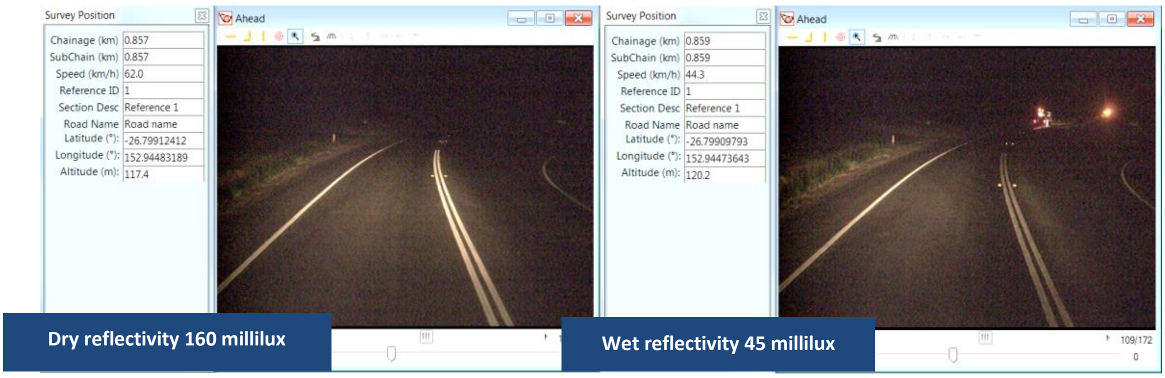
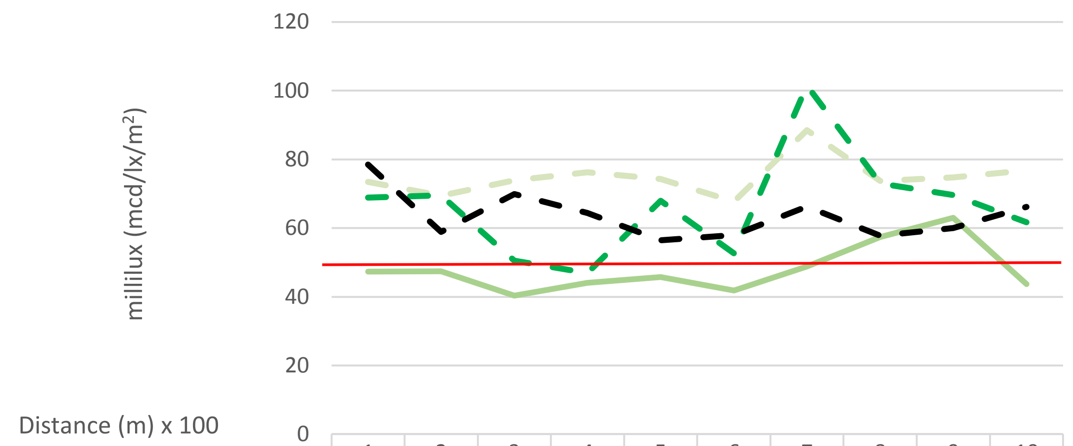


Figure 9: RL, site 6 dry and wet reflectivity

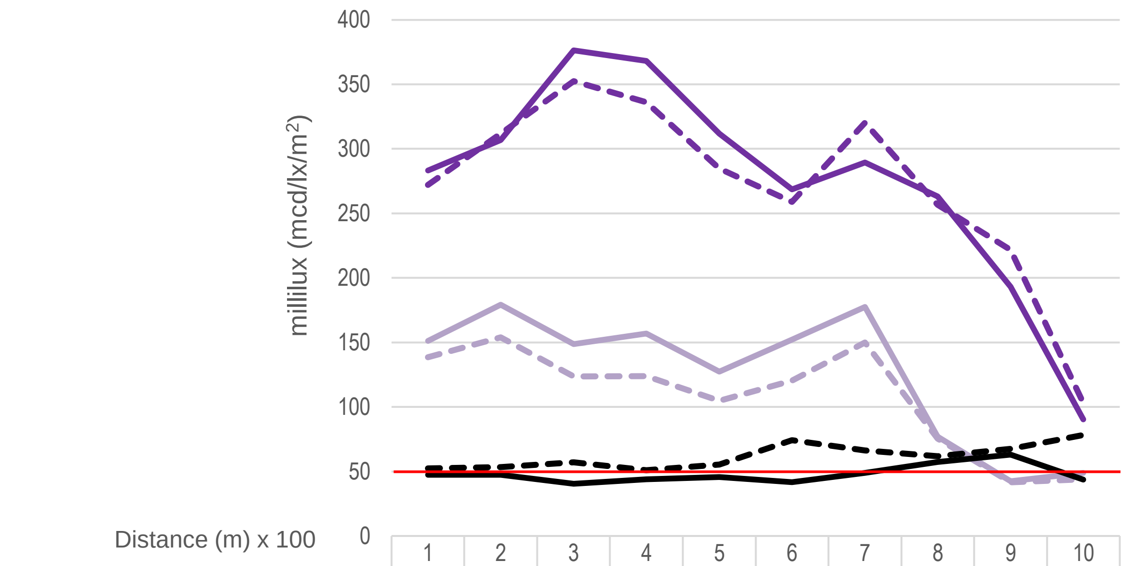
The average reflectivity of each tested product and control at the various sites are shown in Figure 10 to Figure 12. These values show the difference in wet reflectivity between the products.



	1	2	3	4	5	6	7	8	9	10
RRPMs - Site 1 - DC1	47	47	40	44	46	42	49	57	63	44
RRPMs - Site 1 - DC2	73	69	74	76	74	68	88	74	75	77
RRPMs - Site 2 - DC2	69	70	50	47	68	53	101	73	70	62
Waterborne - Ctrl B DC2	78	59	70	64	56	58	66	58	60	66

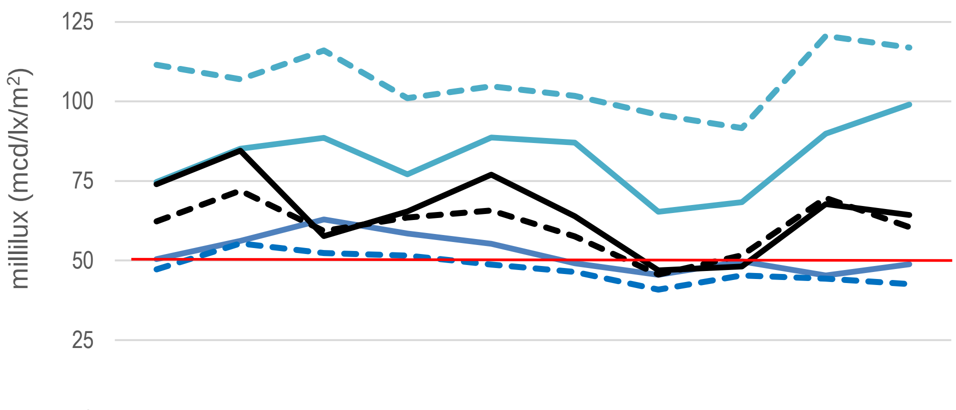
Note: The data from DC1 for site 2 has been omitted from the graph as it was considered inaccurate, possibly due to the condition of the road surface at the time of data collection (debris, dust etc.).

Figure 10: RRPM, wet weather reflectivity average readings over site lengths



	1	2	3	4	5	6	7	8	9	10
Cold Applied Plastic - Site 3 - DC1	283	307	376	368	312	269	290	263	193	90
Cold Applied Plastic - Site 3 - DC2	272	312	352	336	285	259	320	257	222	103
Cold Applied Plastic - Site 4 - DC1	151	179	149	157	127	152	177	77	42	49
Cold Applied Plastic - Site 4 - DC2	138	154	124	124	105	120	150	75	42	44
Waterborne - Ctrl C DC1	47	47	40	44	46	42	49	57	63	44
Waterborne - Ctrl C DC2	52	53	57	51	55	74	66	62	68	78

Figure 11: CAP, wet weather reflectivity average readings over site lengths



Distance (m) x 100	1	2	3	4	5	6	7	8	9	10
RainLine - Site 5 - DC1	75	85	89	77	89	87	65	68	90	99
RainLine - Site 5 - DC2	112	107	116	101	105	102	96	92	121	117
RainLine - Site 6 - DC1	50	56	63	58	55	49	46	50	45	49
RainLine - Site 6 - DC2	47	55	52	52	49	46	41	45	44	43
Waterborne - Ctrl A DC1	74	85	58	65	77	64	47	48	68	64
Waterborne - Ctrl A DC2	62	72	59	63	66	58	46	52	70	61

Figure 12: RL, wet weather reflectivity average readings over site lengths

Comparison of reflectivity data

A comparison of the dry and wet reflectivity averages for CAP and RL are shown in Figure 13. This figure shows the reduction of reflectivity at each site when the road surface is wet; it also shows that CAP wet reflectivity is mostly well above the 50 millilux wet reflectivity intervention threshold, whilst RL is marginally above the threshold.

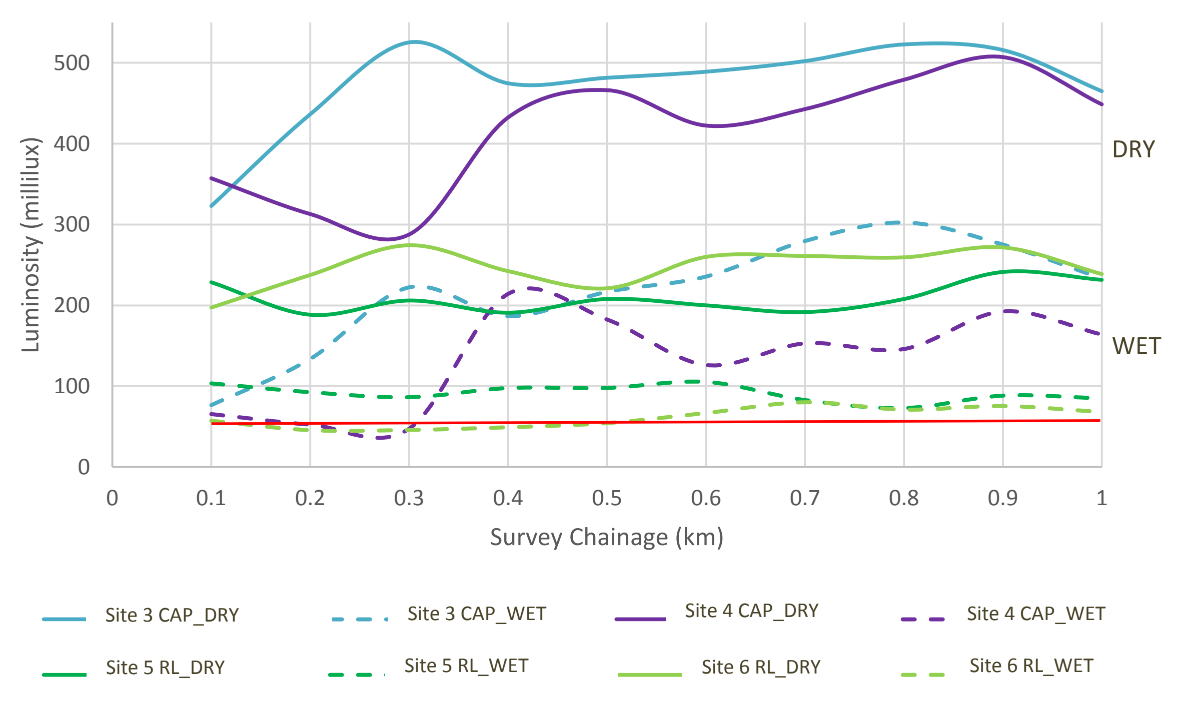


Figure 13: Average site reflectivity readings of data collection 2, over site lengths

The average wet weather reflectivity values collected during data collection 2 are shown in Table 5. The data indicates that:

- CAP with Type D-HR W glass beads
    - provided the highest wet reflectivity of all trial sites
    - demonstrated wet reflectivity readings up to 4 times higher than waterborne paint even when 7 months older
    - demonstrated wet reflectivity readings up to 2.4 times higher than RL with Type D-HR W glass beads with the same installation age.
- RL with Type D-HR W glass beads
    - provided higher reflectivity readings than waterborne paint at trial site 5 and comparable to installation age at trial site 6
    - at trial site 5, RL demonstrated wet reflectivity readings up to 1.7 times higher than waterborne paint even when 7 months older
    - at trial site 6, RL demonstrated 0.7 of the wet reflectivity of waterborne paint when 7 months older.
- Waterborne
    - Provided reflectivity marginally above the required wet reflectivity threshold of 50 millilux
    - control site B marginally exceeded the threshold only after 3 months and the remaining sites after 15 months.

Table 5: Wet weather linemarking reflectivity ranges and installation time

Site	AADT	Wearing Course	Product	Average wet reflectivity all DC2 runs over the site length (millilux)		Installation age (months)
				Gazettal	Anti-Gazettal	
1	19,500	Asphalt (Dense Graded)	RRPMs at 12 m reduced spacing	75#	75#	24
2	33,000	Asphalt (Dense Graded)	RRPMs at 12 m reduced spacing	66#	56#	24
3	7,000	Bitumen Spray Seal	Cold applied plastic	272	229	21
4	5.000	Asphalt (Dense Graded)	Cold applied plastic	108	132	21
5	12,700	Asphalt (Open Graded)	RainLine (thermoplastic)	107	114	10
6	7,000	Asphalt (Dense Graded)	RainLine (thermoplastic)	47	56	10
Control Site A (for site 6)	7,000	PMB Spray Seal	Waterborne	61	66	15
Control Site B (for site 1)	19,500	Asphalt (Dense Graded)	Waterborne	64	56	3*
Control Site C (for site 3)	7,000	PMB Spray Seal	Waterborne	62	75	15

Notes:

* The linemarking on this section was repainted in 2016 in-between data collection 1 and 2.
\# The reflectivity values for the RRPM sites are believed to be for the linemarking only.

Interim conclusions

After an installation age of 24 months, the average wet reflectivity of the combination of Cold Applied Plastic with Type D-HR W glass beads was between 58-222 millilux above the wet reflectivity intervention threshold of 50 millilux.

At an installation age of 10 months, the average wet reflectivity of the combination of RainLine with Type D-HR W glass beads was between 6-64 millilux above the wet reflectivity intervention threshold.

At an installation age of 15 months, the average wet reflectivity of the combination of Waterborne paint with Type D-HR W glass beads was between 11-75 millilux above the wet reflectivity intervention threshold at 2 of the control sites. A third control site at an installation age of 3 months had a wet reflectivity of 6-16 millilux above the wet reflectivity intervention threshold.

Cold Applied Plastic with Type D-HR W glass beads to date has demonstrated superior wet reflectivity compared to Waterborne paint and RainLine with Type D-HR glass beads. The higher reflectivity levels provided by Cold Applied Plastic Type D-HR W glass beads have demonstrated to date to exceed those of waterborne paint by at least 7 months.

There is a noticeable difference between the two Cold Applied Plastic and RainLine sites. The variances in average wet reflectivity values do not appear to be consistent with age, AADT or geometry however, the lower wet reflectivity of a product does occur on surfaces with low macro-texture, i.e. dense graded asphalt.

The wet reflectivity readings for both Cold Applied Plastic sites indicate that the wet reflectivity levels will remain above the threshold for in excess of 24 months, compared to Waterborne, which is expected to drop below the threshold after 16-17 months and Rainline at 10 months at one site and an expected 20 months at the second RainLine site. This will however be monitored in years 2 and 3 of the project.

Continuing work

The trial and control sites will continue to be monitored and reflectivity readings collected for a total of 3 years. It is intended that the final report will identify the following:

- deterioration over time in terms of dry and wet retroreflectivity
- estimation of product life (in terms of dry, wet retroreflectivity and percentage of line with RL measurements below 50 mcd/lx/m^2)
- crash rates at trial and control sites – before-and-after comparison (a minimum of 2 years before-and-after data required for appropriate statistical testing to take place).

It is also anticipated that a deterioration curve for each product may be progressively produced.

Rainfall data will be acquired from the Bureau of Meteorology for the periods before and after the linemarking is installed. It will be used to normalise the crash data.

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AUTHOR BIOGRAPHIES

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Santosh Tripathi

Santosh Tripathi is currently a Principal Engineer (Safer Roads) with the Queensland Department of Transport and Main Roads. Before this he was a Senior Engineer (Traffic Management). Santosh has 14 years of local and international experience from his private and public sector work both in Australia and overseas working on road design, construction, traffic engineering, and transport planning and road safety.

Santosh has a special interest in road safety and traffic engineering. He is continually applying his knowledge and capability to providing specialist services in these areas.