Final Report
Research Project T1803, Task 20
Reflectivity Markings

REFLECTIVITY OF PAVEMENT MARKINGS: ANALYSIS OF RETROREFLECTIVITY DEGRADATION CURVES

by

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16. ABSTRACT

The intent of this project was to develop retroreflectivity degradation curves for roadway pavement markings. To accomplish this objective, this study utilized a vehicle-mounted Laserlux retroreflectometer to take measurements on approximately 80 test sections throughout Washington state.

The resulting retroreflectivity values from roadways with similar average annual daily traffic (AADT) and environments displayed a significant amount of variability. Best-fit trendlines were extrapolated to determine when each category of paint would fall below a selected minimum threshold of 100 mcd/m^2/lux and require repainting.

Unfortunately, given the variability of the data observed to date, it may not be possible, even with the collection of more data, to create striping performance predictions that have a high level of statistical confidence. The data do not suggest conclusively that the existing WSDOT striping schedule should change. According to that schedule, long line painted markings should be painted at least once a year, and heavy wear, long line pavement markings should be painted at least twice a year.

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EXECUTIVE SUMMARY

The intent of this project was to develop retroreflectivity degradation curves for roadway pavement markings. These degradation curves would be used to forecast the performance of pavement markings and to help determine a cost-effective schedule for reapplying them.

To accomplish these objectives, this study utilized a vehicle-mounted Laserlux® retroreflectometer to take measurements on approximately 80 test sections throughout Washington state. The project included test sections of waterborne and solvent-based paint, as well as a limited number of durable material sections. The degradation curves focus on the waterborne and solvent-based paint. Data collection for the project took place between July 2003 and July 2004.

On the basis of the literature review of previous retroreflectivity studies, a minimum acceptable retroreflectivity threshold of 100 mcd/m²/lux was selected. Best-fit trendlines were extrapolated to determine when each category of paint would fall below the minimum threshold and require repainting.

The resulting retroreflectivity values from roadways with similar average annual daily traffic (AADT) and environments displayed a significant amount of variability. Potential causes of this variability could have been changes in application methods by different striping crews, inherent variability in the Laserlux device, difficulty calibrating the device, different environmental conditions on data collection trips, or simply that retroreflectivity measurements can be inconsistent.

Unfortunately, given the variability of the data observed to date, it may not be possible, even with the collection of more data, to create striping performance predictions

that have a high level of statistic confidence. The degradation curves developed in this study should not be used as the sole basis for determining the service life of pavement markings or creating a striping schedule. The WSDOT should continue the current schedule outlined in the WSDOT *Maintenance Manual* (2002). According to that schedule, long line painted markings should be painted at least once a year, and heavy wear, long line pavement markings should be painted at least twice a year.

BACKGROUND

Retroreflectivity occurs when an object reflects light directly back to the source of the light. Highway markings can be made retroreflective, which makes the markings bright and noticeable with only a small amount of headlight output. This characteristic is essential to highway safety. The *Manual for Uniform Traffic Control Devices* states, "Markings that must be visible at night shall be retroreflective unless ambient illumination assures that the markings are adequately visible. All markings on Interstate highways shall be retroreflective" (2000). Although no national standard exists to require a minimum level of retroreflectivity, the Federal Highway Administration (FHWA) is working to establish a reasonable and manageable minimum threshold standard. The intent of this project was to develop retroreflectivity degradation curves for roadway pavement markings. These degradation curves can be used to forecast the performance of pavement markings and to help determine a cost-effective schedule for reapplying them.The unpredictability of the service life of pavement markings makes establishing a minimum retroreflectivity threshold difficult. Pavement marking degradation varies because of roadway wear and curvature, as well as winter maintenance plowing. The values determined by retroreflectometers can vary depending on the device's placement on the line and orientation of the device. Dirt on the lines, the color of the markings, the background color of the roadway, and traffic volumes can also affect the retroreflectivity values.

Highway markings are retroreflective because of glass beads embedded in the stripe. For paint markings, as the striping truck moves down the roadway, a spray gun paints the stripes, and glass beads are dropped into the paint. The pattern of the glass beads and how deeply they sink into the paint will affect retroreflectivity levels. If the beads embed too deeply, the light will not be able to reach them. If the beads do not embed far enough, light is reflected poorly and the beads may come loose. Beads are also embedded into other striping materials such as methyl-metyhacrylate (MMA) and thermoplastics.

The American Society for Testing and Materials (ASTM) has developed many standards related to the testing and measuring of retroreflective materials. The devices used to measure retroreflectivity are designed to duplicate the angles created by an average headlight height and average driver eyeball height. Although the average driver tends to look about 50 meters down the road, this geometry produces angles that are too flat to measure properly. Therefore, the ASTM has standardized what is called the "30-meter geometry" (about 100 feet).

The unit of measurement for retroreflectivity is millicandelas per square meter per lux ($mcd/m^2/lux$). The ASTM D 6359-99 set a standard specification for newly applied pavement markings at a minimum initial coefficient of retroreflective luminance of 250 $mcd/m^2/lux$ for white and 175 $mcd/m^2/lux$ for yellow. However, a new pavement marking should start at a much higher luminance to allow for degradation of the material and provide a longer duration until the minimum level of retroreflectivity is reached.

Currently, the WSDOT *Maintenance Manual* outlines the schedule for renewing pavement markings. Long line (centerline, lane line, and edge line) painted markings are painted at least once a year, and heavy wear (high AADT, extreme weather environment) long line pavement markings are painted at least twice a year (2002). MMA and thermoplastics renewal frequency varies, but more expensive pavement markings are replaced less frequently. This project focused mainly on waterborne and solvent-based paint pavement markings.

LITERATURE REVIEW

In an effort to set new threshold levels, the FHWA has encouraged research on striping schedules and the service life of pavement markings. A variety of information is available to evaluate the performance of pavement markings.

Minimum Threshold

A study in New Jersey used a Laserlux retroreflectometer and a survey of the New Jersey driving public to determine the visibility of markings on a 32-mile circuit (Parker and Meja 2003). Parker and Meja concluded that the threshold value of an acceptable level of retroreflectivity appeared to be between 80 and 130 mcd/m²/lux for drivers under 55 and between 120 and 165 mcd/m²/lux for drivers older than 55 (2003).

An earlier study focused specifically on retroreflectivity requirements for older drivers. Graham et al. (1996) used measurements of the retroreflectivity of existing roadway markers and subjective evaluations of their adequacy to determine a threshold. The authors reported that 85 percent of subjects aged 60 years and older rated a marking retroreflectance of 100 mcd/m²/lux adequate or more than adequate for nighttime conditions (1996).

The Minnesota Department of Transportation (MnDOT) conducted research to determine a threshold for acceptable retroreflectivity (Loetterle et al. 2000). Members of the general public drove state and county roads after dark and were asked to grade the visibility of edgelines and centerlines. The project results pointed to a threshold level of between 80 and 120 mcd/m²/lux. As a result of the project, MnDOT uses 120 mcd/m²/lux as a threshold for its pavement marking management program (2000).

Service Life

A pavement marking material evaluation in Michigan studied the retroreflectivity and durability of four striping materials at 50 different sites throughout the state (Lee et al. 1999). The study determined degradation rates of the different materials on the basis of a minimum acceptable retroreflectivity level of 100 mcd/m^2/lux. Waterborne paints were found to have a service life of 445 days, or about 15 months (1999). However, the variance in service life was large (1999).

Migletz et al. (2001) performed a similar study over four years throughout 19 states to evaluate the durability of a variety of marking materials. The threshold values were set in the project to range between 85 to 150 mcd/m^2/lux for white lines and 55 to 100 mcd/m^2/lux for yellow lines. The values varied on the basis of the roadway type and its speed classification. Using these thresholds, the study found the service life for white waterborne paint on freeways to average 10.4 months, but calculated values ranged from 4 to 18 months (2001).

Abboud and Bowman conducted a study of the cost and longevity of paint and thermoplastic striping to determine a useful paint lifetime (2002). The authors used a minimum retroreflectivity threshold of 150 mcd/m^2/lux, determined from their previous study of crash data and traffic exposure on state highways in Alabama. Abboud and Bowman concluded that the useful lifetime (in months) for low-AADT (<2500 vehicles per day) highways is 22 months; mid-AADT (2500 to 5000 vpd) highways is 7.5 months; and high-AADT (>5000 vpd) highways is 4.5 months (2002). The minimum retroreflectivity of 150 mcd/m^2/lux was slightly higher than the threshold used in other reviewed studies.

RESEARCH APPROACH

Measurement Device

This project utilized a vehicle-mounted Laserlux retroreflectometer. The FHWA provided a surplus 1995 Chevrolet Beauville van for conducting retroreflectivity measurements. The mobile retroreflectometer takes a large number of measurements while traveling at highway speeds. The device has a scan width of 1.1 meter and can sample over 1,150 measurements per mile while traveling at 60 miles per hour. An on-board computer calculates and displays retroreflectivity values in real time. The project initially utilized the Gamma Scientific Laserlux software version 1.4 but updated to version 1.6 by the end of data collection. The vehicle is equipped with a distance measuring instrument to label data and a GPS receiver to tag the values with latitude and longitude coordinates. The software processes the data and summarizes values in database-compatible output. The data file reports an average of the data points for a user-specified distance of approximately 250 feet. These data points are used to find the overall average retroreflectivity for the paint line in a section of roadway.

The use of the mobile retroreflectometer provides an efficient form of data collection. The laser can take retroreflectivity measurements during both day and night. The laser takes measurements at highway speeds, as opposed to traditional handheld units that take static measurements at each location. The large number of data collected by the mobile retroreflectometer make the results more statistically significant. The process also provides a great improvement in the safety of data collection, for both the device operators and vehicles on the roadway.

Pavement Markings

Pavement markings throughout Washington state consist of various materials. Most of WSDOT's state regions use waterborne paint. The WSDOT Northwest Region uses solvent-based paint. The Northwest Region is in the process of changing to waterborne paint to coordinate with the rest of the state. Some of the more highly traveled roadways in the state use more durable pavement markings, such as 3M-tape and methyl metyhacrylate (MMA). Durable pavement markings are significantly more expensive but have a longer service life. These durable materials can last over 10 years; otherwise, all stripes of paint are repainted at least once a year.

This project included test sections of waterborne and solvent-based paint, as well as a limited number of durable material sections. The degradation curves focus on the waterborne and solvent-based paint sections because of the timeline of the study, as well as the fact that durable materials maintain their retroreflectivity for several years, thus making it difficult for this study to properly analyze their degradation over time.

Data Collection Procedure

Data collection was limited by regional striping crews finishing their seasonal painting. Striping crews can only repaint roadways in dry weather conditions, so the painting season ranges from March to September throughout the state. The Laserlux can operate only in dry weather conditions, so the inconsistency of Washington weather created difficulty in scheduling data collection trips.

Data collection for the project began at the end of July 2003. Throughout the next three months, the project team faced technical difficulties with the software and the equipment, as well as vehicle maintenance problems. Although these problems caused setbacks, the project team was able to collect a significant number of data on the retroreflectivity of test sections. In addition to the reflectivity data collected in the field, information about pavement marking age and type of material was collected through conversations with regional striping crews and traffic engineers, as well as a review of striping databases and reports. This information allowed the study analysis to compare the age of the paint stripe against the measured reflectivity. In the spring of 2004, the project team returned to the test sections to collect additional data.

The other primary data item collected to help explain differences in reflectivity were average annual daily traffic (AADT) estimates taken from the WSDOT 2002 Annual Traffic Report (WSDOT, 2002). The AADT data for 2003 were released after data analysis, but the new data appear consistent with the estimates from 2002.

Approximately 80 roadway sections were selected around Washington state. The test sections are listed in Appendix A. Each of the sections was visited between three and five times. In addition, some Interstate roadway sections that had to be traveled to reach multiple test locations were included in as many as ten data collection sessions.

Data Analysis

Statistical analysis was completed to determine a pattern of how the retroreflectivity of pavement markings decreases over time. The retroreflectivity data were plotted to represent the relationship between the average retroreflectivity value and the time elapsed since the painting of a particular test section. A best-fit regression curve was calculated to fit the data. This curve displayed the degradation pattern of retroreflectivity. A minimum threshold was selected, and the curve was extrapolated to estimate the service life of the pavement marking.

FINDINGS

Data Variability

The data collected reveal a significant amount of variability in the retroreflectivity values of the test sections. This variability exists among roadways with similar AADT, as well as among the data collected for each individual test section. This variability had a significant impact on the ability to determine patterns in retroreflectivity degradation. Before reviewing the degradation curves, it is important to first analyze the variability characteristics of the data upon which the curves are based.

Figure 1 portrays the average retroreflectivity value for a section of roadway on Interstate 5. This section was tested on eleven different data collection trips from August to October 2003. The test section consisted of a durable MMA skip stripe that had been in place since 1998. Given the durability of the material and its 15-year life span, the data were expected to display little variability in the three-month testing period. However, the average retroreflectivity measured for this section ranged from 76 to 197 mcd/m^2/lux. The standard deviation of the average retroreflectivity for these trips was approximately 42 mcd/m^2/lux. This is a relatively large standard deviation, meaning that the variability in the data is significant. The variability seen in this test section is an extreme example from the project, but it clearly reflects some of the data inconsistencies.

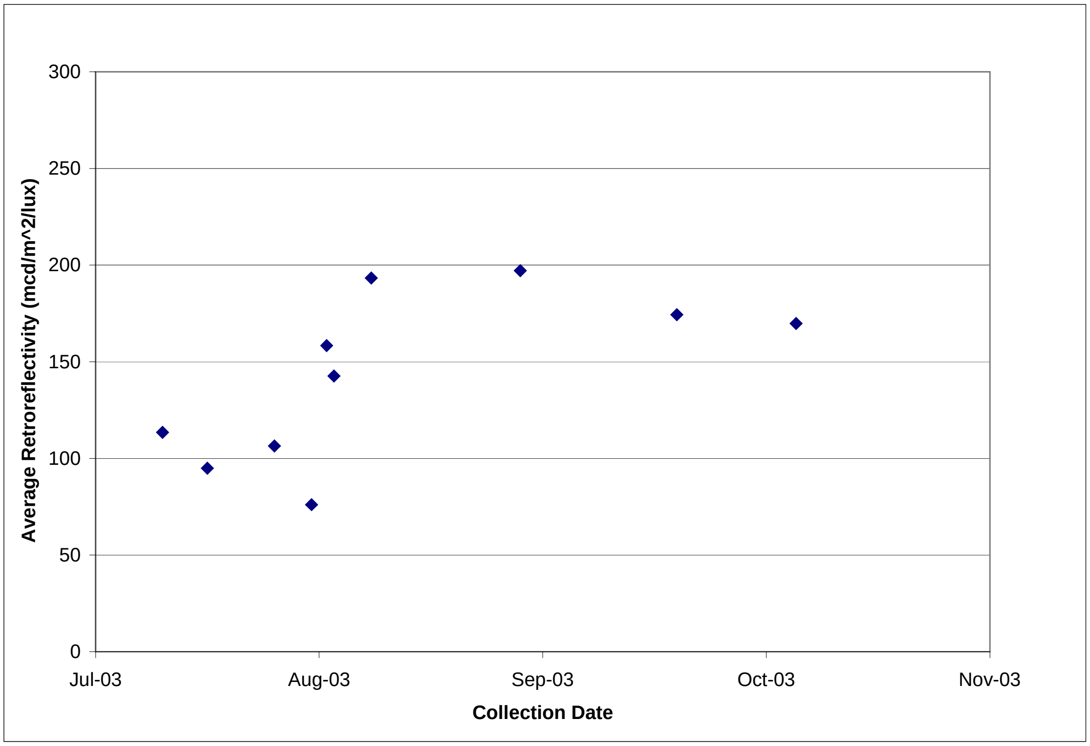

Figure 1. White MMA skip stripe on I-5 SB, mileposts 161-154

To analyze the source of variability in these data, the retroreflectivity values across the test section were examined. Figure 2 represents all of the measurements taken for the roadway section on the different test dates. The data show little similarity across test runs. They also show measured reflectivity actually increasing with the age of the paint stripe by as much as a factor of 3 between some test runs (see August 26 versus September 23.) It is difficult to recognize any patterns of reproducibility within the data. The lack of similarity from data collection session to data collection session presents the possibility of problems inherent in the use of the current version of the Laserlux device.

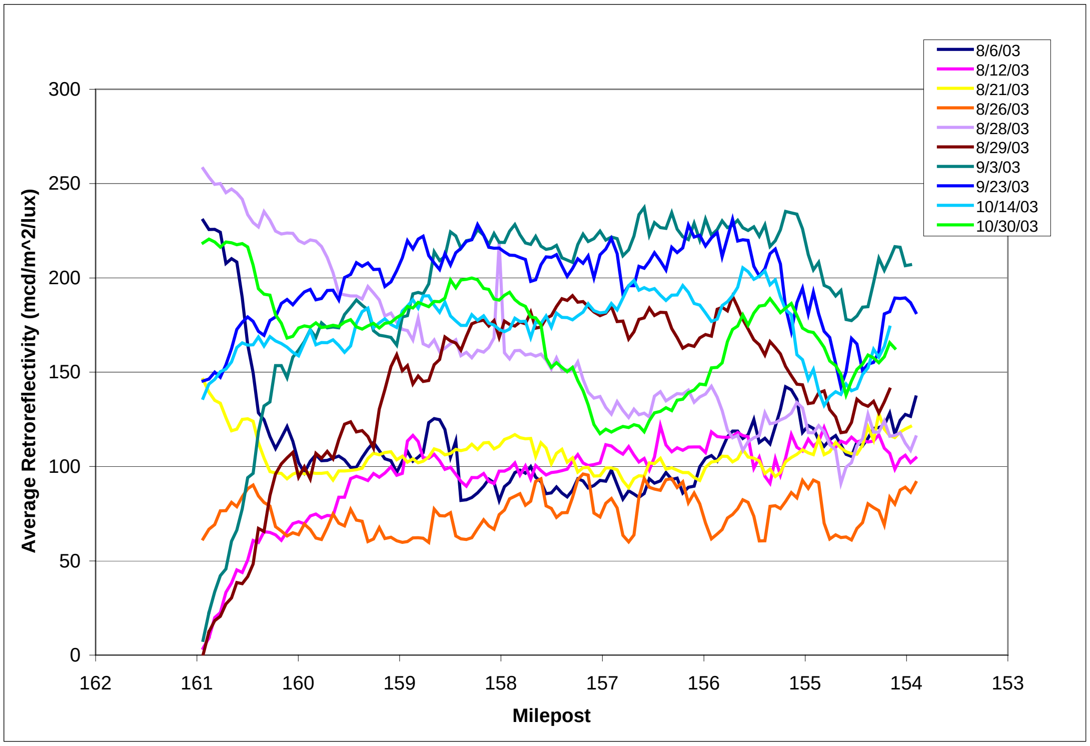

Figure 2. Data values across the section on I-5 SB, mileposts 161-154

Because of the variability detected in the data, the Laserlux retroreflectometer was tested to verify the repeatability and reproducibility of its results. Repeatability is the closeness in agreement between the results of successive measurements of the same test section carried out by the same method of measurement, operator, and measuring instrument over a specified period of time. Although the manufacturer tested the repeatability of the device, the device may have changed during use. Figure 3 displays the results of data collection on a test section of waterborne skip stripes on Interstate 90. Three data collection runs were conducted on October 2, 2003. The Laserlux was calibrated before the test runs, and conditions such as weather and vehicle speed remained constant.

Figure 3. Repeatability and reproducibility tests on I-90 EB, mileposts 51-57

The results seen in Figure 3 show that the Laserlux produced consistent results for the test section. Clear similarities can be viewed across the mileposts of the test section. The average retroreflectivity measured in runs 1, 2, and 3 was 170.71, 164.20, and 162.01 mcd/m²/lux, respectively. These values have a standard deviation of 4.53 mcd/m²/lux. These results indicate that the variability in the performance of the device within a given set of reasonably consistent environmental conditions may not have been enough to affect the repeatability of the Laserlux device. However, when combined with the variability observed in Figure 2, the results do raise questions about the performance of the device and its calibration process. It is difficult to determine whether the variability was caused by problems with the device, the calibration process, the fact that environmental conditions changed from moment to moment and day to day, or just the fact that reflectivity is more variable than we wish it to be.

Figure 3 also contains the data collected on the same test section on August 19, 2003. This plot displays the reproducibility of the Laserlux. Reproducibility is similar to repeatability; however, it includes more significant changes in data collection conditions, such as changes in the device's operator, the device's calibration settings, the age of the equipment, and the environmental conditions at the time of data collection. The graph of this data collection trip parallels the test runs in October (see Figure 3). The average retroreflectivity value calculated from the August trip was 170.40 mcd/m²/lux. This value is very close to those found in October. These data indicate the potential for consistency in results, despite varying trip conditions and calibration values.

Figure 4 exhibits the retroreflectivity of yellow centerlines located on two-lane roads with lower average annual daily traffic (AADT). Road sections included in this figure were taken from nine locations around the state. The Laserlux retroreflectometer finds an average retroreflectivity value for a portion of roadway. Because yellow centerlines can vary throughout a test section, from double lines to single skip stripes, the Laserlux finds averages for both lines. The values on the graph represent an average of all of the averages found by the retroreflectometer in the test section, including both stripes measured. Figure 4 shows a significant amount of variability among test sections with paint stripes that were less than 100 days old.

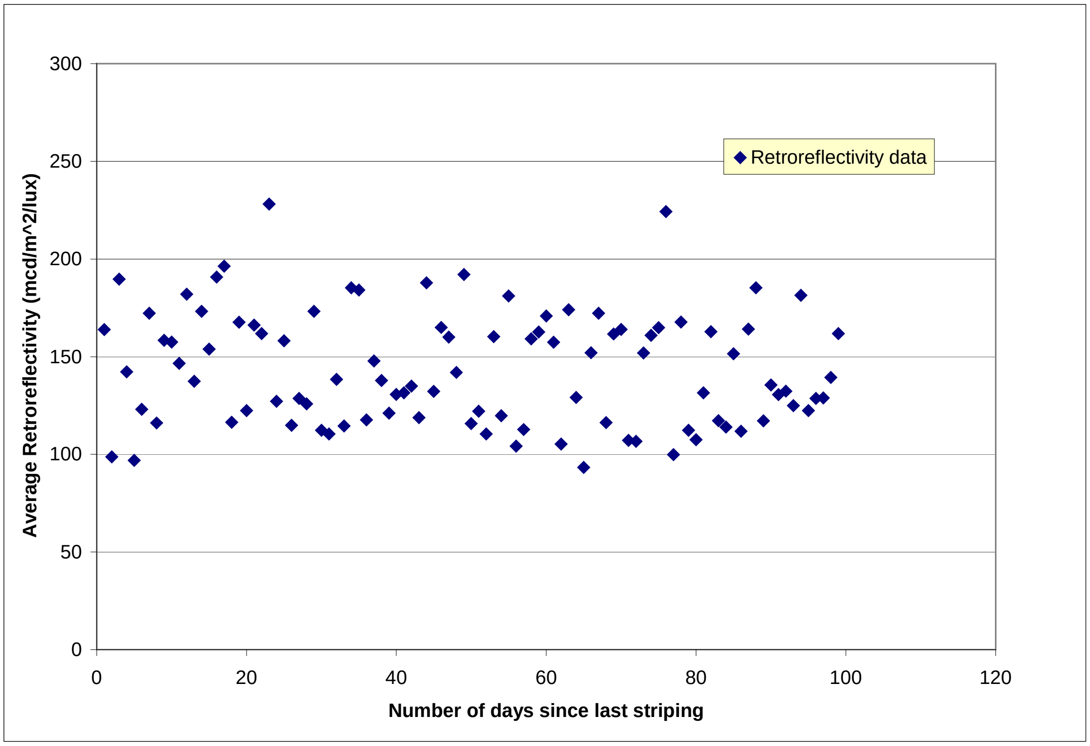

Figure 4. Yellow waterborne paint with low AADT (<3,500)

In comparing the retroreflectivity across roadways with similar AADT while accounting for the age of the paint stripe, a significant amount of variability appears in the values. One explanation for this variability could be the misalignment of the Laserlux. The laser and measurement aperture were slightly misaligned, so the Laserlux retroreflectometer needed to be sent to the Gamma Scientific laboratory in California for testing and repair work. The misalignment could have resulted in lower retroreflectivity averages, especially those collected in the first few months after striping.

Another cause of variability may have been changes in application methods by different striping crews. The typical striping procedure does not always result in consistent stripes. As a truck moves down the roadway, a spray gun paints the stripes, and glass beads are dropped into the paint to create retroreflectivity. The pattern of the glass beads and how deeply they sink into the paint will affect retroreflectivity levels. A related issue is calibration of the Laserlux. The Laserlux is calibrated by using a standard paint stripe with a tested retroreflectivity value. A calibration factor is calculated on the basis of the readings for the standard test stripe. However, multiple calculations in a row can produce a range of factors. This result occurs because the laser reflects off different beads as it scans the stripe. All of these striping and calibration issues can affect data variability.

The variability may also have been a result of the threshold levels for retroreflectivity measurements set during calibration. The low threshold was meant to eliminate any retroreflective values caused by glare from the roadway. When data were collected on bright, sunny days, the roadway reflected a significant amount of background light. This background light could be detected by the device and may have lowered the calculated average value for the section. The combination of these issues may have resulted in lower overall retroreflectivity values for the state, as well as variability among daily results from the same test sections. The low values collected for relatively new paint could also have been a result of these problems.

In addition to data variability concerns, the project team faced technical difficulties that interfered with efficient data collection. For example, the van used for data collection experienced frequent maintenance problems. Trips were postponed and occasionally cancelled en route because of vehicle issues.

Degradation Analysis

Despite the variability observed in the initial analysis, the data were used to calculate degradation curves. The data were grouped together by similar roadway conditions to minimize the effect of environment on variability. The test sections were broken up into the following three regions in the state:

- Western Washington (west of the Cascades)
- Central and Eastern Washington (east of the Cascades)
- the Cascade Mountains.

The test sections in these regions were determined to have similar environments. For example, the test sections from the mountain passes may experience more wear if snowplows frequently travel the roadway. Western Washington typically encounters more rainfall. Central and Eastern Washington are subject to higher temperatures in the summer months and snow and colder temperatures during the winter.

Within the three regions, the data were broken down by type of paint used and the average annual daily traffic. As mentioned, the Northwest Region used solvent-based paint during this study. Therefore, the Western Washington data include both solvent-based and waterborne paint. The solvent-based data are from the Northwest Region, and the waterborne paint data were collected in the Olympic and South Central regions. The Cascade Mountain area also includes both solvent-based and waterborne paint results from the respective regions. The Central and Eastern Washington data consist solely of waterborne paint test sections.

Figures 5 through 17 represent the retroreflectivity data collected on the approximately 80 test sections throughout the state. A best-fit trendline was calculated for each set of data. The trendlines, and their corresponding equations and coefficients of determination (R^2), are also displayed on the graphs. The R^2 value ranges from 0.0 to 1.0

and is used to indicate how closely the estimated trendline values correspond to the actual retroreflectivity data. The trendline is more accurate when the R^2 value is closest to 1.0.

Solvent-based Paint in Western Washington

Figures 5 through 7 present the retroreflectivity data for solvent-based paint in Western Washington. All of these data were collected in the Northwest Region.

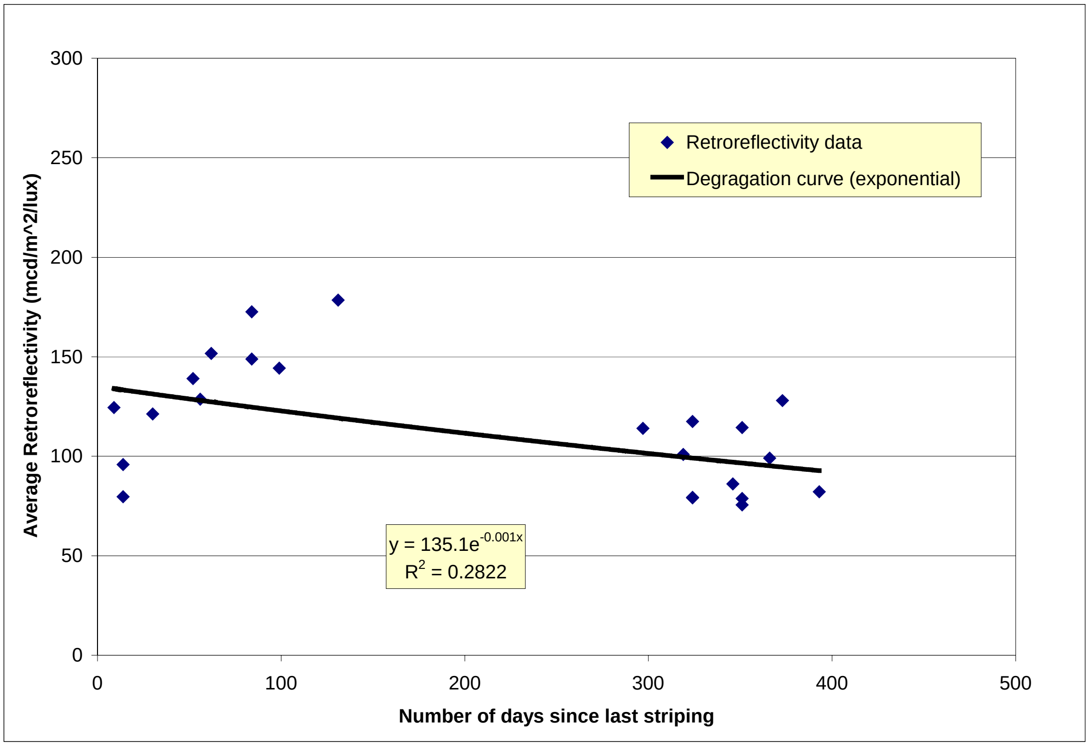

Figure 5. Yellow solvent-based paint in Western Washington with low AADT (<7,500)

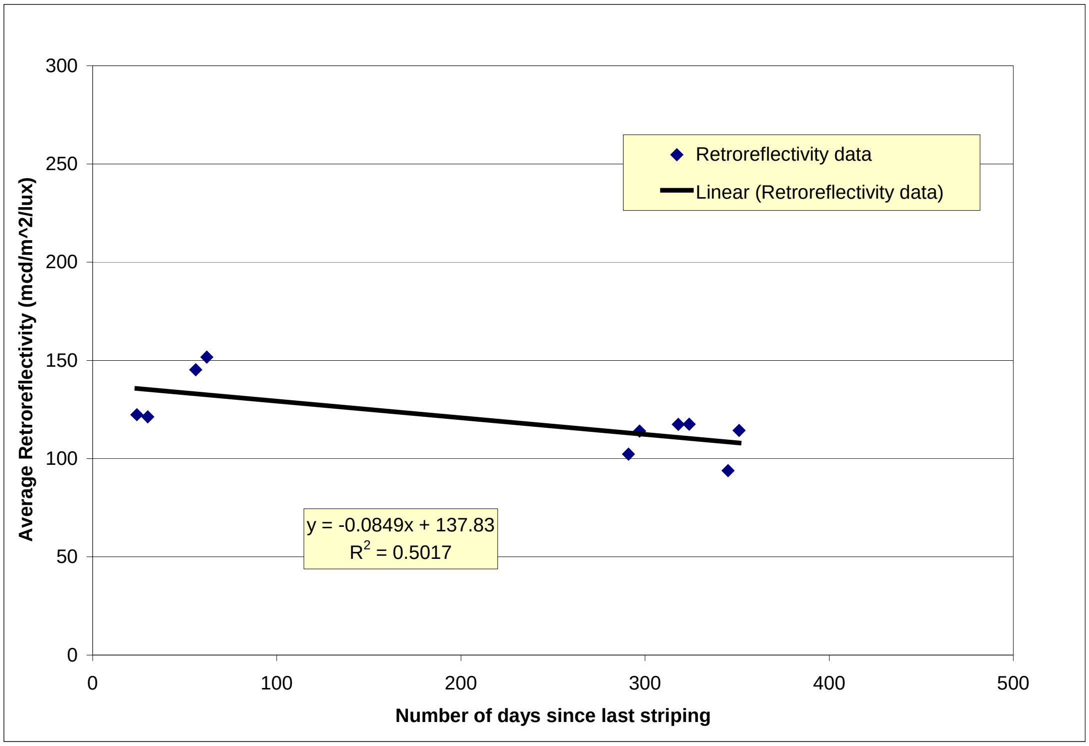

Figure 6. White solvent-based paint in Western Washington with moderate AADT (7,500-15,000)

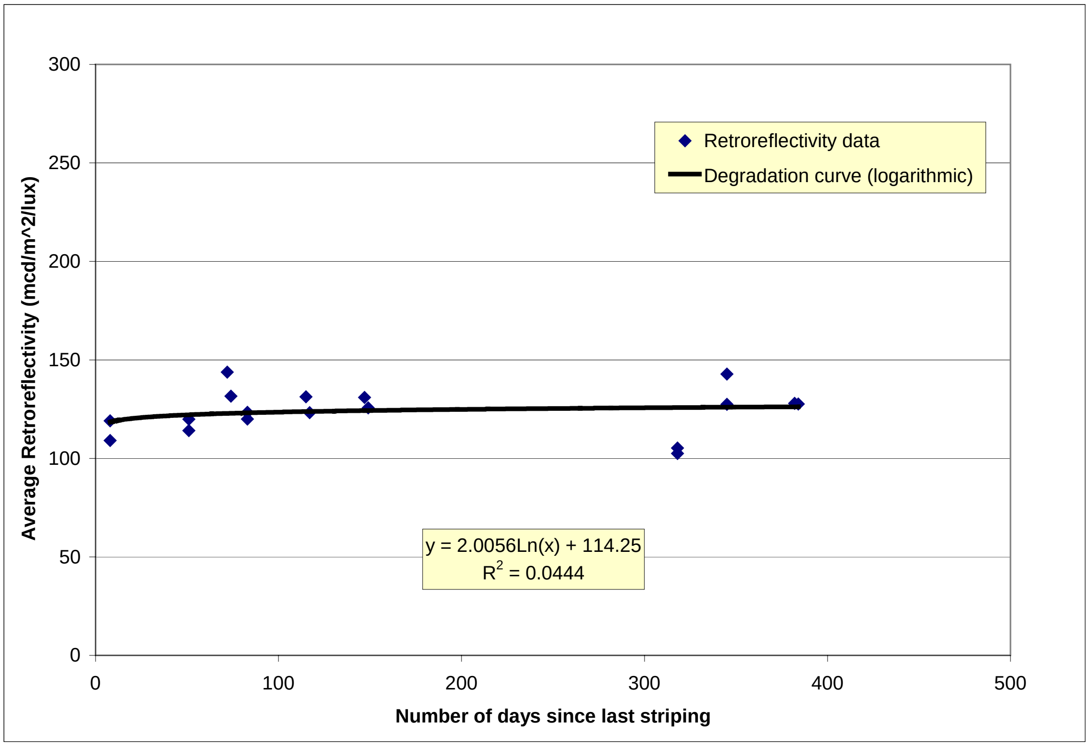

Figure 7. White solvent-based paint on I-5 with high AADT (>50,000)

On the basis of the literature review of previous retroreflectivity studies, a minimum acceptable retroreflectivity threshold of 100 mcd/m^2/lux was selected. The best-fit trendlines were extrapolated to determine when that category of paint would fall below the minimum threshold and require repainting. Table 1 displays the calculated estimated service life for the solvent-based pavement markings.

Table 1. Service life of solvent-based paint in Western Washington

Paint Color	AADT (vehicles per day)	Estimated Service Life
Yellow	<7,500	10 months
White	7,500-15,000	14-15 months
	>50,000	----

For solvent-based paint in Western Washington, the estimated service life ranges from 10 to 15 months. The service life for white lines with an AADT of greater than 50,000 cannot be calculated because the retroreflectivity data collected at those sites produce an increasing trendline (see Figure 7). The finding that the paint retroreflectivity was increasing is a result of the variability inherent in the data collection. The variability is also notable in the low corresponding coefficient of determination in Figure 7.

Waterborne Paint in Western Washington

Figures 8 through 10 represent data collected in Western Washington for test areas with waterborne paint. These test areas were located mainly in the South Central and Olympic regions of Washington.

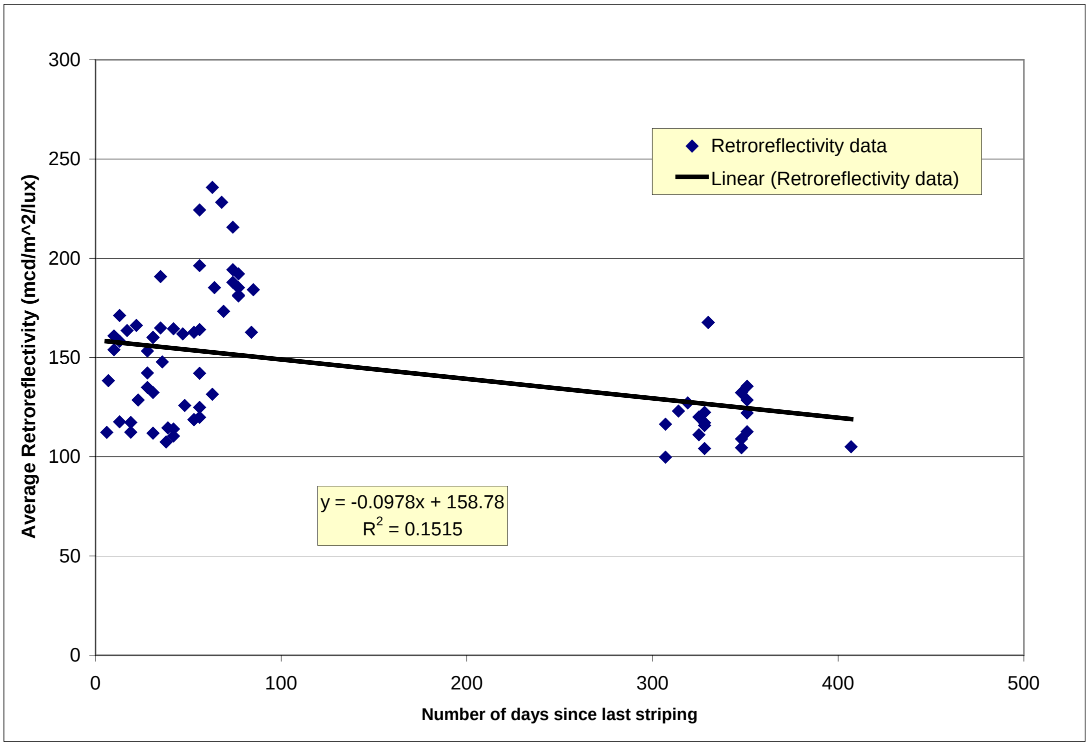

Figure 8. Yellow waterborne paint in Western Washington with low AADT (<7,500)

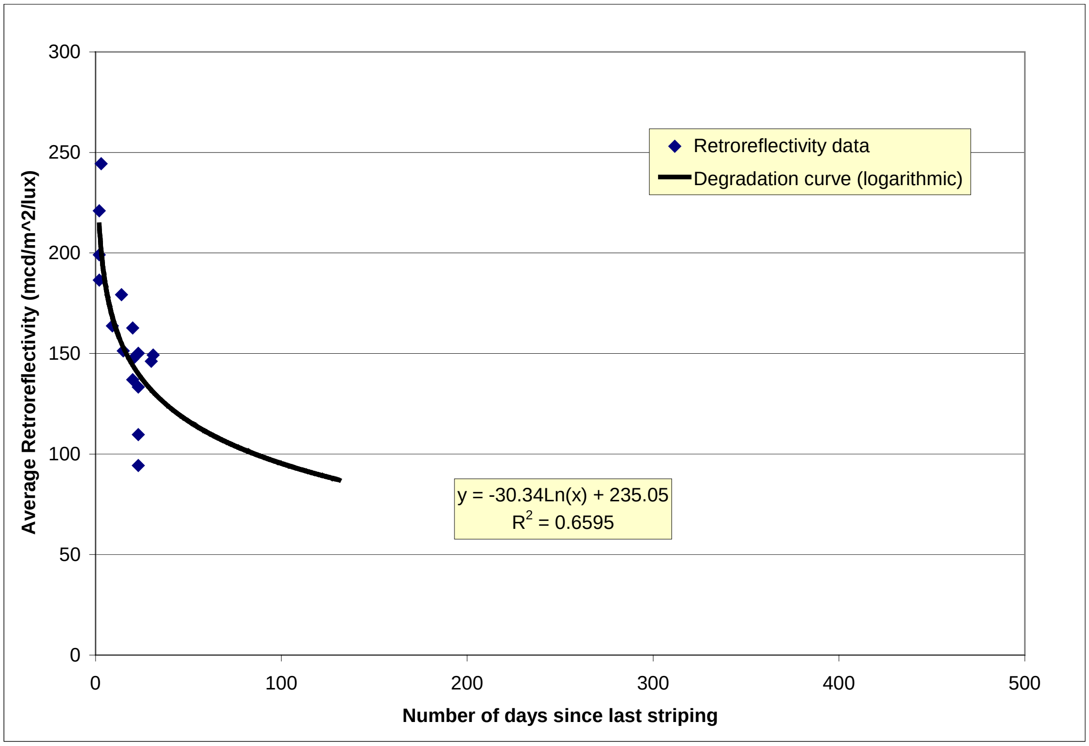

Figure 9. White waterborne paint in Western Washington with low AADT (<7,500)

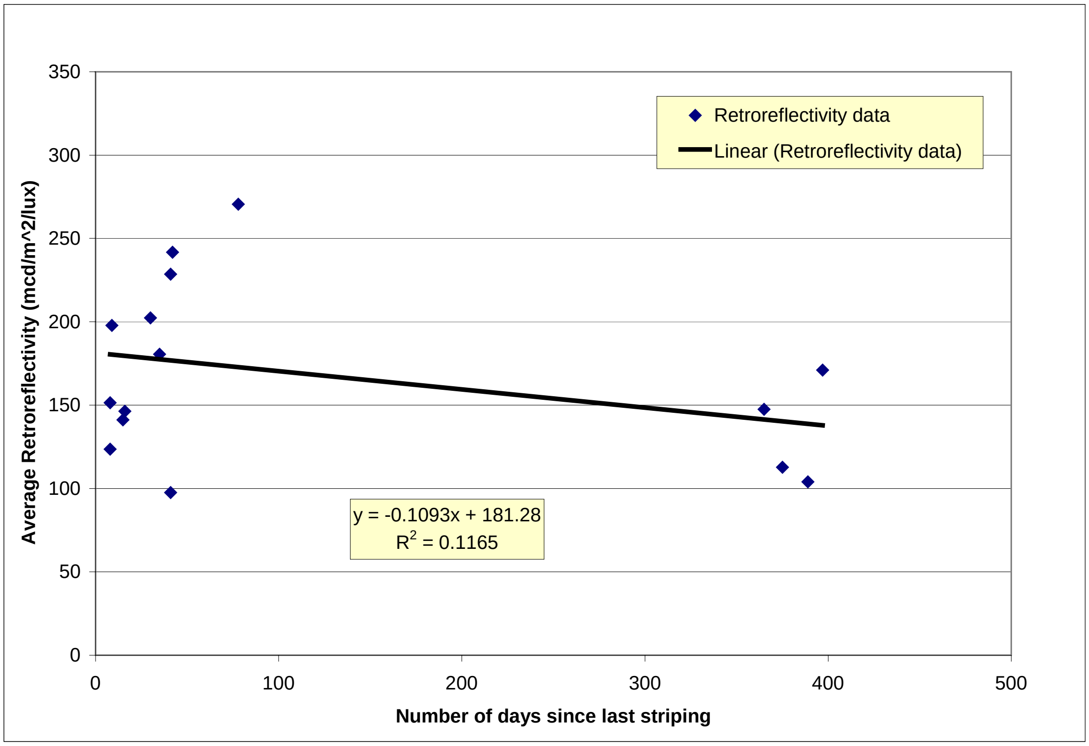

Figure 10. White waterborne paint on I-5 with high AADT (>50,000)

Table 2 presents the extrapolated service life for waterborne paint in Western Washington. These values were calculated by using the best-fit trend lines displayed in figures 8 through 10. The estimated service life determined for white waterborne paint with low AADT was only three months. This questionable value could be a result of the range of data collected for this paint type. All of the data for white waterborne paint in this area was collected in the first one or two months after painting. Without data for later in the season, it is difficult to calculate an accurate trend line that is representative of the whole year.

Table 2. Service life of waterborne paint in Western Washington

Paint Color	AADT (vehicles per day)	Estimated Service Life
Yellow	<7,500	20 months
White	<7,500	3 months
	>50,000	24-25 months

Waterborne Paint in Central and Eastern Washington

Figures 11 through 13 display retroreflectivity data from Central and Eastern Washington. The test areas in this area of the state consisted mainly of waterborne paint pavement markings. Figures 11 and 12 are from two-lane roads with low AADT. Figure 13 displays data from white skip stripes on I-90 and SR 12, roadways with moderate AADT.

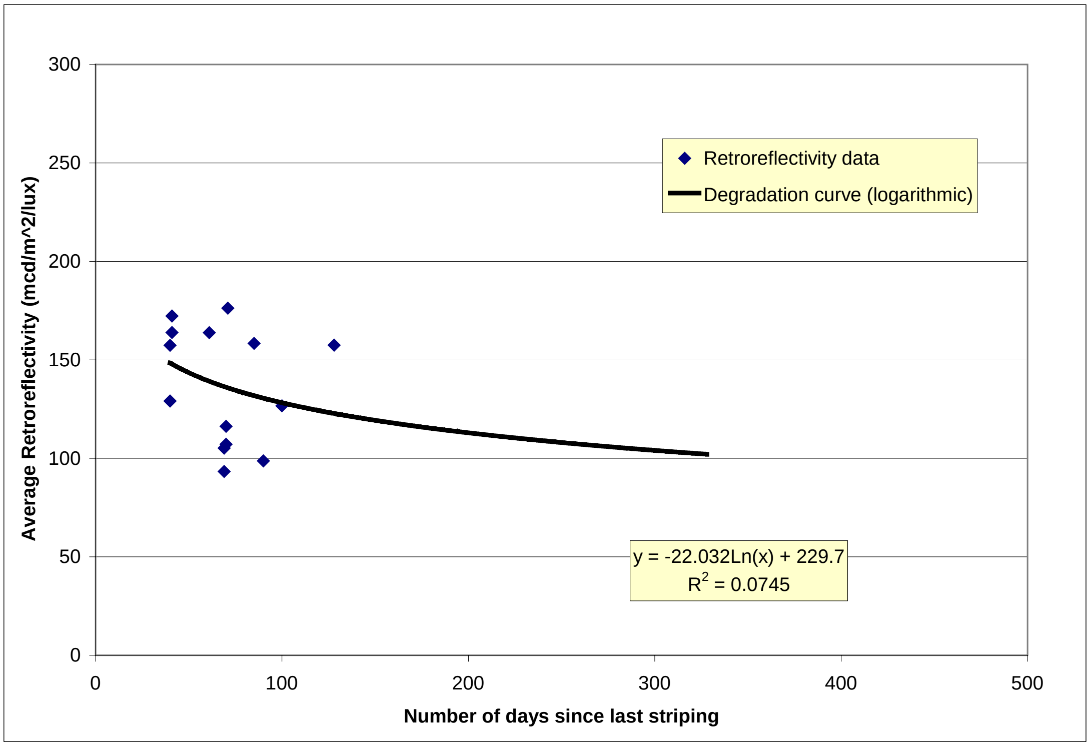

Figure 11. Yellow waterborne paint in Central and Eastern Washington with low AADT (<7,500)

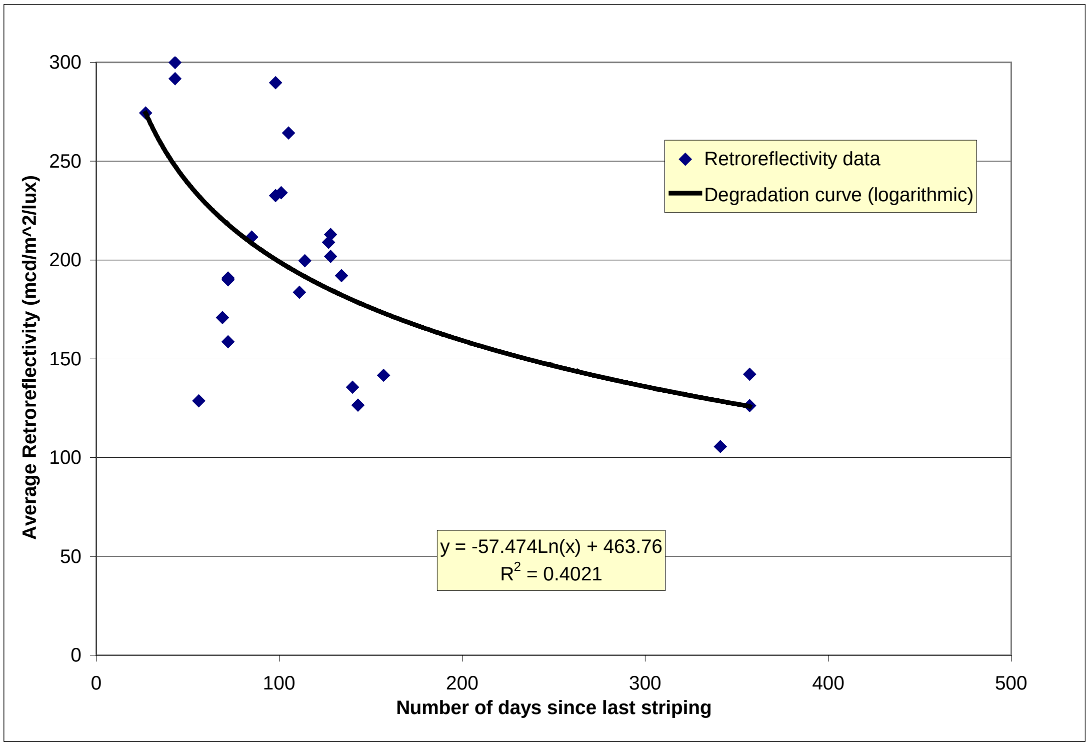

Figure 12. White waterborne paint in Central and Eastern Washington with low AADT (<7,500)

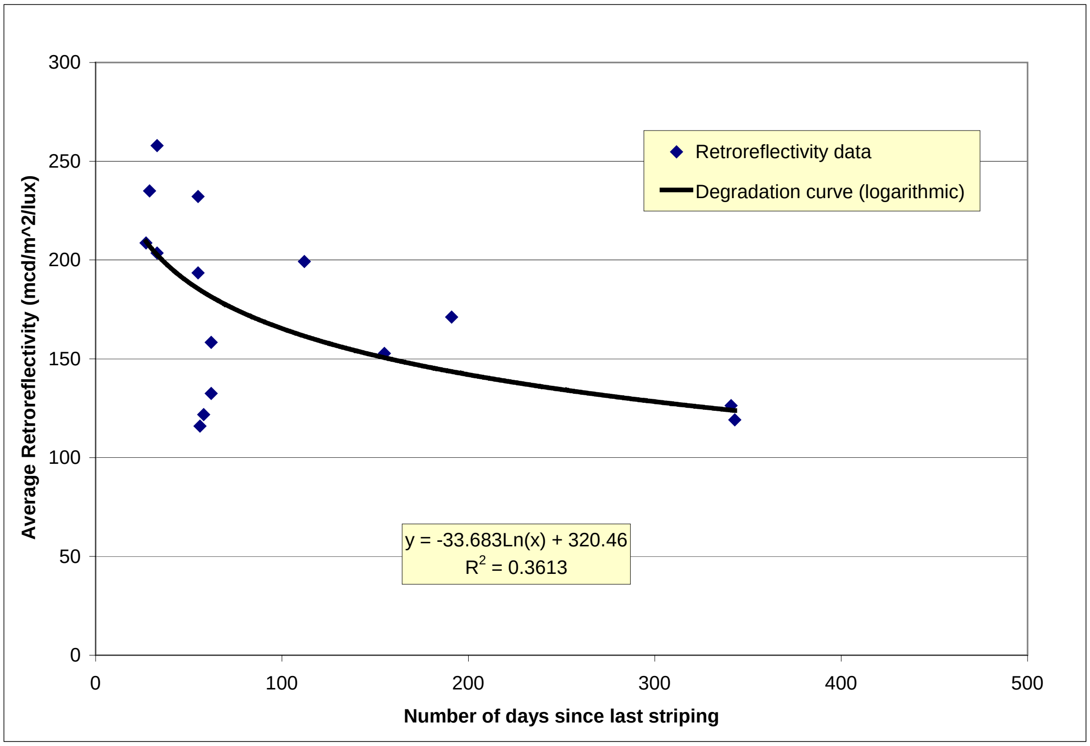

Figure 13. White waterborne paint in Central and Eastern Washington with moderate AADT (7,500-15,000)

Table 3 shows the estimated service life for waterborne paint in Central and Eastern Washington. The service life ranged from 12 to 23 months.

Table 3. Service life of waterborne paint in Central and Eastern Washington

Paint Color	AADT (vehicles per day)	Estimated Service Life
Yellow	<7,500	12 months
White	<7,500	18-19 months
	7,500-15,000	23 months

Solvent-based Paint in the Cascade Mountains

The test sections in the Cascade Mountains were analyzed separately from the rest of the state data. The weather there can reach significantly lower temperatures during the winter season. These roadways are also subjected to snowplows and other winter maintenance procedures. The test sections are usually painted twice during the striping season, once in March or April and again toward the end of the season in September. Figures 14 and 15 display data for solvent-based paint in the mountains. These data were mainly collected near Mt. Baker in northwest Washington.

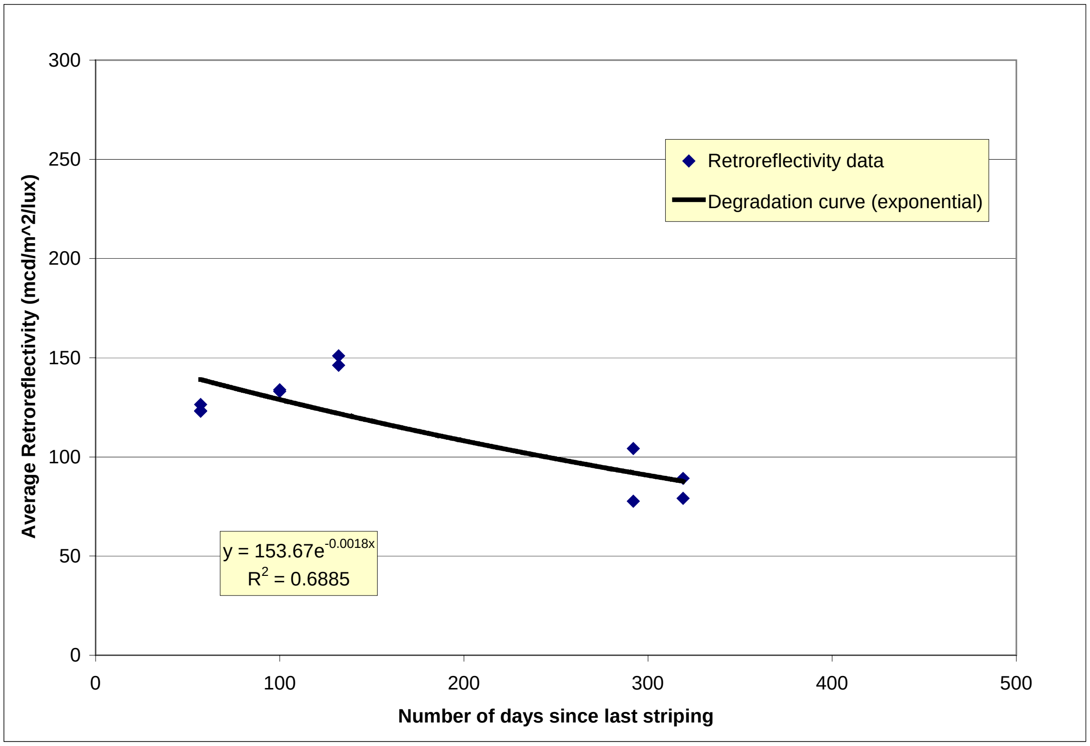

Figure 14. Yellow solvent-based paint in the Cascade Mountains with low AADT (<3,500)

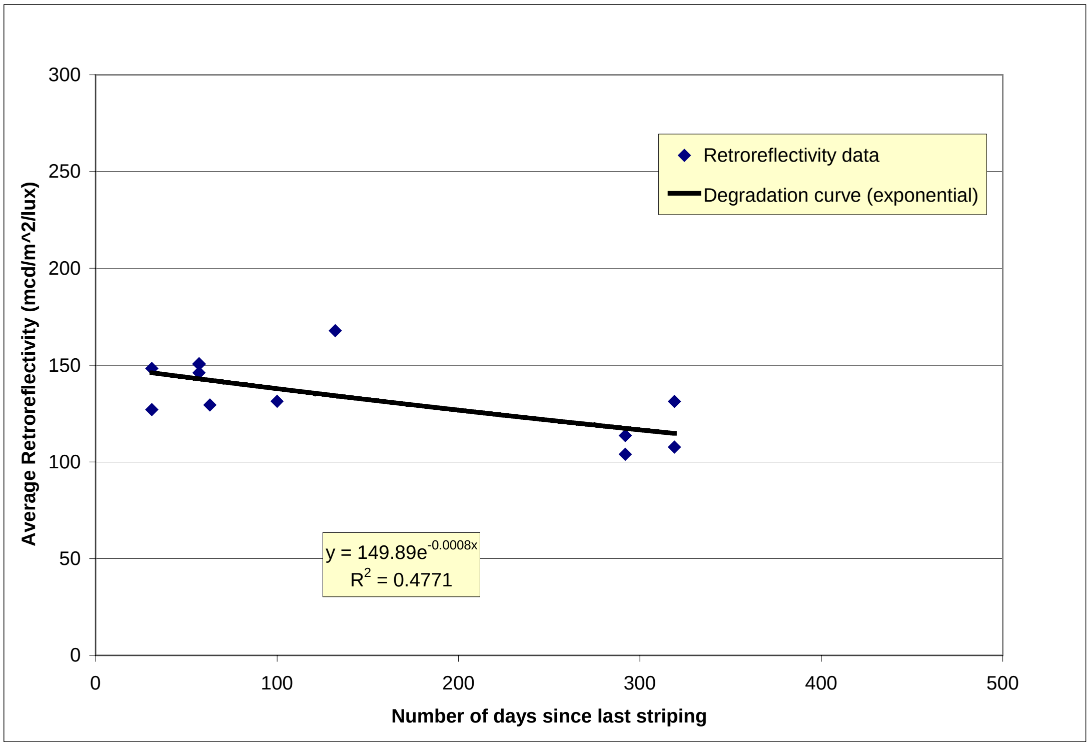

Figure 15. White solvent-based paint in the Cascade Mountains with low AADT (<3,500)

Table 4 presents the estimated service life for solvent-based paint in the mountains. The service life estimated for white paint is a higher value than expected. The pavement markings on the mountain roadways are typically painted twice per year since they experience more wear from maintenance work, so the estimated service life was expected to be shorter than the service life for other areas of the state. Therefore, the reliability of this result is questionable.

Table 4. Service life of solvent-based paint in north Cascade Mountains

Paint Color	AADT (vehicles per day)	Estimated Service Life
Yellow	<3,500	8 months
White	<3,500	16-17 months

Waterborne Paint in the Cascade Mountains

Figures 16 and 17 present the retroreflectivity data for waterborne paint in the mountains. These data come from test sections outside of the Northwest region. These sections are located on Stevens Pass (SR 2), White Pass (SR 12), and Blewett Pass (SR 97).

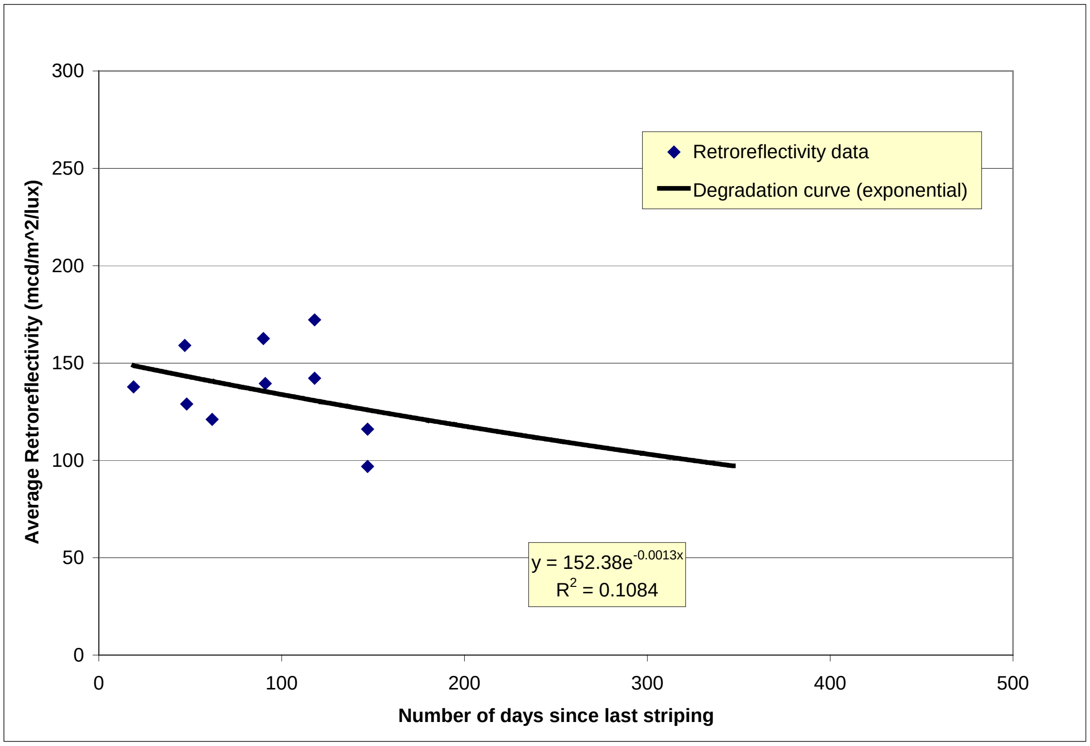

Figure 16. Yellow waterborne paint in the Cascade Mountains with low AADT (<3,500)

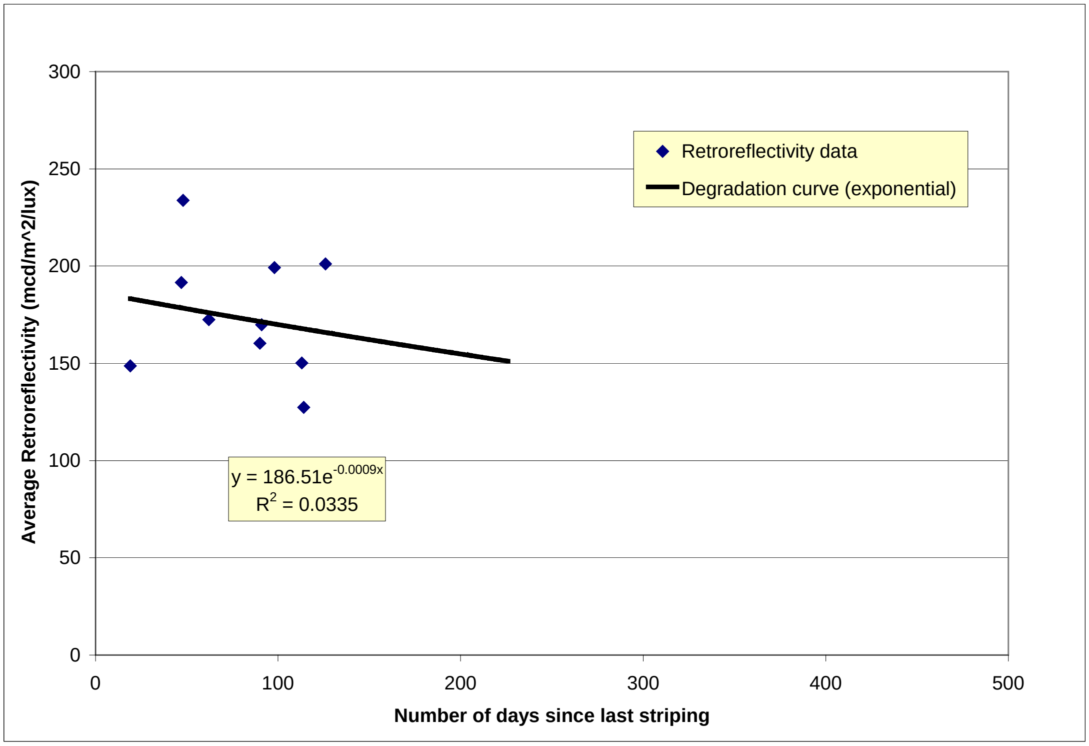

Figure 17. White waterborne paint in the Cascade Mountains with low AADT (<3,500)

Table 5 shows the calculated service life for waterborne paint in the mountains. It is difficult to extrapolate from data sets consisting of data solely from the first few months after striping. As seen with the solvent-based paint, the service life of white waterborne paint is over one year. These test sections are typically painted twice a year because previous tests have shown that the pavement markings lose their luminance as a result of being driven over by snowplows and traction devices. Therefore, the service life result for waterborne paint is unreliable.

Table 5. Service life of waterborne paint in central Cascade Mountains

Paint Color	AADT (vehicles per day)	Estimated Service Life
Yellow	<3,500	11 months
White	<3,500	23 months

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The retroreflectivity values from roadways with similar AADT and environments displayed a significant amount of variability. Potential causes of this variability could have been changes in application methods by different striping crews, inherent variability in the Laserlux device, difficulty calibrating the device, different environmental conditions on data collection trips, or simply that retroreflectivity measurements can be inconsistent.

While it is possible to compute trend lines from the collected retroreflectivity data, the statistical precision of many of those trend lines is quite weak. Table 6 summarizes the estimated service lives for the various types of paint stripes.

Table 6. Estimated service lives of paint stripes

Region	Paint Color	AADT (vehicles per day)	Coefficient of determination (R^2)	Estimated Service Life
Western WA solvent-based	Yellow	<7,500	0.2822	10 months
	White	7,500-15,000	0.5017	14-15 months
		>50,000	0.0444	----
Western WA waterborne	Yellow	<7,500	0.1515	20 months
	White	<7,500	0.6595	3 months
		>50,000	0.1165	24-25 months
Central and Eastern WA waterborne	Yellow	<7,500	0.0745	12 months
	White	<7,500	0.4021	18-19 months
		7,500-15,000	0.3613	23 months
Mountains solvent-based	Yellow	<3,500	0.7321	11 months
	White	<3,500	0.5095	15-16 months
Mountains waterborne	Yellow	<3,500	0.1084	9-10 months
	White	<3,500	0.0335	23 months

Table 6 also summarizes the inconsistency of the data collected in this project. The estimated service lives based on the best-fit trend lines range from three months to over two years. Although a number of factors can affect the service life of pavement markings, the service lives should not display such considerable variability. It is difficult to distinguish any pattern among the linear, logarithmic, and exponential trend lines.

In addition, research has found that the AADT on a roadway affects service life (Abboud and Bowman 2002). A higher AADT is expected to correlate with a shorter service life, since the roadway experiences more traffic wear. However, in this study, service life was estimated to increase with AADT in all regions.

The large range of estimated service lives corresponds with the findings of previous studies. Lee et al. (1999) documented a 15-month average service life for waterborne paint; however, the variance of service life was relatively large. The correlation Lee et al. (1999) determined between the age of the paint and the service life was low (R^2=0.17). Migletz et al. (2001) concluded that waterborne paint on freeways has an average service life of 10.4 months, but the calculated values varied from 4 to 18 months. The authors acknowledged that regression modeling identified significant variations among identical types of lines and materials at different sites (2001). In another study, Abboud and Bowman (2002) concluded that the useful lifetime for paint ranges from 4.5 to 22 months, depending on the AADT of the roadway.

The results of this study confirm what has been found in previous pavement marking research: retroreflectivity is unpredictable. Given the inherent variability of the retroreflectivity data, the degradation curves developed in this study should not be used as the sole basis for determining the service life of pavement markings or creating a striping schedule.

<u>Recommendations</u>

The variability in data from this project is too significant to discount. The retroreflectivity values produced a range of degradation curves and estimated service lives, similar to the results found in the literature review. There are too many possible causes of variability to determine the source of the unpredictable data. These potential causes include the following:

- various environmental conditions
- calibration problems
- application methods by different striping crews
- depth of the glass beads in the paint
- orientation of the laser reflection off of the beads
- roadway differences such as dirt on the markings and the background color of the pavement
- inherent variability in the Laserlux device.

Unfortunately, given the variability of the data observed to date, it may not be possible, even with the collection of more data, to create striping performance predictions that have a high level of statistic confidence.

The unpredictability of the service life of pavement markings and the methodology to measure the retroreflectivity values will potentially make it difficult for the FHWA to establish a minimum retroreflectivity threshold. The data do not suggest conclusively that the existing WSDOT guidelines outlined in the WSDOT *Maintenance*

Manual (2002) should be changed. According to that schedule, long line painted markings should be painted at least once a year, and heavy wear, long line pavement markings should be painted at least twice a year.

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APPENDIX A

ROADWAY TEST SECTIONS

ROADWAY TEST SECTIONS

Highway	Stripe Type	Color	Milepost begin	Milepost end	Striping Material	Estimated AADT
530	Center	Yellow	66	56	Solvent-based	1,000
542	Center	Yellow	42	32	Solvent-based	1,000
542	Center	Yellow	54	44	Solvent-based	1,000
9	Center	Yellow	74	64	Solvent-based	3,500
20	Center	Yellow	90	97	Solvent-based	3,500
530	Center	Yellow	43	33	Solvent-based	3,500
542	Center	Yellow	26	16	Solvent-based	3,500
20	Center	Yellow	70	80	Solvent-based	7,500
4	Center	Yellow	20	25	Waterborne	1,000
6	Center	Yellow	25	15	Waterborne	1,000
12	Center	Yellow	156	146	Waterborne	1,000
26	Center	Yellow	84	94	Waterborne	1,000
26	Center	Yellow	104	114	Waterborne	1,000
101	Center	Yellow	25	29	Waterborne	1,000
101	Center	Yellow	30	25	Waterborne	1,000
261	Center	Yellow	48	38	Waterborne	1,000
261	Center	Yellow	61	51	Waterborne	1,000
4	Center	Yellow	1	6	Waterborne	3,500
4	Center	Yellow	37	42	Waterborne	3,500
6	Center	Yellow	12	2	Waterborne	3,500
6	Center	Yellow	44	35	Waterborne	3,500
12	Center	Yellow	180	170	Waterborne	3,500
12	Center	Yellow	100	89	Waterborne	3,500
12	Center	Yellow	142	132	Waterborne	3,500
26	Center	Yellow	123	133	Waterborne	3,500
97	Center	Yellow	156	166	Waterborne	3,500
101	Center	Yellow	50	45	Waterborne	3,500
103	Center	Yellow	2	11	Waterborne	3,500
103	Center	Yellow	10	2	Waterborne	3,500
970	Center	Yellow	2	10	Waterborne	3,500
101	Center	Yellow	61	66	Waterborne	5,000
101	Center	Yellow	66	61	Waterborne	5,000
4	Center	Yellow	50	55	Waterborne	7,500
12	Center	Yellow	77	67	Waterborne	7,500
195	Center	Yellow	34	26	Waterborne	7,500
542	Edge	White	16	26	Solvent-based	3,500
2	Edge	White	44	34	Solvent-based	7,500
544	Edge	White	1	9	Solvent-based	7,500
539	Edge	White	3	10	Solvent-based	15,000
5	Edge	White	233	243	Solvent-based	50,000
5	Edge	White	244	254	Solvent-based	50,000
5	Edge	White	196	206	Solvent-based	115,000

Highway	Stripe Type	Color	Milepost begin	Milepost end	Striping Material	Estimated AADT
5	Edge	White	183	193	Solvent-based	175,000
2	Edge	White	219	209	Waterborne	1,000
2	Edge	White	148	140	Waterborne	1,000
2	Edge	White	173	163	Waterborne	1,000
12	Edge	White	147	156	Waterborne	1,000
12	Edge	White	133	143	Waterborne	3,000
2	Edge	White	242	232	Waterborne	3,500
2	Edge	White	261	253	Waterborne	3,500
2	Edge	White	70	64	Waterborne	3,500
2	Edge	White	84	74	Waterborne	3,500
12	Edge	White	170	180	Waterborne	3,500
12	Edge	White	90	100	Waterborne	3,500
195	Edge	White	49	59	Waterborne	3,500
2	Edge	White	276	268	Waterborne	7,500
2	Edge	White	138	128	Waterborne	7,500
12	Edge	White	67	77	Waterborne	7,500
195	Edge	White	26	34	Waterborne	7,500
195	Edge	White	82	86	Waterborne	7,500
2	Edge	White	111	104	Waterborne	15,000
12	Edge	White	191	198	Waterborne	15,000
5	Edge	White	100	90	Waterborne	50,000
5	Edge	White	123	113	Waterborne	115,000
82	Skip	White	4	14	3M 380	15,000
82	Skip	White	14	4	3M 380	15,000
82	Skip	White	16	26	3M 380	15,000
82	Skip	White	26	16	3M 380	15,000
90	Skip	White	27	33	MMA	45,000
90	Skip	White	18	25	MMA	50,000
5	Skip	White	161	154	MMA	215,000
542	Skip	White	32	42	Solvent-based	1,000
542	Skip	White	44	54	Solvent-based	1,000
90	Skip	White	196	206	Waterborne	7,500
90	Skip	White	208	218	Waterborne	7,500
90	Skip	White	113	123	Waterborne	15,000
12	Skip	White	198	191	Waterborne	15,000
90	Skip	White	125	135	Waterborne	15,000
90	Skip	White	139	149	Waterborne	15,000
90	Skip	White	160	170	Waterborne	15,000
90	Skip	White	38	48	Waterborne	30,000
90	Skip	White	51	57	Waterborne	30,000
5	Skip	White	63	73	Waterborne	50,000