Pavement Marking Durability
Statewide

December 2005
2005-2

State of Vermont
Agency of Transportation
Materials and Research Section

Dawn Terrill, Secretary of Transportation
Rich Tetreault PE, Director of Program Development
Don Lathrop PE, Materials and Research Engineer

Prepared by:

Kat Patterson
Research Technician

Jennifer Vosburgh. EI
Research Civil Engineer

Craig Graham
Research and Development Supervisor

Reviewed by:

William E. Ahearn. PE
Research and Testing Engineer

Date: 1/18/06

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
2005-2		

4. Title and Subtitle	5. Report Date
Pavement Marking Durability in Vermont	
	6. Performing Organization Code
7. Author(s) **K. Patterson, J. Vosburgh**	8. Performing Organization Report No. **2005-2**
9. Performing Organization Name and Address **Vermont Agency of Transportation Materials and Research Section 1 National Life Drive Montpelier, VT 05633**	10. Work Unit No. 11. Contract or Grant No.
9. Performing Organization Name and Address **Vermont Agency of Transportation Materials and Research Section 1 National Life Drive Montpelier, VT 05633**	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report discusses the results of the continuing pavement marking study on thermoplastic, polyurea, and epoxy marking products. Retroreflective data was gathered using a LTL 2000 retrometer, manufactured by DELTA Light & Optics – Denmark. This study's information spans a four year period starting in 2000. Most of the readings were taken during the spring, summer and fall of each year, though a number of projects have also had winter retroreflectivity readings collected as well.

The intent of this study was to statistically compare the durability of thermoplastic and experimental pavement markings applied to roadway sections throughout the State of Vermont. Roadway and traffic characteristics varied between test sections and were evaluated to estimate service life and determine any possible trends in the degradation of pavement markings. Best fit trend lines were used to generate degradation models for thermoplastic pavement markings. As of this interim report, additional data collection is needed for the experimental markings in order to provide an accurate degradation analysis.

17. Key Words	18. Distribution Statement
Thermoplastic Retroreflectivity Polyurea Epoxy	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No.of Pages	22. Price
Unclassified	**Unclassified**	**16**	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

INTRODUCTION:

Safety is an important factor in all transportation projects. As such, there has been a continued effort by various state agencies to improve the quality and visibility of items, such as sign sheeting and pavement markings throughout the United States. This has been in response to concern for public safety and the perceived durability of various marking material. Many anecdotal instances of failed markings have been documented not only in Vermont, but in other states as well. As with other agencies, the Vermont Agency of Transportation has conducted studies on individual types of pavement markings throughout the past number of years. This study includes analysis on markings applied on interstate highways as well as major and minor arterials in various parts of the state, as it was determined that a more comprehensive assessment was needed to allow comparative analysis and description of failure. Therefore a project was developed in 2002, funded under the State Planning and Research (SPR) program, which sought to examine various different types of markings that either were being or would be applied on state highway projects. The markings in question consisted of polyurea, thermoplastic, pavement marking tape, and epoxy markings.

Pavement markings are an important part of any construction project by contributing to the safety of the roadway. Many materials are available for use in the State of Vermont, without any policy as to which materials should be used based on relevant criteria. This research project is intended to make recommendations for the development of such a policy, and includes a field study with data collection to determine the life cycle cost of materials used, and an engineering study into the mechanisms that affect the performance of each material. The study was divided into the following phases:

Phase I: Literature Review to determine what practices for evaluation of pavement markings exist in other states including research and operation activities.
Phase II: Compilation of data taken from existing research projects, and continued collection of data from those projects.
Phase III: Collection of additional data from newly constructed projects.
Phase IV: Analysis and reduction of data, including supplemental data collection descriptions.
Phase V: Economic Analysis to evaluate life cycle costs over the projected pavement life.
Phase VI: An engineering evaluation of the deterioration mechanisms of the performance factors.
Phase VII: Compilation of data and findings in the form of a final report including conclusions, recommendations and a summary program outline.

The literature search was completed previously and is appended to this report. This report will detail the efforts of Phase II, with the rest of the phases being addressed in later reports.

BACKGROUND:

Under the scope of work, the first effort following completion of the literature search was to determine the number of projects as well as the types of materials that would be surveyed. After review of projects which had been constructed in 2000, 2001, and 2002, it was determined to concentrate the efforts on describe the performance of thermoplastic and polyurea markings, but also include some experimental data from experimental epoxy and permanent tape applications. As a corollary, waterborne paint performance was also reviewed. The next step would be to select the projects for study.

Twenty separate thermoplastic projects were selected for data collection. One thermoplastic project was added in the 2003 construction season with three thermoplastic projects in 2004. These projects varied in AADT, classification, and geographic region. The three geographic locations are the Champlain Valley (Region 1), the northeast/central area (Region 2) and the southern region (Region 3) of the state. Within these three regions the roadways vary from high to low AADT, as well as road classification. These projects are listed below (A more complete table is included in Appendix A):

2000 Thermoplastic Projects									
Year	**Project**	**Route**	**Begin MM**	**Town**	**End MM**	**Town**	**Region***	**AADT Low****	**AADT High****
2000	Woodbury-Hardwick	VT 14	2.2	Woodbury	1.0	Hardwick	2	2400	2500
2000	Montpelier	VT 12	1.3	Montpelier	4.4	Montpelier	2	4100	5400
2000	St. Albans-Highgate	I 89 SB	117.9	St. Albans	130.0	Highgate	1	4100	9600
2000	Rutland-Pittsford	US 7	2.4	Rutland	2.8	Pittsford	3	9600	9600
2000	Grand Isle	VT 314	2.6	Grand Isle	3.9	Grand Isle	1	400	820
2000	Rockingham-Windsor	I 91 SB	35.6	Rockingham	57.3	Windsor	3	10600	13100
2000	Londonderry-Weston	VT 100	5.8	Londonderry	6.6	Weston	3	2100	3700
2000	Hartland	VT 12	0.6	Hartland	7.7	Hartland	3	1600	3400
2001 Thermoplastic Projects									
Year	**Project**	**Route**	**Begin MM**	**Town**	**End MM**	**Town**	**Region***	**AADT Low****	**AADT High****
2001	East Montpelier	VT 14	0.1	E. Montpelier	5.8	E. Montpelier	2	4100	5000
2001	Norton-Canaan	VT114	5.4	Norton		Canaan	2	560	3400
2001	St. Albans-Highgate NB	I 89	117.9	St. Albans	130.3	Highgate	1	4100	9600
2001	Rutland-Killington	US 4	0.0	Rutland	2.7	Killington	3	7200	13000
2001	St. Albans-Bakersfield	VT 36	2.8	St. Albans	2.5	Bakersfield	1	1300	5700
2002 Thermoplastic Projects									
Year	**Project**	**Route**	**Begin MM**	**Town**	**End MM**	**Town**	**Region***	**AADT Low****	**AADT High****
2002	Brookfield-Montpelier	I-89	32.7	Brookfield	53.0	Montpelier	2	13100	21600
2002	Moretown-Middlesex	VT 100 B	7.0	Moretown	0.1	Middlesex	2	2600	2900
2002	Wallingford-Clarendon	VT 103	0.0	Wallingford	2.0	Clarendon	3	5800	6900
2002	Williston-Richmond	US 2	1.7	Williston	0.8	Richmond	1	3400	9100
2002	Marlboro-Brattleboro	VT 9	4.9	Martlboro	4.3	Brattleboro	3	4900	11200
2002	Cavendish-Weathersfield	VT 131	0.0	Cavendish	1.3	Weathersfield	3	1960	3620

* Region indicates climatic region
**AADTLow and High indicates the range limits over the project length

Table 1- Thermoplastic Projects

The standard specification for the thickness of thermoplastic markings are 90 ± 10 mils for the above listed projects. However, in the 2002 construction season a project, Brookfield/Montpelier IM 089-1(21), was let which included two thicknesses of thermoplastic, 125 mil and the VTrans standard of 90 mils. The data will be discussed at the end of the thermoplastic data evaluation section of the report.

To further assess other commercially available marking materials, two polyurea projects were added in 2003, and one polyurea project was added in 2004. Epoxy markings were also applied to one project in 2003. Some projects had numerous markings applied to offer comparison between the markings systems. The projects and materials used are listed in Table 2.

Polyurea									
Year	Project	Route	Begin MM	Town	End MM	Town	Region*	AADT Low**	AADT High**
2001	Lyndon-Barton	I 91 NB	137.1	Lyndon	156.1	Barton	2	4200	5400
2003	Brattleboro/Westminster	I-91 NB	11.9	Brattleboro	30.0	Westminster	3	14400	16500
2003	Burlington/South Burlington	I-189	0.0	Burlington	1.5	S.Burlington	1	N/A	39600
2004	Montpelier/Waterbury	I-89 SB	53.1	Montpelier	63.6	Waterbury	2	25100	26300
2004	Montpelier/Waterbury NB	I-89 NB	53.0	Montpelier	62.5	Waterbury	2	25100	26300
Epoxy									
2002	Lyndon-Barton	I-91 SB	137.2	Lyndon	150.7	Barton	2	5100	6400

* Region indicates climatic region

**AADTLow and High indicates the range limits over the project length

Table 2-Polyurea and Epoxy Projects

In addition to these materials, limited areas of waterborne paint markings were sampled to attempt to ascertain the effectiveness of a 22 mil vs. a 15 mil wet application. The majority of these readings were sampled on the markings installed as part of the 2001 Lyndon/Barton ACIM 091-3(10) project listed above. In an effort to examine other types of markings, an experimental application of 3M series 820 Wet/Night Reflective tape was applied on the Brookfield/Montpelier IM 089-1(21) project. The results of this test were documented in Update Report U2004-2.

EVALUATION PROCEDURE:

ASTM Standard E1710-97 was utilized to collect data to evaluate the performance of the markings. In this standard, the number of test locations and readings are determined by the user. In this evaluation, at least five test sites were selected on each project. These sites were determined randomly and delineated by their associated mile markers. Each of the sites on the projects were marked so that five readings could be taken on each of the edge lines, with five readings also taken on center or skip lines where feasible. The retroreflectivity readings were taken using a LTL 2000 Retrometer, manufactured by DELTA Light & Optics – Denmark. Readings were always taken in the direction of traffic on both the white edge and yellow center lines. The readings were usually taken during the spring, summer and fall of each year, although a selected number of projects have had retroreflectivity values collected in the winter time as well. As one may expect, weather is one of the natural conditions that sometimes prevent collection from taking place as wet and dirty markings typically inhibit optical readings.

The procedure developed for sampling the retroreflectivty data involves taking the first reading at the beginning of the designated test site with each consecutive reading taken 10 feet ahead of the last. Each reading location is marked with a paint dot and is freshened each time a reading is taken. All readings are taken similarly to the methods described in ASTM E1710-97 and recorded on a sampling form. In addition to these data, a subjective durability rating is also given to each reading location in accordance with ASTM Standard D913-00 and noted on the sampling record form. Each site is photographically documented with a digital camera during each visit to the project in question. This involves taking an overall picture of the entire site with close up photos of each of the white lines, center lines and yellow lines.

During those periods of time when winter readings are required, a modification to section 9 of ASTM E1710 is followed to ensure that the lines are cleaned before sampling. This protocol for this is to clean the lines by dispensing a 50/50 mixture of water and windshield washer fluid via a portable sprayer to remove large particulate matter, such as residual salt, dirt and other debris. Then the lines are thoroughly rinsed with the water dispenser which removes the windshield washer mixture. A squeeze mop or sponge is used to remove as much excess water as possible, followed by a rag wipe of the surface to clear away any remaining debris and moisture. The lines are then dried with an air compressor or similar device. Retroreflectivity testing is completed following the methods as indicated in E1710.

The subsequent photograph illustrates how the lines are dried after they are cleaned

Figure 1. Winter Cleaning Protocol (Drying of the Lines)

MATERIALS:

In the past, personnel from the Materials and Research Section have conducted single experimental material studies into the durability of new types of markings. The focus of this research is to examine the performance of the various types of pavement marking materials that are currently in use, or are in an experimentation phase on new construction of Vermont roads.

Thermoplastic pavement markings have been the most frequently specified marking for new construction since 1992. The application temperatures for thermoplastic are 50^o F and rising for both pavement and ambient conditions. This provides a challenge to applicators given the short construction season experienced in Vermont. These markings have been used on almost all types of highways throughout the state, including high ADT interstate highway locations in Burlington and Hartford as well as town highways in smaller communities such as Addison and Berkshire. The typical pattern of use has been to use hydrocarbon thermoplastic for arterial and non urban highways and alkyd thermoplastic for urban and other routes which may experience a greater amount of traffic congestion.

Epoxy markings have been applied in the past on only a few highways in Vermont. The application temperature for both ambient and pavement conditions is 40^o F. Prior to this study, these markings were applied as part of a study on US 302 in the town of Barre. The results of this study indicated that these markings were an adequate alternative for thermoplastic, though it was evident that additional retroreflectivity data was needed. In 2002, a newer version of this material, Epoplex LS -90, was applied as part of a rehabilitation project on I -91 in Lyndon and Sheffield. The data from this application is included in this report.

Polyurea markings are relatively new to the transportation arena. These materials are marketed as having a higher initial retroreflectivity with a higher retention over a multi year period. The application temperature for these materials can range from 35^o F to 40^o F, depending on the material selected. Because of this, the manufacturers also market them as having application temperatures lower than thermoplastic. Thus like epoxy markings they do have a longer window for installation, which is especially valuable in the limited construction season in Vermont. This material was first applied as an experimental feature in 2001 on I-91 in Lyndon and Barton. The material used in this application was 3M's Liquid Pavement Marking

Series 1200 (LPM 1200) and Liquid Pavement Marking Series 1000 (LPM 1000) LPM 1200 was also applied in 2003 on I-189 (Burlington and South Burlington) and in 2004 on I-89 (Montpelier and Waterbury). LPM 1000 as well as Epoplex LS90 polyurea were applied on I-91 in 2003 as part of a rehabilitation project in Brattleboro and Westminster. All applications, with the exception of the 2004 projects, are reviewed in this report.

Thermoplastic:

For a majority of projects in Vermont over the past 10 years, three thermoplastic products have been used as the main marking material. Between 1999 to 2004 most of the applications utilized a hydrocarbon material, STUD- GARD SG-70, which was originally manufactured by Linear Dynamics, but is now supplied by Ennis Paint from Ennis, TX. Additionally two alkyd thermoplastic products are approved for use on state projects. The first of these is Pavemark Alkyd, also owned by Ennis Paint, but was originally developed and manufactured by Pavemark Inc. The second, CataTherm 308 Alkyd, originated with Cataphote Inc, but also is now manufactured by Ennis Paint. Other materials, such as Dobco Hydrocarbon and Crown Technology Tuffline Hydrocarbon have also been used on an experimental basis. For all applications since 1997, crushed glass has been incorporated into the thermoplastic material at a rate of 10% by weight of the combined material. The glass is substituted for 10% of the filler material. Thirty-five percent of the total thermoplastic composition, classified as filler, remains unchanged. The crushed glass is produced from cullet of clear glass, with a maximum size of 33 mils (100% weight). The remainder of the marking components consists of binder material, which includes pigment (25% of the total material) and glass beads, meeting requirements of VTrans Standard Specification 708.09. The glass beads are incorporated in the thermoplastic composition at a rate between 28 – 30% by weight of the total material. These beads are slightly finer than the AASHTO Type 1 beads, as 20 percent are allowed to be retained on the No 30.sieve, while AASHTO allows up to 25 percent retainage when tested according to M247.

Generally, thermoplastic materials exhibited a sharp drop in retroreflectivity after one winter. This pattern rebounds after the spring thaw and rainfall. However, while the average white line retroreflectivity values remain above 100 mcdl, the yellow readings generally fall below this value. An examination of four projects with varying degrees of traffic volumes and in different microclimates of the state may help to illustrate this pattern. The first to be examined was VT 131 in Cavendish and Weathersfield, which is an example of a moderate climate, medium volume highway. Following that was a review of the performance on US 2 in the towns of Williston and Richmond, an example of a lower snowfall yet high traffic volume project, and VT 314 in Grand Isle, with a warmer climate, yet a lower AADT. The final project to be examined was VT 114 in Norton and Canaan, which is near the Canadian border in Essex County and is characterized by cooler winter temperatures and a lower traffic volume than the other sites.

<u>Cavendish/Weathersfield</u>

The project test site is a moderate volume two lane route with an AADT of 3200 and numerous curves that follow the contour of the Black River. Most of the test sites are set up on straight section of the roadway except for one which is located on a gradual curve (8 degrees). The traffic increases slightly during the winter months as this is one of the direct routes from I-91 to the Okemo mountain resort. The roadway, experiences 100” to 150”of snowfall per year, which requires frequent deicing and plowing operations.

The SG-70 hydrocarbon thermoplastic was applied in 2002. Initial retroreflectivity values obtained just after the markings were applied averaged 350 mcdl for the white edge line markings, rising slightly after a two month period. After the winter maintenance season the retroreflectivity values dropped significantly to 117 mcdl (average for all white edge line readings) but then rose 47 % to 172 mcdl. Eventually the readings leveled off at approximately 140 mcdl after two years of service. The total readings taken are included in Appendix C. The yellow center lines on this project exhibited lower retroreflectivity values than the white as exhibited in figure 1. It should be noted that, this pattern is evident in some fashion in all the marking materials reviewed in this study. While the overall durability rating is 8 on a 1 to 10 scale, actual retroreflectivity readings would indicate a somewhat lower rating, based upon night time visibility.

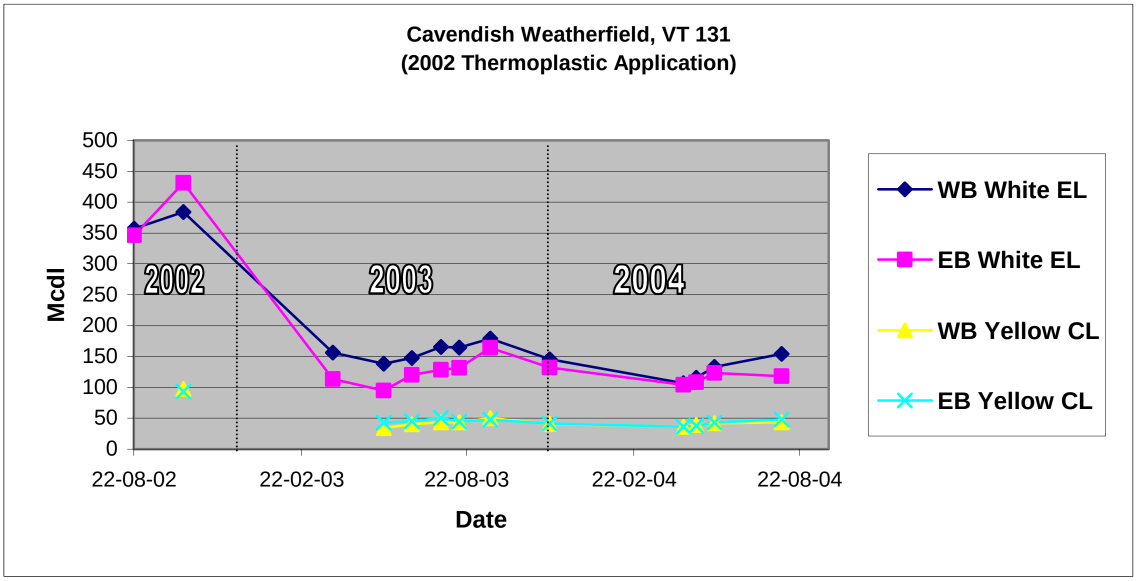

Figure 2 – Cavendish/Weathersfield Retroreflectivity Values

Figure 3 -2002 Cavendish/Wethersfield – Test Site 1

Williston Richmond

Another project which was marked with thermoplastic is on US 2 in the towns of Williston and Richmond. This road is a heavily traveled two lane roadway with an AADT between 10,700 at Taft's Corners (US 2/VT 2A) in Williston, to 3,700 at the junction of VT 117 in Richmond. The first test site is located in the higher AADT area, with the others in the lower traveled section. Snowfall in this area is about 80" – 100" per year making snow removal frequent during the winter months. As seen on the graph below, initial readings began at 300 mcdl then rose slightly in two months. The readings then fell sharply after the first winter. Readings leveled out around the 150 mcdl range in 2004. Overall durability for the white markings was 8 while the durability readings for the yellow markings were 7 after two years.

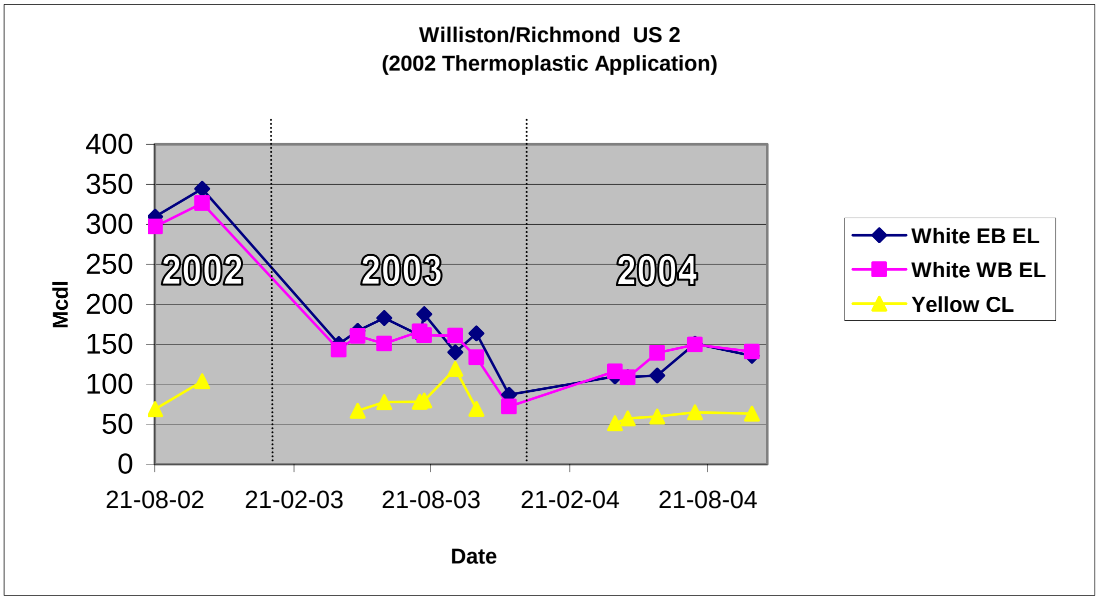

Figure 4 - Williston/Richmond Retroreflectivity Values

Figure 5 -2002 Williston-Richmond Test Site 2

Grand Isle

The trend of readings recovering after winter is somewhat less evident on projects with a lower AADT. For example, in 2000 thermoplastic was applied on VT 314 in the town of Grand Isle. This road is a two lane roadway with a low traffic count (AADT 960). This is mostly due to local traffic, but also includes commuters who access the ferry to New York State. The average yearly snowfall for this area is 70 inches per year. Initial readings are not available, but two year readings were in the 250 mcdl range. Readings fluctuated widely in 2003 and started to level off in the mid 100 mcdl to 125 mcdl range by May 2004. The overall durability reading in May 2004, for the white and yellow markings was 7 on a 1 to 10 scale. The retroreflectivity readings confirm the subjective rating.

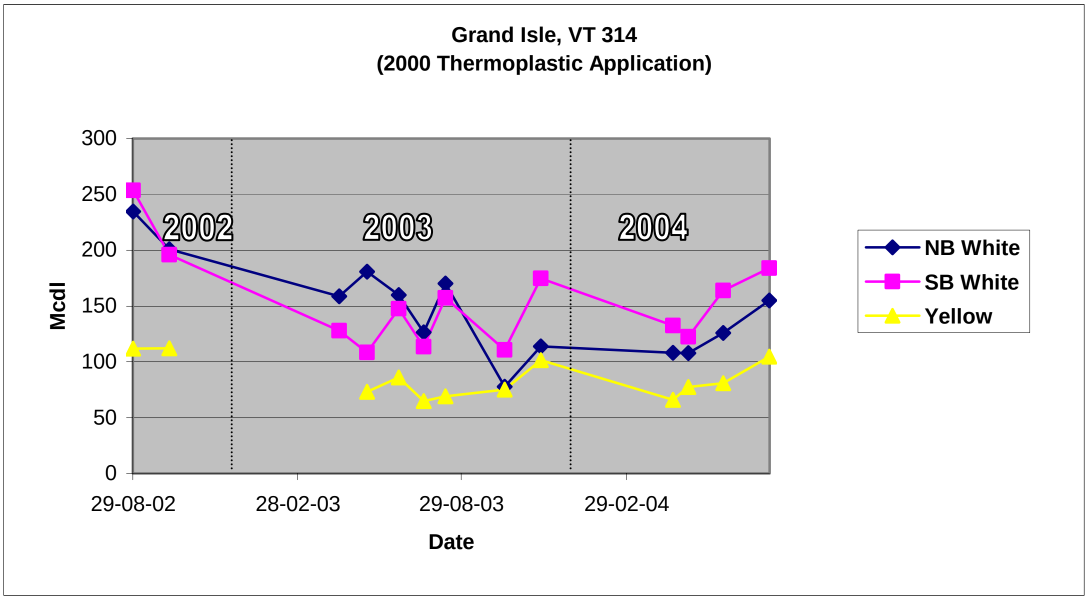

Figure 6 - Grand Isle Retroreflectivity Values

Figure 7 -VT 314 Grand Isle (2000) Test Site 2

Norton-Canaan

Another lower traffic volume road is Vermont 114 in the towns of Norton and Canaan. The AADT is considerably lower than in other areas of the state with values ranging from 960 to 1000 over the length of the project. The average yearly snowfall in this area is greater than 130" which is comparable to that that on VT 131 in Cavendish/Weathersfield, but more than that in Williston/Richmond and Grande Isle. Retroreflectivity readings were extremely varied this project, with the average values originating at 160 mcdl, falling to 80 mcdl in four months. Rebounding of the readings took place after the winter as the average values rose to 140 mcdl range by July 2003. The readings dropped sharply 40-60 mcdl in September 2003 and then to level off at around 120. At this time it is unclear whether equipment problems or data collection errors caused this anomaly.

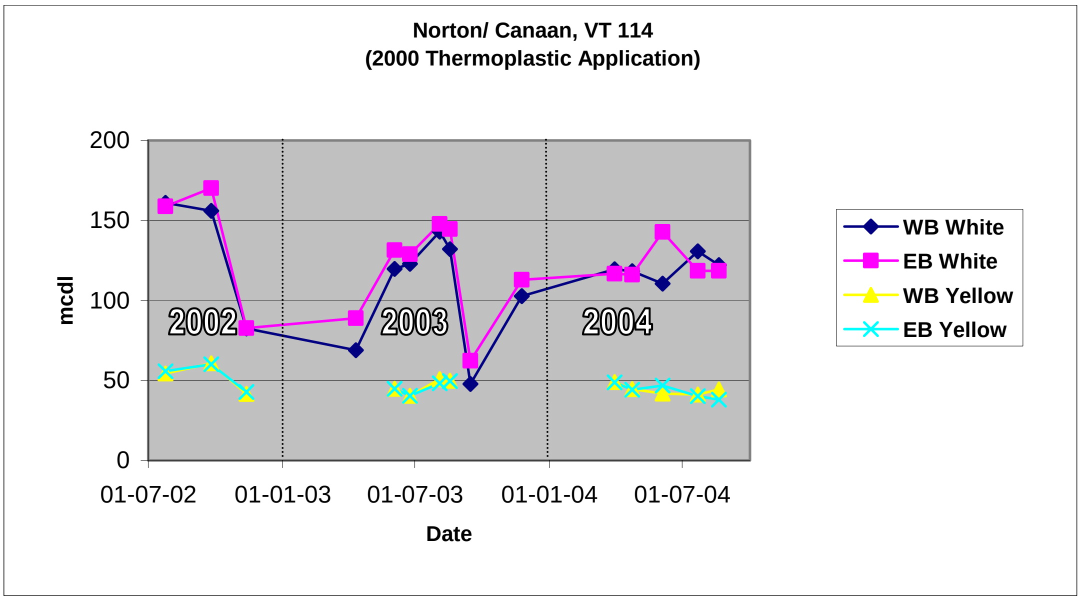

Figure 8 Norton/Canaan Retroreflectivity Values

Figure 9 - 2001 Norton-Canaan Test Site 1

While all the readings tend to fluctuate, the overall trend is very apparent. The typical pattern of rebounding was apparent on these four projects, while some were more apparent than others. It may be inferred that this slight rebound in the retroreflectivity readings may be attributed to the cleaning of the line by the environment during the warmer months of the spring or by the exposure of the embedded glass beads.

Based upon the criteria identified in a 1998 FHWA sponsored study, generally the retroreflectivity levels are satisfactory after nearly four years of service. These levels range from 85 to 100 for non freeway applications to 150 mcdl for white edge lines on freeway applications. Yellow readings were less with 55 to 65 for non freeway and 100 for freeway installations. Most all of the readings fall within these criteria, however it must be noted that the average October 2003 readings in Grand Isle and those taken in December 2003 at the Williston-Richmond test site did not rise above retroreflectivity levels of 100 mcdl. These readings did rise again to above this level by April, 2004.

Thermoplastic at Different Application Thicknesses

In 2002 two different application thicknesses of thermoplastic markings were applied on the Brookfield/Montpelier I 89 project. Three miles of the project consisted of 125 mil white edge lines and skip lines, while the rest of the project had markings installed with Vermont's standard thickness of 90 mils. The two year performance of these markings (white edge line) are shown in the graph below.

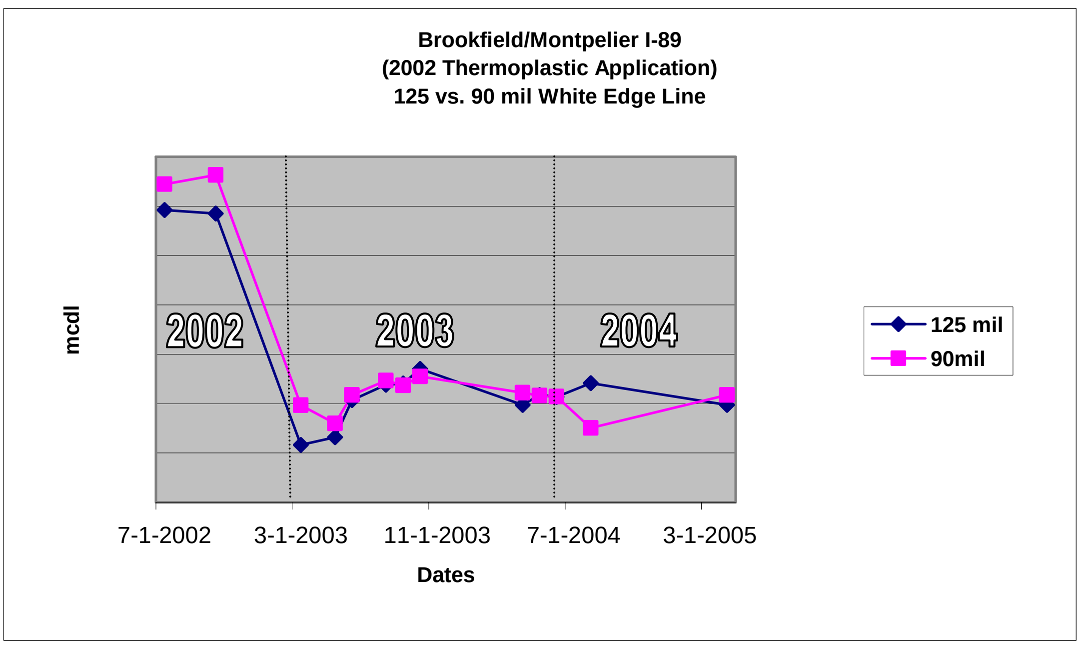

Figure 10 – Brookfield/Montpelier Retroreflectivity Values

In reviewing this data, it is interesting to note that the except for one set of readings in August 2004, the retroreflectivity values between the differing thicknesses did not differ significantly, However, further data will need to be collected into the spring and summer of 2005 to verify this trend.

Paint:

Waterborne paint is a non durable marking material that is applied as a maintenance marking on state highways throughout Vermont. In the past the performance of the material had been less than desirable with many applications deteriorating to an unacceptable standard in less than six months. One of the possible reasons for this problem is the thickness of the marking. Between the years 1997 and 2003, waterborne paint was applied at 15 mils (.015") wet film thickness. In 2003 an experimental application of 22 mil (.022") wet film thickness paint was applied on I-89 in Middlesex. The results of this test were conclusive and encouraging enough the recommend the widespread adoption of a 22 mil thick paint marking standard in 2004.

In an effort to quantify the performance of these materials data has been collected on paint applications on I-91 in Lyndon/Barton, between MM 146.1 and 150.0. This is adjacent to a polyurea marking experimental site. The data collected in this application is interesting as it appears that the readings associated with the 22 mil thick paint pavement markings were more consistent in thickness than those that were applied at 15 mils. It also appears that the 50% increase in thickness has resulted in an initial 100 mcdl increase in retroreflectivity. However, at this time there is not enough data to draw any conclusion. Once additional data is gathered in the early spring of 2005, it will be better able to compare the performance of both paint thicknesses.

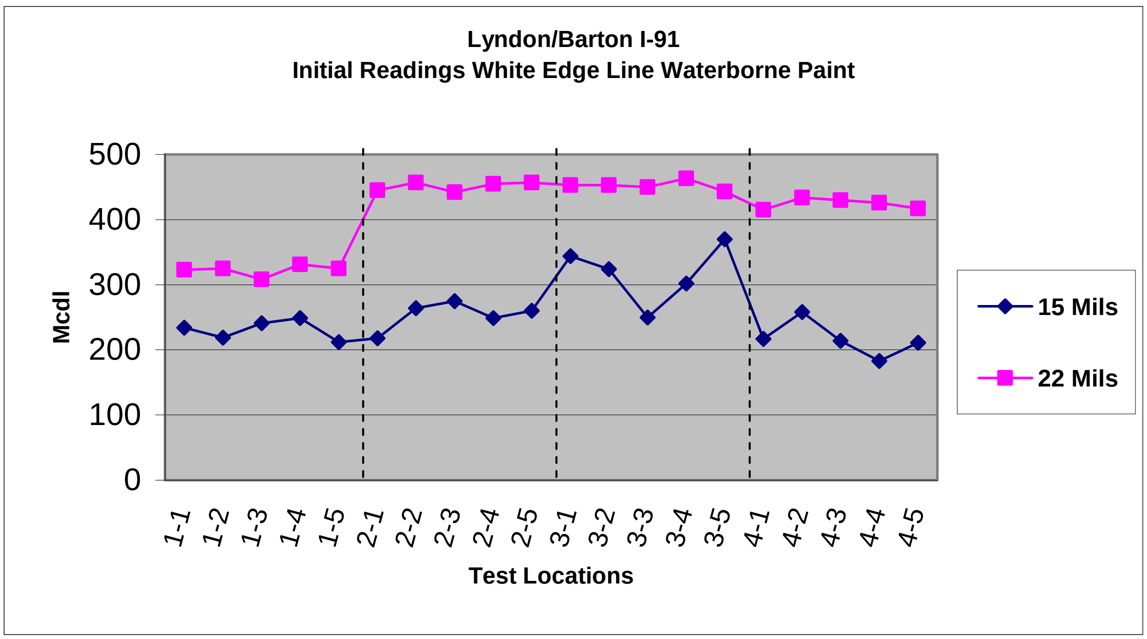

Figure 11- Initial Readings on White Paint, I-91 Lyndon/Barton

Epoxy:

Epoxy was applied as an experimental marking on October 22, 2002 on new bituminous concrete pavement on I-91 on the Lyndon and Sheffield. The material applied was Epoplex LS50 manufactured by Epoplex, Inc. of Maple Shade, NJ. The material was surface applied to edge, center and skip line on the southbound lanes of I 91 between MM 137.75 (Exit 24) and MM.150. For this region of Vermont, the average snowfall is 100" per year, with the elevation being the highest on I-91 in the state. The AADT was measured at 5100 between Exits 24 and 25 in 2002.

The performance of the epoxy markings follows a pattern similar to the thermoplastic in this study, as the initial readings are relatively high (250-325), and then drop to below 100 mcdl. After a sharp spike in November 2003, values for the epoxy markings remain somewhat consistent, remaining close to 100 mcdl for white and 50 mcdl for yellow markings. . The average durability is 7 (good) for the white markings and 6 for the yellow. At this point in time it is unclear what reasons may exist for the sudden upturn in the readings in December 2004.

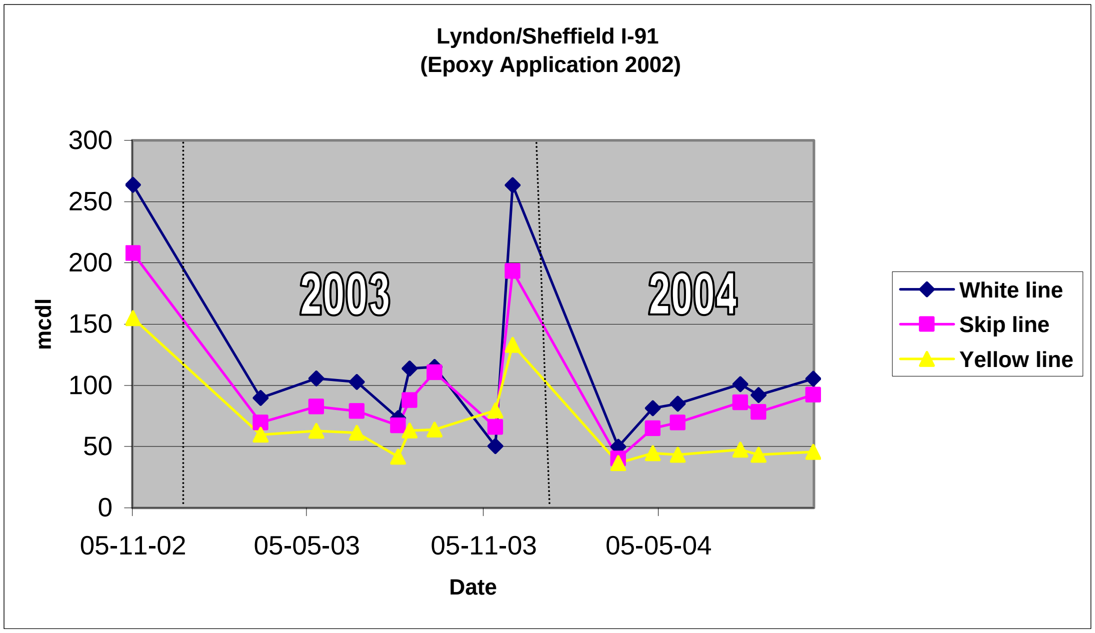

Figure 12 – Lyndon/Sheffield Epoxy Retroreflectivity Values

Figure 13 -2002Lyndon- Sheffield Test Site 3
I 91 Southbound, Epoxy

<u>Polyurea:</u>

Three materials, 3M Liquid Pavement Marking 1200 (LPM 1200) and Liquid Pavement Marking 1000 (LPM 1000) as well as Epoplex LS 90 are increasingly being used in highways in Vermont. Currently they are being evaluated in three locations. The first was applied in 2001 on I-91 in Lyndon-Barton. This involved two five mile sections of 3M LPM Series 1000 and Series 1200 along with thermoplastic for comparison. In 2003, LPM 1200 was recessed (inlaid) on part of I-189 in South Burlington with the rest of the project utilizing the same materials with a standard surface application. The third project involved an evaluation between 3M LPM 1000 and Epoplex LS90 materials on I-91 from Brattleboro to Westminster.

A fourth and fifth project, Montpelier/Waterbury and Waterbury Bolton on I-89 was constructed in 2004, but has yet to provide a comparable data.

The test site on I-189, in South Burlington, is a heavily traveled area with an AADT of 39,600. It is the major link between I-89 and US Route 7 also known as Shelburne Road. On this test site approximately one half of the pavement markers were inlaid and one half was surface laid (conventional application). After one winter the inlaid polyurea markings test locations retained higher retroreflectivity for a greater time than the surface applied material. Although both surface–applied and recessed markings had readings of 900 mcdl after application (July 9, 2003), the recessed markings (with an average value greater than 200 mcdl) was 220% better the surface applied material(with an average value of 90 mcdl) after nine months of service (April 7, 2004). Even though these higher readings only include evidence from one winter's maintenance season, the inlaid markings appear to be performing much better than the surface laid material at this time.

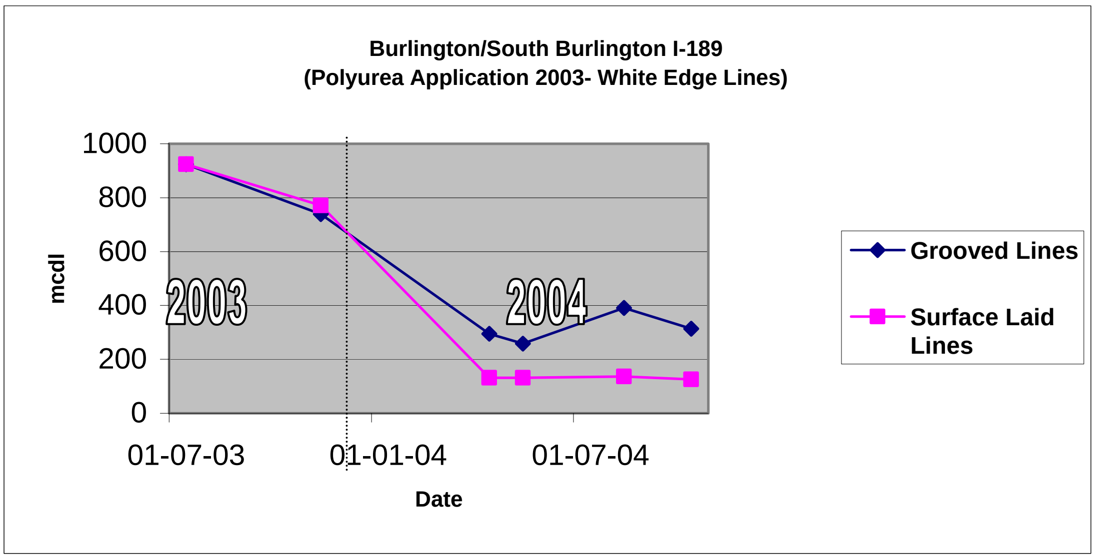

Figure 14 – Burlington/South Burlington Retoreflectivity Values

Polyurea has performed similarly to thermoplastic pavement marking material over the past three years. Each exhibit comparable retroreflectivity and durability values when installed as a surface-applied material. When polyurea is recessed into bituminous concrete its durability improves and it retains its high initial retroreflectivity for a much longer time than surface applied polyurea or thermoplastic material. On the Burlington/South Burlington I-189 project, the initial readings on average varied less on the recessed markings, but the surface applied markings began to exhibit a closer distribution of values as both applications aged.

Figure 15, from the Lyndon-Barton I 91 test sites, can be used as a comparison of marking systems. As seen on the graph, all products applied begin with relatively high readings with the 3M LPM Series 1200 having the highest readings, and all lower through the winter. In the graph below all test materials are in the same geographic area with the similar traffic patterns, snowfall, snow removal and other conditions, with each exhibiting a similar retroreflectivity pattern after 3 years.

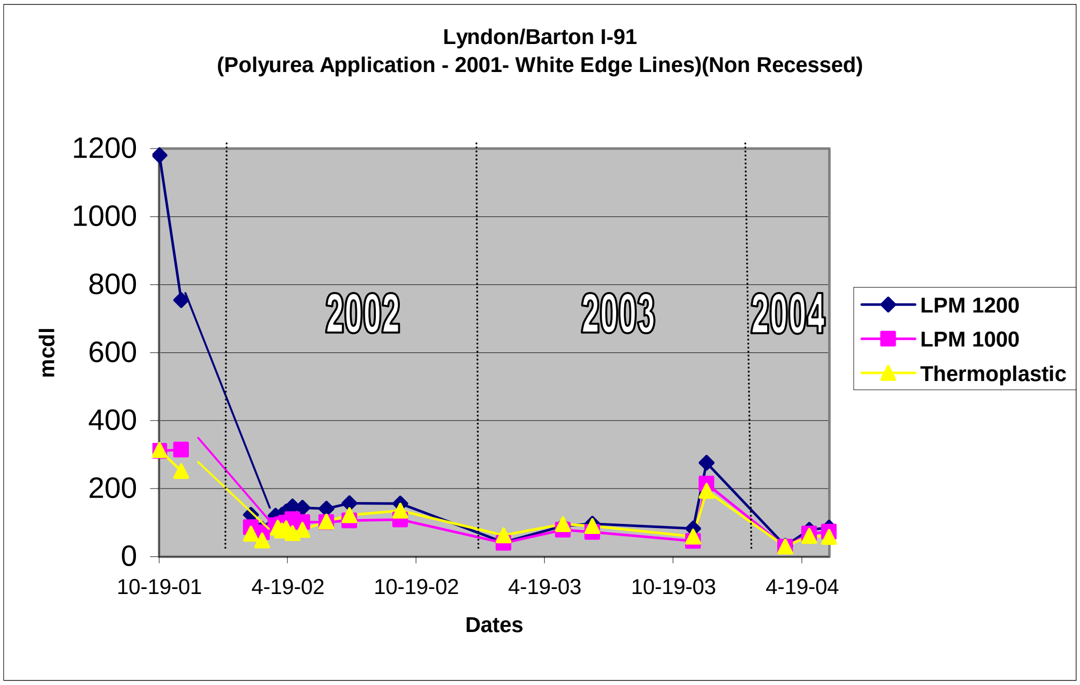

Figure 15 - Lyndon –Barton Average Yearly Retroreflectivity Readings

REDUCTION AND STATISTICAL ANALYSIS OF THE RETROREFLECTIVITY DATA

One objective of this report was to statistically compare the durability of thermoplastic and experimental pavement markings applied to roadway sections throughout the State of Vermont. The analysis was performed on retroreflectivity readings of markings applied to pavement projects constructed during 2000 through 2004. Roadway and traffic characteristics, including roadway type, AADT and average annual snowfall amounts, varied between test sections and were evaluated in an attempt to estimate service life and determine any possible trends in the degradation pavement markings.

Overall, the retroreflectivity readings displayed a significant amount of variability among roadways with similar roadway and traffic characteristics as well as each individual test section. The variability had a significant impact in determining an estimate for service life and patterns in retroreflectivity degradation. In addition to roadway and traffic characteristics, variations in pavement marking durability can also be attributed to type of marking, the manufacturer of the marking materials and glass beads, quality control during installation and winter maintenance snow removal. The following sections will present the statistical analyses performed and the results of the service life and degradation evaluation.

SERVICE LIFE

The service life of pavement markings was used to compare the durability and degradation rates of various types of the markings to a predefined benchmark in order to evaluate and determine life cycle costs, which will be addressed in Phase V of this research project. The analysis of the service life of pavement markings was performed by comparing the retroreflectivity readings vs. the time since installation and the number of cumulative traffic passages required to decrease from its initial value to a minimum acceptable value. To date the Federal Highway Administration, (FHWA), and other federal and state authorities have not established minimum required values of the retroreflectivity of pavement markings. The table below provides the FHWA recommended retroreflectivity values of white and yellow pavement markings for different classes of roads:

1998 FHWA Research-Recommended Pavement Marking Values			
Type	**Non-Frwy**	**Non-Frwy**	**Freeway**
Option 1	<= 40 mph	>= 45 mph	>= 55 mph
Option 2	<= 40 mph	>= 45 mph	>= 60 mph, >10K ADT
Option 3	<= 40 mph	45-55 mph	>= 60 mph
White	85	100	150
Yellow	55	65	100

Figure 16

These values were used as the standard for determining the end of useful service life.

<u>Thermoplastic</u>

As described previously, nineteen roadway sections with thermoplastic markings, consisting of interstate highways, other state highways and minor arterial highways throughout of the State of Vermont were selected for this analysis. Over 1,100 individual R_L, or coefficient of retroreflected luminance, measurements were evaluated on approximately 69 longitudinal pavement marking lines with the LTL 2000 Retrometer. A small number of roadway sections were excluded from the service life analysis as test sites were repainted periodically throughout data collection impacting the cumulative rate of degradation of the pavement markings. Additionally, roadway sections where pavement marking installation dates were unavailable or test sites with less than four data collection trips were also excluded. For evaluation purposes, retroreflectivity readings of lines of the same material, type, and color in the same direction of travel within a roadway section were analyzed together.

The data collected to date reveals a significant amount of variability in the R_L values of the individual test sites within roadway sections. As the variability increases, the level of statistical confidence in any trends or models decreases, therefore it is important to examine the variability upon which the service life and degradation analyses are based. Figure 15 displays the average retroreflectivity reading across all test sites within a roadway section on I-91 between the towns of Lyndon and Barton for the entire duration of the study. The test section consisted of a durable thermoplastic westbound white edge line that was applied in October of 2001. Readings were expected to display little variability during summer months, as indicated on the graph, where environmental conditions are relatively constant. However, the average retroreflectivity readings measured in the test sections during the summer of 2002, one year subsequent to application, ranged from 70 and 135 mcdl with an average of 94 mcdl. The standard deviation of the average retroreflectivity readings was approximately 23 mcdl. This is a relativity large standard deviation displaying the significance of the variability of the data set. Figure 17 is provided below:

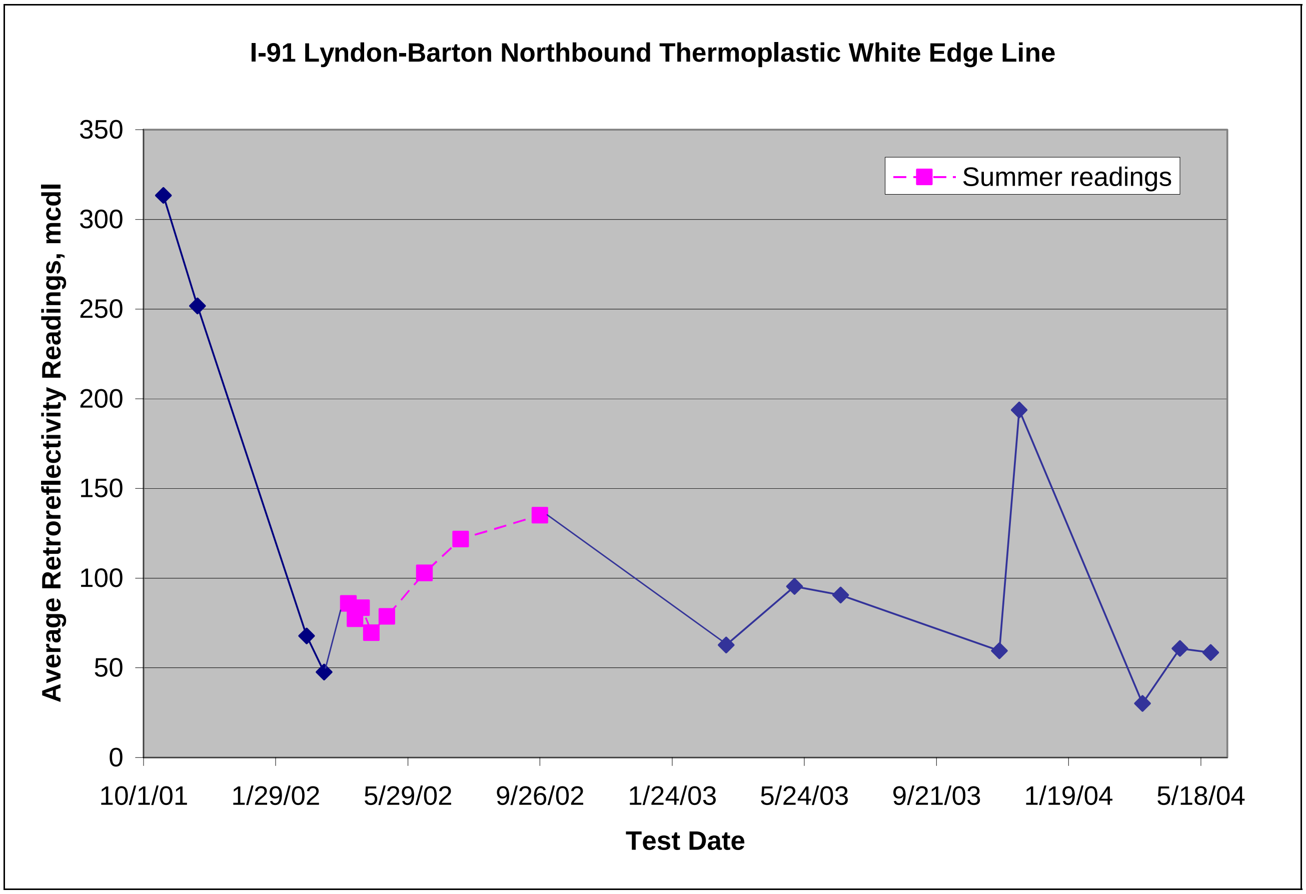

Figure 17

In examining the graph it is also important to note the seasonal trend of the retroreflectivity of the pavement markings. The markings display a sharp decline during the winter months and appear to rebound during summer months, peaking in late summer to early fall. According to the Vermont Fire Prevention Division, the average annual snowfall accumulation in Vermont varies from approximately 60" along the southeastern edge of the state to as much as 150" in the Town of Stowe. Pavement markings may be damaged during winter maintenance snow removal practices resulting in an increased rate of pavement marking degradation. Each freeze thaw cycle may damage the lines by causing delamination, bead popout, and general wear and tear. The varying climate during winter in Vermont may cause the lines to endure many freeze thaw cycles. Areas that are subject to greater annual snowfall amounts are more susceptible to winter maintenance damage. This factor combined with any moisture or debris remaining on the markings following the winter cleaning protocol, prior to the collection of data, accounts for the seasonal trend of the reduction of retroreflectivity during winter months. Typically, the average peak values of the retroreflectivity reading during summer months continue to decline each year following application. Note however that the snowfall amounts were not taken into account for the degradation analysis as the majority of the annual snowfall amounts were within 10" of one another.

In order to account for the differences in traffic flows in the various test sections, the markings were evaluated on cumulative traffic passages which are both a function of the AADT and the time since installation of the marking. Traffic flow estimates were based on traffic counts performed by the Vermont Agency of Transportation. In order to assess the large data sets for each roadway section, the mean of the retroreflectivity values from all of the test segments by line type and color, and direction of travel was calculated for each date of data collection. The date of installation for each marking was determined by accessing work reports for each of the pavement projects through Site Manager, a "construction management system". Utilizing the installation dates and date of data collection, the number of days since installation was determined. The cumulative number of traffic passages in thousands of vehicles was computed by multiplying the number of days of since installation by the AADT and then dividing the resultant by 1000. Please note that this procedure was followed for each of the various types of pavement markings.

As a final step, all of the calculated average retroreflectivity reading and correlating cumulative AADT in thousands of vehicles were compiled into a larger data set by line type and color, grouped by non-freeway and freeway FHWA classifications as indicated above. These data points were then plotted on a graph with the cumulative AADT on the x-axis and correlating retroreflectivity readings on the y-axis. Once the points were plotted, a regression analysis was performed using the trend line function in Excel in order to provide a logarithmic equation that predicts the degradation of the reflectivity of pavement markings as a function of time and traffic flow. Note that an R^2 value, or coefficient of determination, was also presented below each equation that demonstrates how closely the estimated values for the trend lines compared to the actual data. Given as a number between 0 and 1, the closer the R^2 number is to one, the more accurate the trend lines and resulting degradation equations.

Figures 2 through 5 display retroreflectivity data collected on thermoplastic markings applied on roadway sections throughout the State of Vermont. Figures 2 and 3 are derived from "Non-Freeway" test sections, which consist mainly of two lane roads with AADT's that vary from approximately 600 in Grande Isle on VT 314 to 11600 in Rutland on US 4. Figures 4 and 5 are from "Freeway" test section, which consist of multilane roads with AADT's that vary from 6700 in Northern Vermont to 17900 from Brookfield to Montpelier on I-89.

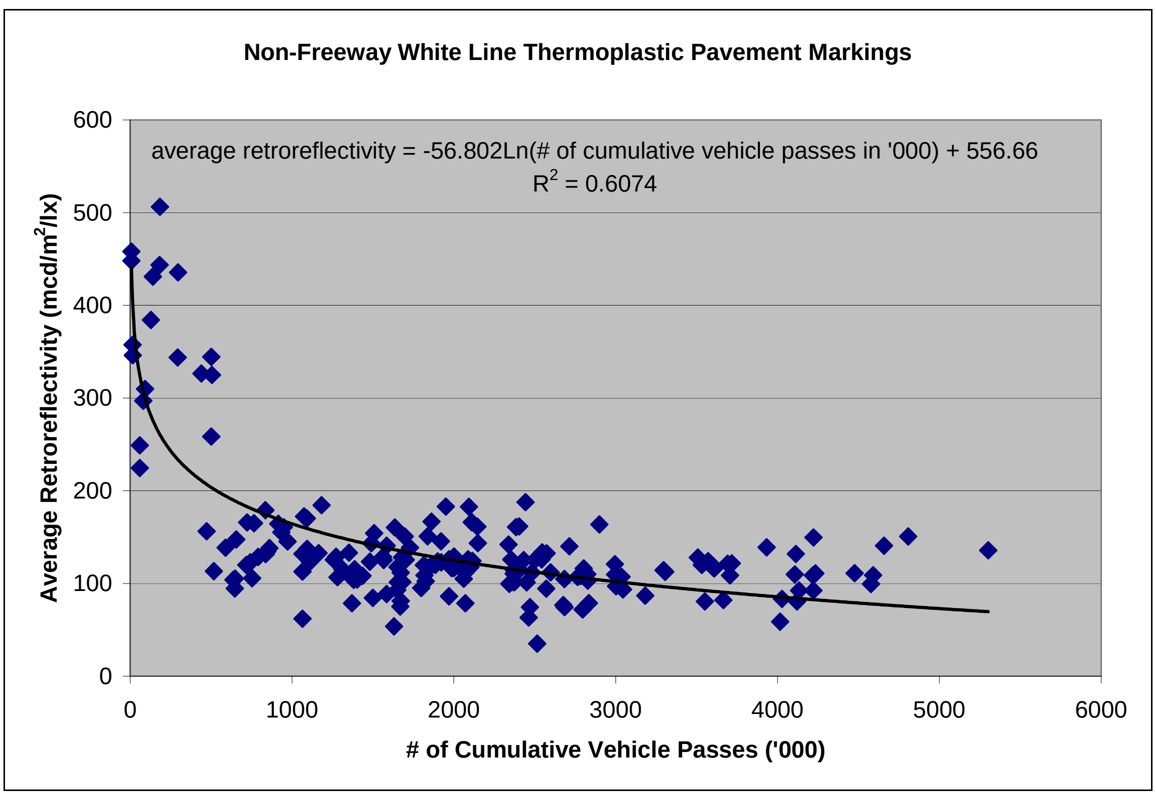

Figure 18

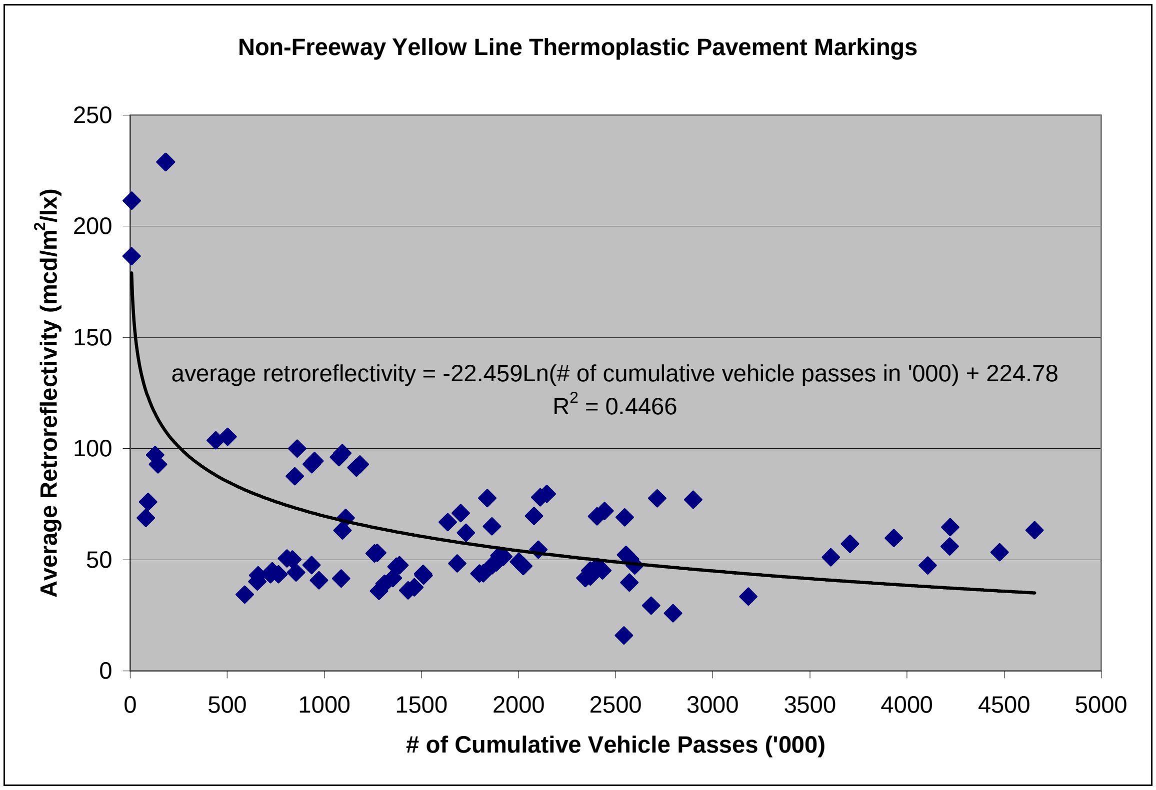

Figure 19

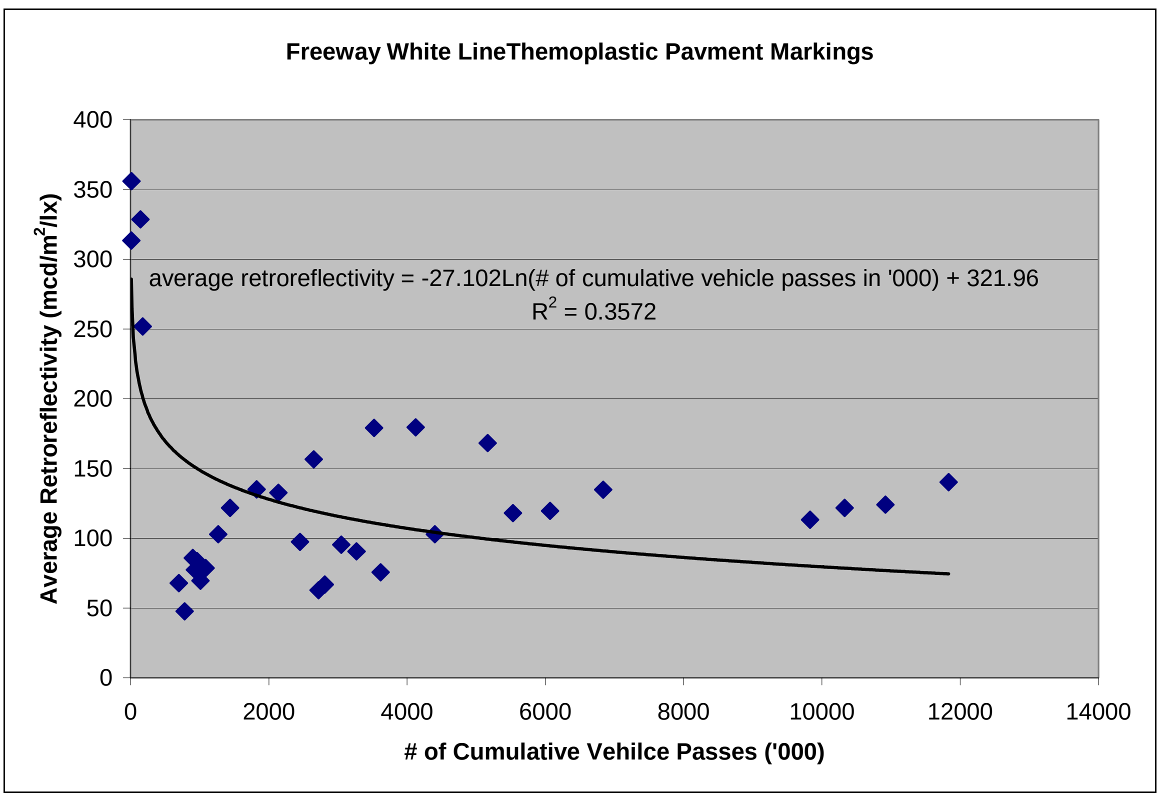

Figure 20

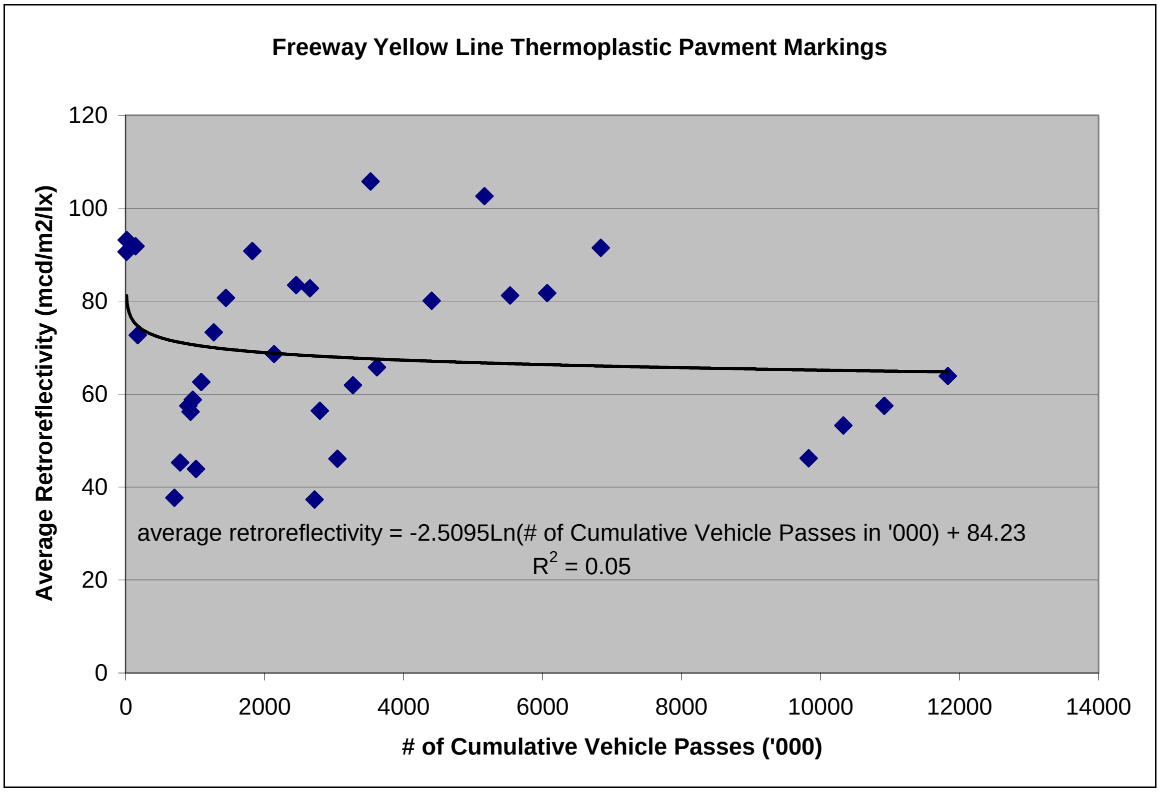

Figure 21

As depicted in Figures 18 through 21, the larger data sets appear to have more accurate degradation models as the coefficients of determination are closer to 1. Non-freeway degradation models are shown to more accurately depict the actual data sets than the freeway models. This may be attributed to a number of factors, including a large variation in the AADT values for the test roadway sections, differing traffic patterns over straight a ways vs. curved sections of roadways altering the degradation rates, and the potential for increased danger from on coming traffic with higher posted speed limits.

The models were solved for the number of cumulative vehicle passes utilizing the equations of the degradation models, along with the recommended retroreflectivity values from the FHWA of white and yellow pavement markings for different classes of roads. The result gives the number of cumulative vehicle passes until the line degrades to the recommended retroreflectivity value, as follows:

Non-Freeway White Lines:	x = 3100
Non-Freeway Yellow Lines:	x = 1230
Freeway White Lines:	x = 570
Freeway Yellow Lines:	x = 540

Where x = the number of cumulative vehicle passes in thousands of vehicles or (AADT)*(number of days since application)/1000

These equations allow the user to substitute the AADT for the roadway section to predict the number of days until the retroreflectivity readings degrade to the FHWA recommended values.

Polyurea and other markings:

As of the date of this interim report, there have not been enough retroreflectivity readings collected from applied epoxy and polyurea pavement markings in order to generate accurate degradation models from the data sets. The Agency will continue to collect retroreflectivity readings from these types of pavement markings throughout the following spring and summer. The Agency has also begun the practice of recessing pavement markings in order to observe any reduction of damage from winter maintenance snow removal practices and from general driving practices. The procedure for determining a model for the degradation of pavement markings will be followed as described in this report. As a final step, the degradation models for the various pavement markings will be compared by service life and a cost benefit analysis in order to provide guidelines proper types of pavement markings for different classes of roadway structures.

SUMMARY:

During three years of service, 3M LPM 1200 retroreflectivity starts out with very impressive high readings but drops very rapidly. The readings eventually level out to around 100 -150 mcdl. These readings are comparable to the other types of pavement markings. Thermoplastic also starts with relatively high readings then drops and levels out in a similar pattern to Polyurea and Epoxy.

However, upon visual inspection the markings durability remains about 5 and up, which is in the fair range. This number is subjective, and it tends to vary according to personnel, while the retroreflectometer readings are not based on opinion or any individual viewpoint. As of the date of this interim report, thermoplastic pavement markings have been evaluated in an effort to generate a degradation model to use as a comparison against the experimental pavement markings and to calculate life cycle costs. More data collection is needed in order to provide an accurate assessment of the degradation of the experimental markings.

Data gaps also have been identified in the process of gathering the information for this report. One of these gaps is the inadequate number of readings of the 125 and 90 mil thick thermoplastic markings on the Brookfield – Montpelier project. Others include additional data for 22 mil thick waterborne paint and additional readings for epoxy and polyurea markings. The latter which will be expanded with the inclusion of data from the 2004 I-89 projects in Waterbury/Bolton and Montpelier/Waterbury. These along with other gaps will be addressed and additional readings will be collected in time for the final report on this project.

Appendix A- Thermoplastic Projects in this study

Year	Project	Project #	Route	Begin MM	Town	End MM	Town	Region*	AADT Low	AADT High
	2000 Thermoplastic Projects									
2000	Woodbury-Hardwick	ACSTP9817(1)S	VT 14	2.2	Woodbury	1.0	Hardwick	2	2400	2500
2000	Montpelier	STP2103(1)S	VT 12	1.3	Montpelier	4.4	Montpelier	2	4100	5400
2000	St. Albans-Highgate	IM089-3(24)	I 89 SB	117.9	St. Albans	130.0	Highgate	1	4100	9600
2000	Rutland-Pittsford	NH2119(1)S	US 7	2.4	Rutland	2.8	Pittsford	3	9600	9600
2000	Grand Isle	STP9725(1)S	VT 314	2.6	Grand Isle	3.9	Grand Isle	1	400	820
2000	Rockingham-Windsor	ACIM091-1(26)	I 91 SB	35.6	Rockingham	57.3	Windsor	3	10600	13100
2000	Londonderry-Weston	STP9819(1)S	VT 100	5.8	Londonderry	6.6	Weston	3	2100	3700
2000	Hartland	ACSTP2110(1)S	VT 12	0.6	Hartland	7.7	Hartland	3	1600	3400
	2001 Thermoplastic Projects									
Year	**Project**	**Project #**	**Route**	**Begin MM**	**Town**	**End MM**	**Town**	**Region***	**AADT Low**	**High**
2001	East Montpelier	ACSTP 9816(1)S	VT 14	0.1	E. Montpelier	5.8	E. Montpelier	2	4100	5000
2001	Norton-Canaan	STP 2222(1)S	VT114	5.4	Norton		Canaan	2	560	3400
2001	St. Albans-Highgate NB	IM 089-3(34)	I 89	117.9	St. Albans	130.3	Highgate	1	4100	9600
2001	Rutland-Killington	ACNH9809(1)S	US 4	0.0	Rutland	2.7	Killington	3	7200	13000
2001	St. Albans-Bakersfield	STP 2128(1)S	VT 36	2.8	St. Albans	2.5	Bakersfield	1	1300	5700
	2002 Thermoplastic Projects									
Year	**Project**	**Project #**	**Route**	**Begin MM**	**Town**	**End MM**	**Town**	**Region***	**AADT Low**	**High**
2002	Brookfield-Montpelier	IM089-1(21)	I-89	32.7	Brookfield	53.0	Montpelier	2	13100	21600
2002	Moretown-Middlesex	RS 0167 (9)	VT 100 B	7.0	Moretown	0.1	Middlesex	2	2600	2900
2002	Wallingford-Clarendon	NH 2216(1)S	VT 103	0.0	Wallingford	2.0	Clarendon	3	5800	6900
2002	Williston-Richmond	STP 2105(1)S	US 2	1.7	Williston	0.8	Richmond	1	3400	9100
2002	Marlboro-Brattleboro	ST NH 2109-1(8)	VT 9	4.9	Martlboro	4.3	Brattleboro	3	4900	11200
2002	Cavendish-Weathersfield	STP9661(1)S	VT 131	0.0	Cavendish	1.3	Weathersfield	3	1960	3620

* Region indicates climatic region

Appendix B- Polyurea and Epoxy Projects in this study

Polyurea										
Year	Project	Project #	Route	Begin MM	Town	End MM	Town	Region*	AADT Low	High
2001	Lyndon-Barton	ACIM 091-3(10)	I 91	137.1	Lyndon	156.1	Barton	2	4200	5400
2003	Brattleboro/Westminster	ACIM 091-1(41)	I-91	11.9	Brattleboro	30.0	Westminster	3	14400	16500
2003	Burlington/South Burlington	IM 189-3(36)	I-189	0.0	Burlington	1.5	S.Burlington	1	N/A	39600
2004	Montpelier/Waterbury SB	ACIM 089-1(39)	I-89	53.1	Montpelier	63.6	Waterbury	2	25100	26300
2004	Montpelier/Waterbury NB	ACIM 089-1(39)	I-89	53.0	Montpelier	62.5	Waterbury	2	25100	26300
Epoxy										
2002	Lyndon-Barton	ACIM 091-3(10)	I-91	137.2	Lyndon	150.7	Barton	2	5100	6400

Appendix C- Cavendish Weatherfield, VT 131 - Westbound Edgeline

Readings	08/22/2002	10/15/2002	03/28/2003	05/23/2003	06/23/2003	07/25/2003	08/14/2003	09/17/2003	11/21/2003	04/16/2004	04/30/2004	05/20/2004	08/02/2004
Test Site 1													
1	396	441	115	127	98	128	174	155	93	71	94	98	135
2	371	432	103	103	140	141	181	178	179	118	145	172	181
3	364	430	113	131	146	174	189	185	175	112	135	162	174
4	355	450	135	134	177	164	189	179	185	122	139	165	175
5	360	428	87	112	138	144	164	189	159	125	155	167	159
Average	369.2	436.2	110.6	121.4	139.8	150.2	179.4	177.2	158.2	109.6	133.6	152.8	164.8
Test Site 2													
1	379	294	215	211	183	194	180	113	110	92	102	129	161
2	366	276	243	121	159	180	166	115	113	103	107	133	141
3	360	305	241	194	126	211	187	114	118	102	102	133	156
4	357	380	144	122	132	138	146	1114	122	109	101	124	148
5	337	378	165	202	124	144	157	119	133	95	105	128	166
Average	359.8	326.6	201.6	170	144.8	173.4	167.2	315	119.2	100.2	103.4	129.4	154.4
Test Site 3													
1	384	406	172	206	184	203	201	158	199	140	130	162	176
2	377	406	229	265	212	248	237	164	234	119	115	150	177
3	371	421	257	364	225	245	228	140	189	112	118	150	175
4	369	419	279	246	242	277	242	157	185	107	112	141	171
5	384	418	260	224	250	260	267	146	189	101	109	132	167
Average	377	414	239.4	261	222.6	246.6	235	153	199.2	115.8	116.8	147	173.2
Test Site 4													
1	379	436	111	74	94	123	107	130	133	101	105	117	127
2	374	407	113	72	96	118	107	124	127	111	116	126	113
3	365	426	94	57	96	114	95	128	128	96	93	101	194
4	380	413	85	55	91	109	96	122	128	102	109	115	121
5	356	418	99	46	85	105	90	123	120	104	107	116	119
Average	370.8	420	100.4	60.8	92.4	113.8	99	123	127.2	102.8	106	115	134.8
Test Site 5													
1	322	353	94	72	109	132	136	135	112	98	125	130	144
2	324	348	95	69	123	125	136	114	119	116	120	127	150
3	301	316	134	80	107	141	142	121	122	95	100	98	138
4	295	277	167	82	129	127	126	128	98	94	104	105	130
5	307	326	157	92	218	198	178	135	160	123	135	145	156
Average	309.8	324	129.4	79	137.2	144.6	143.6	126.6	122.2	105.2	116.8	121	143.6
Average	357.32	384.16	156.28	138.44	147.36	165.72	164.84	178.96	145.2	106.72	115.32	133.04	154.16
Std Dev	27.47	55.31	63.23	80.15	50.56	50.92	48.01	196.16	37.03	13.90	16.39	21.90	21.93

Appendix C - Total readings, White Edge line, Westbound VT131