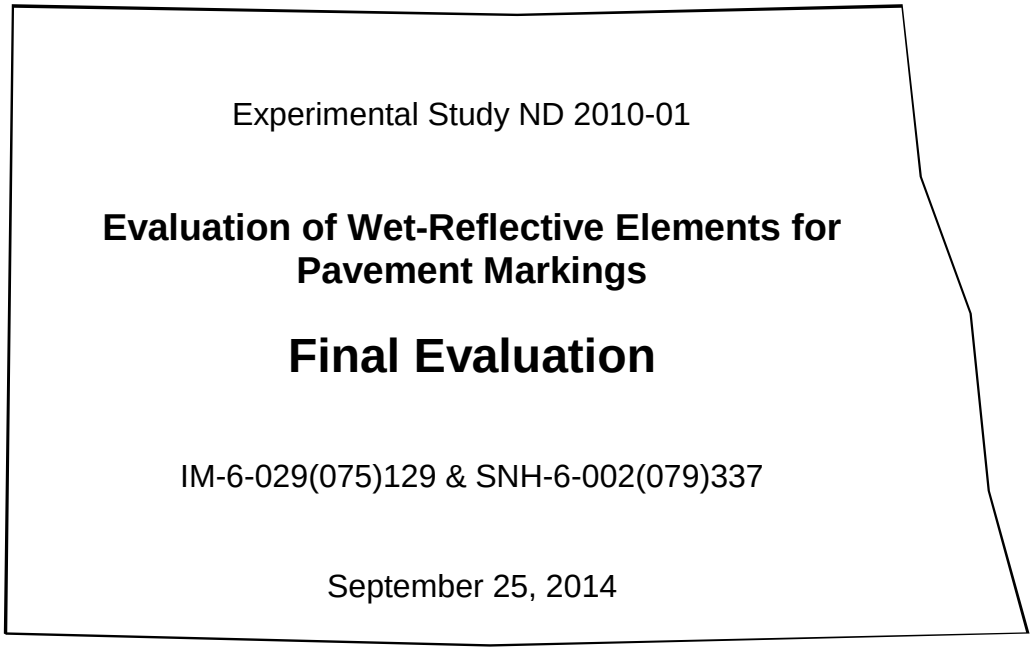
NORTH DAKOTA
DEPARTMENT OF TRANSPORTATION

MATERIALS AND RESEARCH DIVISION



Experimental Study ND 2010-01

Evaluation of Wet-Reflective Elements for Pavement Markings

Final Evaluation

IM-6-029(075)129 & SNH-6-002(079)337

September 25, 2014

Prepared by

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION
BISMARCK, NORTH DAKOTA
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Matthew M. Luger

Disclaimer

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT

EXPERIMENTAL PROJECT NO. (1)

STATE	YEAR		NUMBER	SURF
ND	2010	-	01	

CONSTRUCTION PROJ NO: IM-6-029(075)129; SNH-6-002(079)337

LOCATION (28): I-29/US 2 Grand Forks County

EVALUATION FUNDING (48)

1	HP&R	3	DEMONSTRATION	
2	X CONSTRUCTION	4	IMPLEMENTATION	

NEEP NO. (49):

PROPRIETARY FEATURE? (51): X Yes / No

SHORT TITLE

TITLE (52): Evaluation of Wet-Reflective Elements for Pavement Markings

THIS FORM

DATE (25): MO. September -- YR. 2015

REPORTING: 1 INITIAL 2 ANNUAL 3 X FINAL

KEY WORDS

KEY WORD 1	KEY WORD 2
145 Wet-Reflective Elements	167 Pavement Marking
KEY WORD 3	**KEY WORD 4**
189	211
UNIQUE WORD	**PROPRIETARY FEATURE NAME**
233	255 3M All Weather Pavement Marking

CHRONOLOGY

Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
277 January 2010	281 Fall 2010	285 Fall 2013	289 2014	293 August 2014

QUANTITY AND COST

QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS)	UNITS	UNIT COST (*Dollars, Cents*)
Water-Borne Wet Refl. US 2 169,417	1 X LIN. FT	$0.44
Water-Borne Control US 2	2 SY	$0.09
Water-Borne Wet Refl. I-29 85,952	3 SY-IN	$0.31
Water-Borne Control I-29	4 CY	$0.19
Preformed Tape Wet Refl. I-29 9,833	5 TON	$3.28
Preformed Tape Control I-29	6 LBS	$3.28
	7 EACH	
	8 LUMP SUM	
297	305	306

AVAILABLE EVALUATION REPORTS

CONSTRUCTION	PERFORMANCE	FINAL
315		X

EVALUATION

CONSTRUCTION PROBLEMS		PERFORMANCE	
1 X	NONE	1	EXCELLENT
2	SLIGHT	2	GOOD
3	MODERATE	3	SATISFACTORY
4	SIGNIFICANT	4	MARGINAL
318 5	SEVERE	319 5	UNSATISFACTORY

APPLICATION

320

1	ADOPTED AS PRIMARY STD.	4	PENDING
2	PERMITTED ALTERNATIVE	5	REJECTED
3	ADOPTED CONDITIONALLY	6	NOT CONSTRUCTED

(Explain in remarks if 3, 4, 5, or 6 is checked)

REMARKS

321

The objective of this project is to evaluate the performance of 3M All Weather Pavement Markings on two different projects in the Grand Forks District. Initially, the segments with 3M All Weather Elements performed better than the markings with standard glass beads in both a wet and dry condition. However, after several winter seasons, all surface applied marking have lost most of their wet-night retroreflectivity.

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Definitions

Standard Paint - Water-based paint for pavement marking applications conforming to Section 880 of the North Dakota Standard Specifications.

3M All Weather Paint (AWP) A high build water based paint manufactured by 3M for use with 3M AW Elements.

Standard Glass Beads - Glass beads for pavement marking paint conforming to Section 880 of the North Dakota Standard Specifications (1.5 refractive Index).

3M AW Optics - A material that provides wet-night retroreflectivity with 3M Pavement Marking Products.

3M Elements - A material that consists of 3M AW Optics bonded to a central core. Used to apply wet-night retroreflectivity to liquid markings.

Standard Preformed Patterned Tape (Standard Tape) - preformed patterned tape conforming to section 880 of the North Dakota Standard Specifications.

3M All Weather Tape (AWT) - A preformed patterned tape that incorporates 3M AW Optics.

Evaluation of Wet-Reflective Elements for Pavement Markings

Purpose and Need

The ability of a pavement marking to remain visible at night is due to the retroreflective properties of glass beads. Water on the surface of pavement markings typically reduces the marking's retroreflectivity and may cause pavement markings to become nearly invisible during wet condition. Water on the surface of pavement markings reflects light away from its source and does not allow the glass beads in the pavement marking return light to the driver. To improve a marking's retroreflectivity in all conditions, 3M Company has developed All Weather (AW) Optics to provide retroreflectivity in both dry and wet pavement conditions. These elements can be applied to all types of pavement markings.

Objective

The objective of this experimental project is to evaluate the performance of AW Optics as part of their All Weather Paint System (AWP) and All Weather Tape (AWT), on a roadway in North Dakota in wet and dry conditions. The project will be evaluated annually for three years or until the markings are replaced.

Background

Light is refracted, or bent, as it enters a new medium. A good example is how a fishing pole will appear to bend when it is dipped in clear water. The amount that the light is refracted is known as the refractive index. The most commonly used pavement marking beads have a refractive index of 1.5. The optimum refractive index for dry pavement marking beads is 1.9. However, in order to achieve a higher refractive index, the hardness of the bead must be increased. This can make the glass more brittle and subject to damage. AASHTO M 247 requires glass beads for liquid pavement markings are to have a refractive index between 1.50 to 1.55, to achieve a balance between retroreflectivity and durability. The current North Dakota specifications follow these AASHTO Guidelines.

Water has a different refractive index than air, and therefore a glass bead will need a different refractive index to retroreflect light when wet. The optimum refractive index for a pavement marking bead designed to retroreflect when wet is between 2.4 and 2.5. 3M Company has developed AW Optics that are microcrystalline ceramic material that achieve a refractive index of 1.9 up to 2.4 while maintaining durability.[1] [2]

[1] TRB No. 2015. 2007
[2] 3M Technology Bulletin

Location

NDDOT plans to incorporate wet reflective optics as part of project IM-6-029(075)129 and SNH-6-002(079)337. These projects are located near Grand Forks on I-29 and US 2 respectively. See Figure 1.

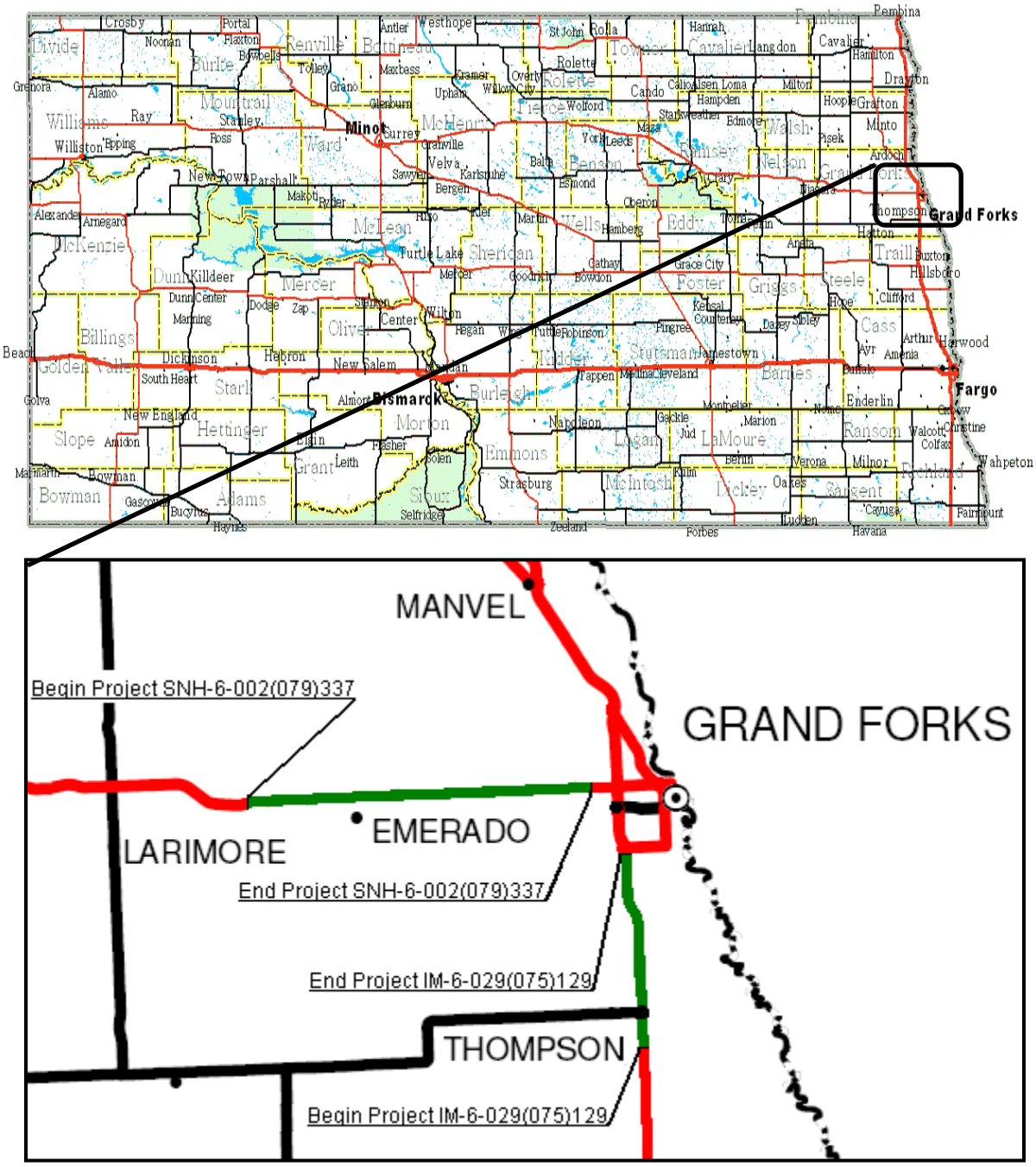

Figure 1

IM-6-029(075)129 - Design

This project consists of the reconstruction of 7.4636 miles of I-29 from RP 129.425 to RP 136.874 on the southbound roadway. The adjacent northbound roadway was also reconstructed in the previous year. Permanent pavement markings will be placed on both roadways at the end of the 2010 construction season as part of project IM-6-029(075)129. Both roadways are constructed with PCC pavement. Grooved preformed patterned pavement markings were placed on the centerline, and surface applied water-based pavement markings were be placed on the edge lines. Standard and AW markings were placed according to Table 1.

Roadway	Location	Segment	Marking Type	Marking Material	AADT
I-29 North Bound	RP 129.4 to RP 133.0	6A Glass	White Center-line	Standard Tape	11,100
		4A Glass	White Edge-line	Standard Water-based Paint with Standard Glass Beads	11,100
		5A Glass	Yellow Edge-line		
	RP 133.0 to RP 136.9	6B AW	White Center-line	AWT	12,800
		4B AW	White Edge-line	AWP with AW Elements	12,800
		5B AW	Yellow Edge-line		
I-29 South Bound	RP 136.9to RP 133.0	3A Glass	White Center-line	Standard Tape	6,620
		1A Glass	White Edge-line	Standard Water-based Paint with Standard Glass Beads	6,620
		2A Glass	Yellow Edge-line		
	RP 133.0 to RP 129.4	3B AW	White Center-line	AWT	6,620
		1B AW	White Edge-line	AWP with AW Elements	6,620
		2B AW	Yellow Edge-line		

Table 1 - I-29 Pavement Marking Design Details

See figure 2 on the following page for a map of the project. Details for the installation of the experimental features were included in the plans by a plan note.

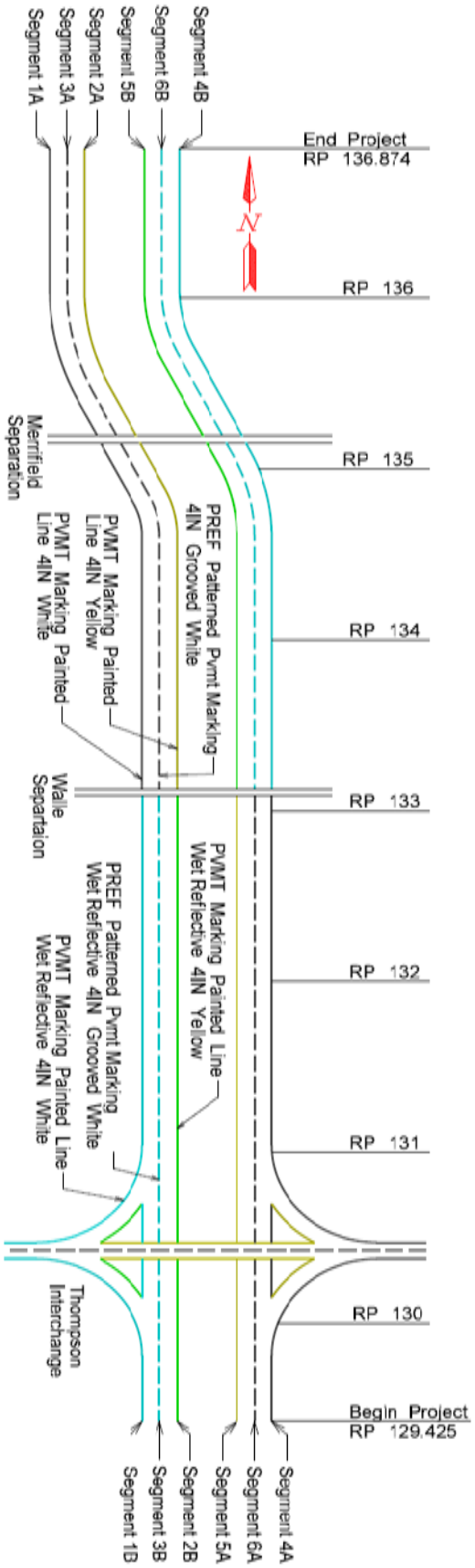

Figure 2 – I-29 Pavement Marking Map

IM-6-029(075)129 - Construction Evaluation

Swanston Equipment Company began the pavement marking application process on September 24, 2010. The curing compound from the new concrete pavement was removed prior to the application of water-based paint. The contractor used a rotomilling machine to accomplish this task. Photo 1 below shows the pavement surface with the curing compound removed for the edge line.

Photo 1 : Cure Removed Prior to Painting

A 3M technical representative, Jason Elsen, was on site to oversee the paint application. Striping for the standard glass bead segments used a truck mounted spraying apparatus equipped with a data logging system. Paint was applied at a 16 mil thickness with a single drop application of standard glass beads (1.5 refractive index). The same truck was used to apply the AWP with AW Elements and the standard paint with standard glass beads. The AWP was applied at a 25 mil thickness. A 'double drop' application was used to apply the retroreflective elements. The first drop is an application of standard glass beads, the second drop is an application of AW Elements. These elements consist of a blend of 1.9 refractive index and 2.4 refractive index microcrystalline ceramic optics bonded to a central core. The AW Elements provide

additional dry retroreflectivity as well as retroreflectivity in a wet condition. Table 2 below details the construction dates and application rates of the painted segments. Segments 3A, 3B, 6A, and 6B are not included because they are preformed patterned tape.

Paint Application								
Segment	1A	1B	2A	2B	4A	4B	5A	5B
Direction	South	South	South	South	North	North	North	North
Type of Optics	Standard Glass Beads	AW Elements	Standard Glass Beads	AW Elements	Standard Glass Beads	AW Elements	Standard Glass Beads	AW Elements
Color	White	White	Yellow	Yellow	White	White	Yellow	Yellow
Date Constructed	9/27	9/27	9/29	9/29	10/14	10/15	10/12	10/12
Paint application Rate (ft/gal)	297.09	195.65	*	*	299.75	191.03	299.52	193.95
Average Thickness Wet (mils)	16.01	24.90	*	*	16.05	25.19	16.05	24.81
Approximate Average Thickness Dry (Mils)	10.57	14.94	*	*	10.59	15.11	10.59	14.89
Average Glass Bead Application Rate (lbs /gal)	8.01	6.46	*	*	8.62	8.11	8.50	6.03
Average AW Elements Application Rate (lbs/gal)	0.00	3.24	*	*	0.00	3.50	0.00	3.32

Table 2 - Construction details of painted segments.
*Information is not available for these segments.

Photo 2 on the following page shows a white edge-line of a water-based paint with standard glass beads; and Photo 3 shows a white edge-line of AWP with AW Elements.

Photo 2 : Southbound White Edge-line with Standard Glass Beads

Photo 3 : Southbound White Edge-line AWP with AW Elements

Both the standard tape and the AWT is manufactured by 3M Company. The standard tape is currently included in the NDDOT Standard Specifications. It is a preformed patterned tape with microcrystalline ceramic optics with a refractive index of 1.5 and 1.9. The AWT contains microcrystalline ceramic optics with a blend of refractive indices to optimize retroreflectivity in all weather conditions. The application process is the same for both products. First, a groove is cut into the existing pavement at 100 mils +/- 10 mils. Then the groove is cleaned to remove debris left behind from the grooving process. All 3M Tape is manufactured with adhesive on the bottom side of the tape. When temperatures were cool, (approx 70° F or less) it is recommended by the manufacturer to apply additional adhesive before placing the tape. The adhesive was applied to the groove with a spray nozzle and allowed a few seconds to become tacky, at which time the tape was placed in the groove. The truck that carried the material was used to apply pressure to insure proper adhesion.

The following photos show a comparison of the two preformed patterned tape materials.

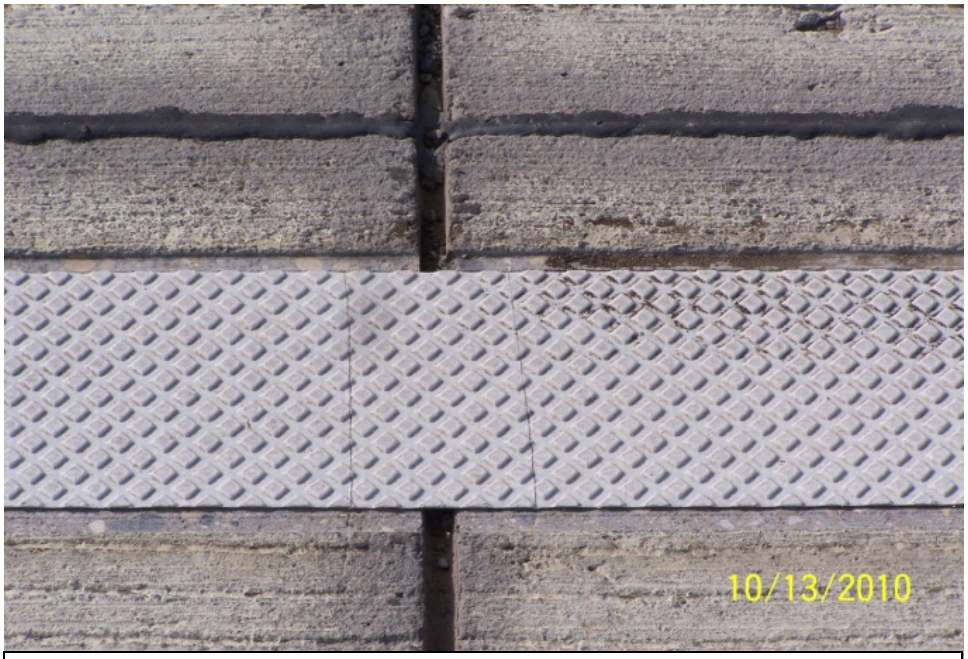

Photo 4 : Southbound Standard Tape

Photo 5 : Southbound 3M AWT

The properties of the AW Optics have an effect on the daytime visibility of the tape. The AW Optics cause the tape to appear off-white in color, closely resembling the color of new PCC pavement. This causes the AWT to blend in with the pavement surface and cause reduced visibility in daylight.

Cost

The AWP and AW Tape have performance properties that cannot be achieved with conventional markings. With these added properties also comes additional cost. A cost comparison is shown in Table 3 below.

Location	IM-6-029(075)129			
Reflective Material	Water-based Paint with Standard Glass	AWP	Tape with Standard Glass	AWT
Bid Price (per LF)	$0.19	$0.31	$3.28	$3.28
Quantity (LF)	88,749	82,952	9,833	9,833
Total Cost	$16,862	$25,715	$32,252	$32,252

Table 3 – Cost from Bid Prices

IM-6-029(075)129 - Final Evaluation

This project was evaluated each spring for 4 years. The project was evaluated visually for distresses and with a Delta LTL 2000 Retrometer for nighttime retroreflectivity. The focus of this research is to compare how the 3M All-Weather Paint System (AWP) performs compared to standard water-based with standard glass beads, and how 3M All Weather Tape (AWT) performs compared to Standard Tape in wet and dry conditions.

Water-based Paint

As described in the design section, water based paint was placed on both white and yellow edge-lines in the northbound and southbound directions. All of the water-based markings are surface applied. After four years of service, the markings are showing signs of significant distress. However, considering that it is NDDOT policy to restripe water-based paint every year, these markings have performed very well throughout their lifespan in both the standard paint and AWP sections.

Photo 6 – White Water-based Paint Southbound – Standard Paint – 6/3/14

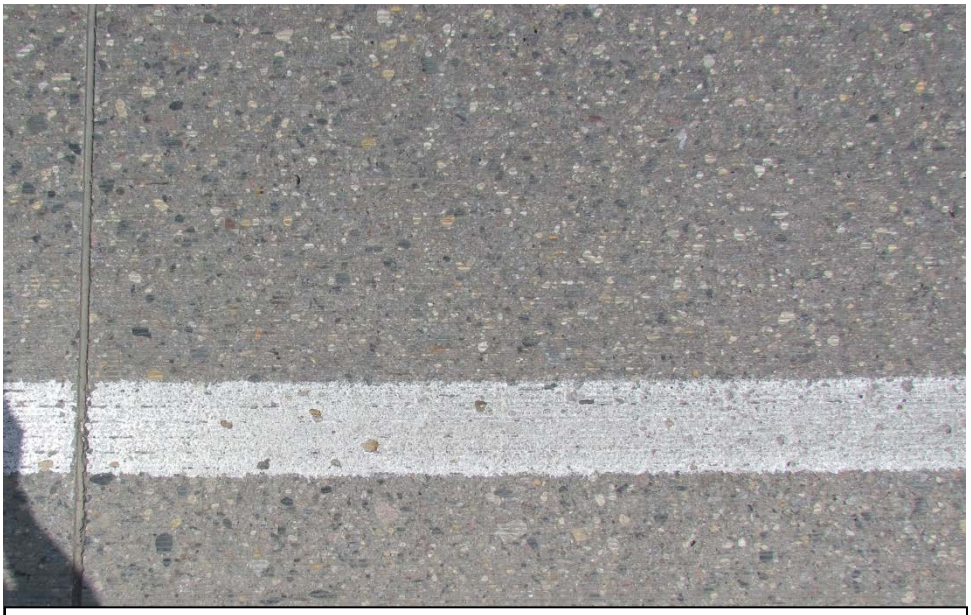

Photo 7 – White Water-based Paint Southbound - AWP – 6/3/14

Photos 6 &7 above show the differences in distress of the white edge-lines. The AWP is showing less distress than the control section. The high build formulation may be more durable than the formulations required by current NDDOT Specifications. Also, the AWP was applied at 25 wet mils, and the control section was applied at 16 wet mils. The additional material may have given the marking an extended service life. A similar effect is visible on the yellow edge-lines below. See Photos 8 & 9.

Photo 8 – Yellow Water-based Paint Southbound – Standard Paint – 6/3/14

Photo 9 – Yellow Water-based Paint Southbound - AWP – 6/3/14

A distress that is not as visible in the photographs is the loss and damage to the AW Elements. The AW Elements are relativity large (approximately 50 mil diameter) which exposes them at least 25 mils above the surface of the pavement marking and to greater impact from snow plows. After the first winter, and largely after the subsequent winters, the AW Elements were damaged in one of three ways. One, the microcrystalline beads were stripped from the central core; two, the core was sheered in half at the interface of the pavement marking; or three, the entire AW Element was stripped from the roadway. The effect of the snowplows on the AW Elements is most evident in the retroreflectivity data collected.

Retroreflectivity readings were collected with a Delta Light and Optics LTL 2000 Portable Retrometer. This device conforms to ASTM D 4061: *Standard Test Method for Retroreflectance of Horizontal Coatings.* Readings were collected in a dry and wet condition. Wet readings were collected according to ASTM E 2177 *Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (R_L) of Pavement Markings in a Standard Condition of Wetness.* This test dictates to spray the markings with water until saturated (30 sec) and waiting a specified amount of time (45 sec) before taking a reading.

Data was collected at three reference points in each segment of the project. Ten dry readings and five wet readings were collected at each reference point. The

following charts show the average retroreflectivity for the white and yellow edge-lines. The charts compare wet to dry readings of each line type. The charts also show how the retroreflectivity changed over time. Although NDDOT does not currently have a minimum retroreflectivity value for water-based paint, for reference, the NDDOT requires that new epoxy pavement markings meet a minimum dry retroreflectivity of 180 mcd/m^2/lux for yellow and 275 mcd/m^2/lux for white at the time of construction. Other states use a dry reading of 100 mcd/m^2/lux as a value to begin planning replacement of the line. There currently are no standards for what is considered an acceptable reading in a wet condition.

I-29 Southbound White Edge-line Paint RL (mcd/m2/lux)											
Material Type	Date	Initial (Fall 2010)		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Location	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standard Paint with Standard Glass (Section 1A)	RP 136	256	11	105	4	57	2	46	2	38	2
	RP 135	313	13	137	4	72	1	53	1	33	3
	RP 133.9	337	18	148	6	89	2	63	2	35	7
3M AWP (Section 1B)	RP 132	450	161	265	41	148	12	132	6	93	11
	RP 131	523	198	297	38	175	13	136	6	103	5
	RP 130	558	200	349	36	195	11	-	-	103	6

Table 4A

I-29 Northbound White Edge-line Paint RL (mcd/m2/lux)											
Material Type	Date	Initial (Fall 2010)		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Location	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standard Paint with Standard Glass (Section 4A)	RP 130	495	33	308	5	147	3	136	2	98	6
	RP 131	471	22	295	2	142	2	142	2	79	2
	RP 132	466	36	286	10	143	2	128	2	90	5
3M AWP (Section 4B)	RP 134	673	292	437	65	238	24	239	17	178	29
	RP 135	532	276	297	20	179	8	143	14	129	5
	RP 136	468	188	288	14	159	9	131	5	114	6

Table 4B

The retroreflectivity data shows that the AWP has higher readings in most circumstances throughout the study. Initially, and for the first spring reading (2011), the AW Elements provided the increased dry retroreflective readings and higher wet readings. In the subsequent years, the AW Elements experienced accumulated damage from plows and the difference between the two types of materials became smaller. By the end of the evaluation, the difference in retroreflectivity can be more attributed to the difference in durability than to the use of the AW Optics.

I-29 Southbound Yellow Edge-line Paint RL (mcd/m2/lux)											
Material Type	Date	Initial (Fall 2010)		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Location	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standard Paint with Standard Glass (Section 2A)	RP 136	225	35	186	18	117	11	88	12	76	10
	RP 135	249	21	204	32	127	5	91	9	89	11
	RP 133.9	200	37	186	15	127	8	90	10	87	7
3M AWP (Section 2B)	RP 132	385	308	309	143	226	71	131	63	160	35
	RP 131	327	308	341	126	212	51	162	54	151	35
	RP 130	375	292	395	166	264	51	-	-	179	28

Table 5A

I-29 Northbound Yellow Edge-line Paint RL (mcd/m2/lux)											
Material Type	Date	Initial (Fall 2010)		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Location	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standard Paint with Standard Glass (Section 5A)	RP 130	357	19	246	28	147	7	91	13	82	8
	RP 131	315	13	207	6	109	4	80	5	63	4
	RP 132	344	6	246	5	166	5	150	4	130	6
3M AWP (Section 5B)	RP 134	452	90	340	114	254	50	205	11	130	11
	RP 135	486	154	266	56	186	21	150	21	129	4
	RP 136	571	88	404	135	341	49	228	33	205	25

Table 5B

Preformed Patterned Tape

Preformed Patterned Tape is placed on the centerline of both the northbound and southbound roadways. All of the Preformed Patterned Tape markings are placed in a 100 mil groove. The southbound markings consist of standard tape (3M IES) as a control section and AWT (Generation 1) as a test section. The northbound markings consist of standard tape (3M IES) as a control section and AWT (Generation 2) as a test section. During the process of the final evaluation, it was discovered that the AWT Generation 1 was directional. That is,it had higher retroreflectivity in one direction than the other. In this project, the tape was placed so that the lower retroreflectivity values were in the direction of travel. The retroreflectivity data reported is the retroreflectivity in the direction of travel. 3M Company stated that it is aware of this occurrence with 3M AWT Generation 1 and that the material is no longer available. The photos below shows the 3 types of tape in June of 2014.

Photo 10 – Standard Tape – Control Section – 6/3/14

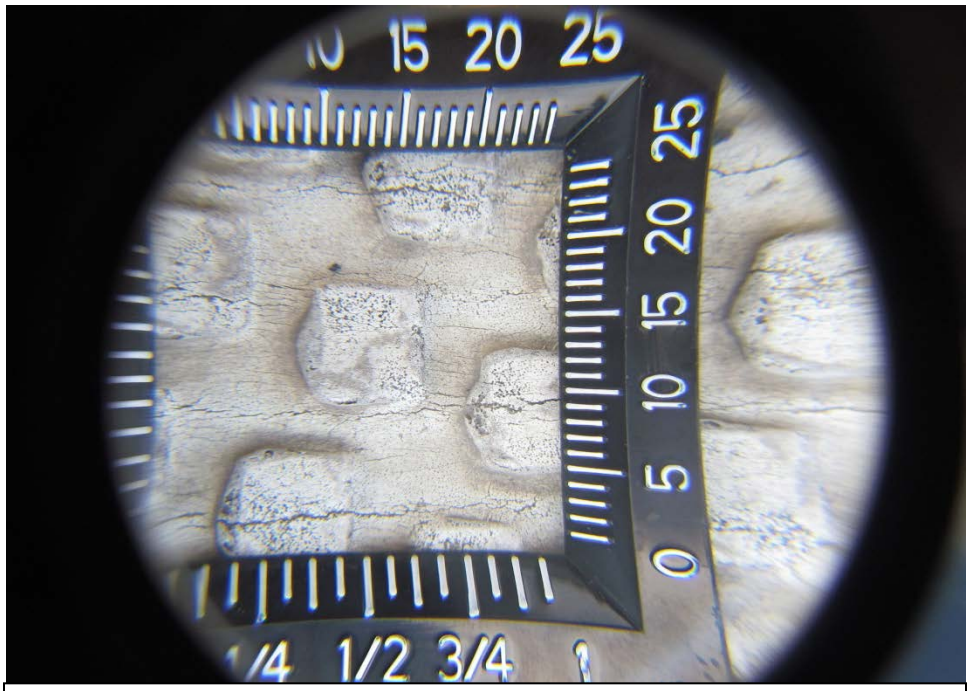

Photo 11 – 3M AWT (Generation 1) – 6/3/14

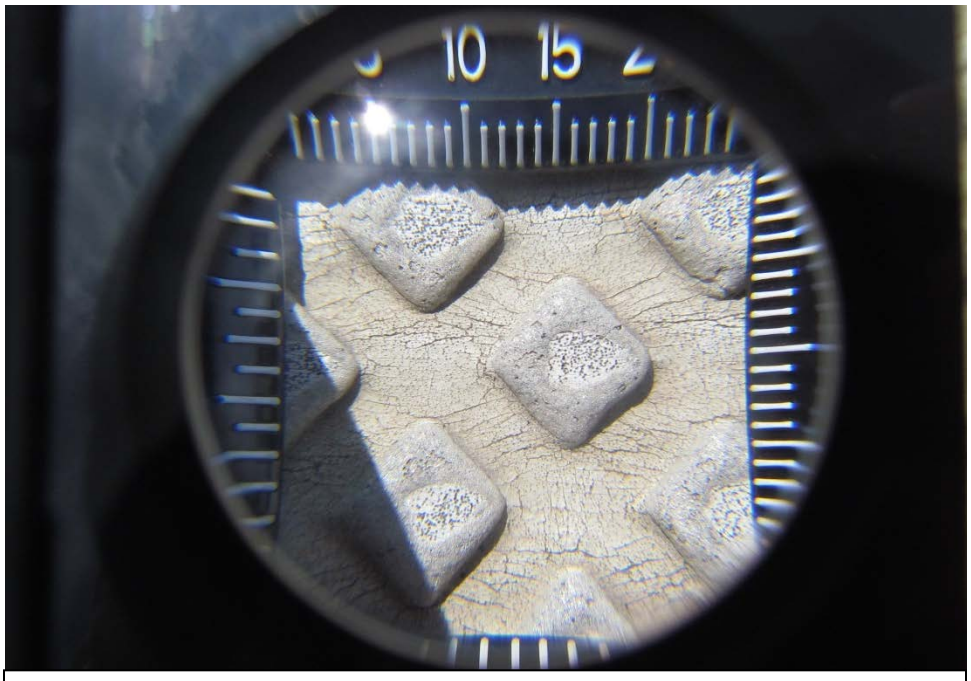

Photo 12 – 3M AWT (Generation 2) – 6/3/14

Visual observations of all three types of tape showed very little differences between the tape in the daytime. The AWT sections are slightly more off-white than the control sections. The off-white nature of the AWT was present at the time of construction. It is the color of the tape and not a function of weathering or yellowing due to UV light. The off-white color can cause AWT to be slightly less visible in the daylight than the control tape because it is a similar color to PCC pavement. 3M is aware of this also, and offers a 'Contrast Tape' to address this problem (See NDDOT study ND 2011-01 for more information on Contrast Tape). The differences between the three types of tape are more apparent when retroreflectivity data is considered.

I-29 White Center-line Tape Southbound RL (mcd/m2/lux)											
Material Type	Date	Initial (Fall 2010)		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Location	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standard Tape (Control) (Section 3A)	RP 136	285	49	940	34	821	35	701	20	315	37
	RP 135	359	87	1005	28	824	38	643	36	300	23
	RP 133.9	369	2	1054	60	890	58	750	64	343	29
3M AWT (Generation 1) (Section 3B)	RP 132	300	446	1108	340	449	80	153	32	124	23
	RP 131	245	308	1019	269	462	125	252	48	182	33
	RP 130	361	375	1195	389	590	153	-	-	195	30

Table 6A

I-29 Northbound White Center-line Tape RL (mcd/m2/lux)											
Material Type	Date	Initial (Fall 2010)		Spring 2011		Spring 2012		Spring 2013		Spring 2014	
	Location	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Standard Tape (Control) (Section 6A)	RP 130	812	22	1009	89	964	28	964	89	744	47
	RP 131	853	118	1045	63	926	62	819	71	613	29
	RP 132	832	59	961	52	864	64	829	56	613	58
3M AWT (Generation 2) (Section 6B)	RP 134	870	519	801	505	648	279	569	215	512	139
	RP 135	790	440	848	447	721	194	554	186	498	131
	RP 136	638	260	844	591	770	425	711	305	725	232

Table 6B

After a quick review of the data above, the first question usually asked is ‘How can the retroreflectivity after one winter be higher than the initial readings?’ 3M has supplied an explanation. During the manufacturing process, and during storage (in a roll), a trace amount of free adhesive may remain attached to the reflective optics on the surface of the tape. Any free adhesive will collect dust and produce lower readings. After the marking is exposed to traffic and weather for a period of time (but protected from snowplows by the groove) the dust and free adhesive is removed from the optics leaving highly retroreflective tape in place.

While all markings are still performing well, a reduction in retroreflectivity has been observed each year.

SNH-6-002(079)337 - Design

This project consists of a hot bituminous overlay of 17.399 miles of westbound US 2 from Arvilla to Grand Forks. This project is divided into four test segments. All of the pavement marking is surface applied water-based paint and was applied according to Table 7 below. Details for the installation of the experimental features were included in the plans by a plan note.

Roadway	Location	Marking Material	Marking Type	AADT
US 2	Beginning of Project (RP 337.325) to RP 340	Pavement Marking Paint	Yellow Edge-line, White Center-line, White Edge-line, 8in White Channel Line, & Messages	4,440
	RP 340 to RP 347	3M AWP with Series 90 Wet Reflective Elements	Yellow Edge-line, White Center-line, White Edge-line, 8in White Channel Line, & Messages	4,440
	RP 347 to RP 351	'Pavement Marking Paint	Yellow Edge-line, White Center-line, White Edge-line, 8in White Channel Line, & Messages	4,440
	RP 351 to End of Project (RP 354.724)	3M AWP with Series 90 Wet Reflective Elements	Yellow Edge-line, White Center-line, White Edge-line, 8in White Channel Line, & Messages	4,440

Table 7 - US 2 Pavement Marking Design Details

Cost

A cost comparison is shown in Table 8 below.

Location	**SNH-6-002(079)337**	
Material	Water-based Paint with Standard Glass	AWP
Bid Price (per LF)	$0.09	$0.44
Quantity (LF)	79,297	169,417
Total Cost	$6,899	$73,696

Table 8 – Cost from Bid Prices

SNH-6-002(079)337 - Construction Evaluation

Swanston Equipment Company applied the pavement markings during the week of August 15, 2011. Jason Elsen of 3M was available during construction to ensure that the wet reflective elements were applied correctly. All segments on this project were surface applied water-based paint. The table below details the construction dates and application rates as recorded by the data logging system on-board the striping truck.

Paint Application US 2					
Line Type	White Edge-line	White Edge-line/ Center-line	White Center-line	Yellow Edge-line	Yellow Edge-line
Type of Optics	3M	Standard Glass	3M	Standard Glass	3M
Date Constructed	8/18	8/18	8/17	8/19	8/16
Paint application Rate (ft/gal)	271	296	166	299	196
Average Thickness Wet (mils)	25.6	16.1	28	16.6	25.8
Average Glass Bead Application Rate (lbs /gal)	9.03	6.5	6.72	6.26	6.42
Average 3M All Weather Elements Application Rate (lbs/gal)	3.15	_	2.85	_	2.17

Table 9 - US 2 Pavement Marking Application Details

The markings appeared uniform and no visual defects were detected except in the following two locations. First, rumble strips that were out of alignment affected a section of about 0.25 miles on the yellow edge-line as it passes beneath the Emerado Interchange. The alignment caused the support wheels of the paint and bead gun apparatus to roll over the rumble strips. This in turn caused the spray apparatus to bounce which may cause uneven thickness in paint and distribution of beads and AW Elements. Second, about 1,000 ft of the white edge-line was tracked near RP 354. No retroreflectivity readings were recorded at these locations. With the exception of the above issues, the construction of the markings occurred without incident. Photos 13 and 14 below show a typical yellow line and a typical white line from this project.

Photo 13: Westbound Yellow AW Paint with AW Elements

Photo 14: Westbound White AW Paint with AW Elements

SNH-6-002(079)337 - Final Evaluation

The US 2 project was evaluated each spring after construction. The first evaluation was on June 5, 2012. After one winter, the pavement markings were showing significant distress. As shown in photo 15 below, a segment of the white edge-line was nearly undetectable. The white edge-line was restriped following the evaluation because of the extent of damage from snow plow operations.

Photo 15: Damaged White Edge-line AWP with AW Elements

The white center-line and yellow edge-line were performing better but were still showing signs of distress. Photo 16 shows a segment of yellow AWP with AW Elements. The white/cream dots on the line are what remains of the AW Elements. The AW Elements were sheared in half from the snow plows, exposing the white core of the AW Elements. All segments on US 2 with AW Elements showed similar distress.

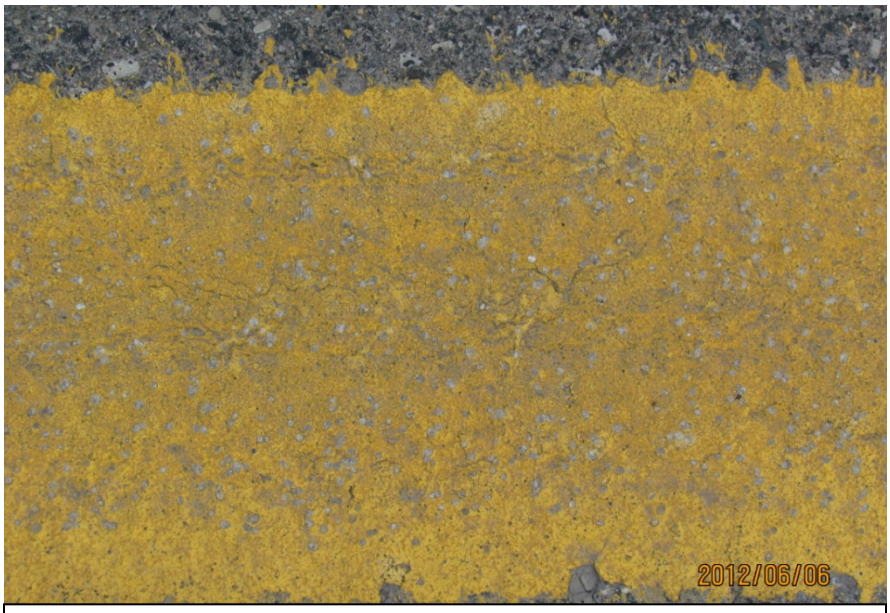

Photo 16: Yellow AWP with Sheared AW Elements

After two winters the pavement markings on US 2 continued to deteriorate. The centerline and yellow edge-line looked similar to how the white edge-line did during the first evaluation. See Photo 17.

Photo 17: Yellow AWP after two winters.

Retroreflectivity readings were collected using the same methods as previously described for the I-29 segments. Twelve test locations were selected for retroreflectivity testing, each at a reference point. Six reference points are located in the control segments and six reference points are located in segments with AW Elements. Five dry readings and three wet readings were collected at each test location on the edge-lines. Four dry readings and two wet readings were collected at each location on the center-lines. The average readings for each line test location and line type are shown in Table 10A, 10B and 10C.

The data shows that initially, the AWP with AW Elements performed better than the control section with standard glass beads in both a wet and dry condition. However, each line in each segment has seen degradation of the retroreflectivity after each winter. The AWP segments with AW Elements seem to have lost their wet-night retroreflective properties.

US 2 White Edge-line RL (mcd/m2/lux)							
Material Type	Date	9/15/2011		6/5/2012		6/26/2013	
	Location	Average Dry	Average Wet	Average Dry	Average Wet	Average Dry	Average Wet
Standard Water-Based Paint with Standard Glass	RP 337.5	376	16	201*	11*	**	**
	RP 338	384	31	130*	7*	**	**
	RP 339	395	20	124*	6*	**	**
	RP 348	353	36	169*	5*	**	**
	RP 349	322	63	189*	4*	**	**
	RP 350	314	34	178*	4*	**	**
AWP with AW Elements	RP 342	516	411	200*	5*	**	**
	RP 344	651	460	212*	3*	**	**
	RP 346	561	482	384*	49*	**	**
	RP 352	306	336	***	***	**	**
	RP 353	402	266	220*	44	**	**
	RP 354	274	178	113*	3*	**	**

Table 10A

*Test locations were adjusted due to damage to the line.

**Tests were not conducted because the line was restriped.

***Tests were not conducted due to extensive damage to the line.

US 2 Yellow Edge-line RL (mcd/m2/lux)							
Material Type	Date	9/15/2011		6/5/2012		6/26/2013	
	Location	Average Dry	Average Wet	Average Dry	Average Wet	Average Dry	Average Wet
Standard Water-Based Paint with Standard Glass	RP 337.5	259	27	79	13	62	6
	RP 338	299	16	128	7	76	2
	RP 339	277	18	149	5	97	5
	RP 348	221	12	119	2	83	5
	RP 349	273	17	128	7	59	4
	RP 350	258	18	157	2	82	6
AWP with AW Elements	RP 342	433	381	178	29	133	14
	RP 344	357	235	174	14	113	7
	RP 346	378	176	194	14	125	7
	RP 352	441	300	168	14	86	7
	RP 353	339	224	144	10	120	19
	RP 354	283	165	110	4	69	9

Table 10B

US 2 White Center-line RL (mcd/m2/lux)							
Material Type	Date	9/15/2011		6/5/2012		6/26/2013	
	Location	Average Dry	Average Wet	Average Dry	Average Wet	Average Dry	Average Wet
Standard Water-Based Paint with Standard Glass	RP 337.5	362	31	95	13	77	5
	RP 338	363	21	87	7	76	10
	RP 339	333	25	155	5	54	5
	RP 348	287	12	164	8	134	4
	RP 349	282	12	86	2	75	8
	RP 350	319	25	167	16	81	8
AWP with AW Elements	RP 342	620	247	127	5	69	9
	RP 344	596	240	260	24	176	10
	RP 346	583	119	342	53	262	35
	RP 352	315	148	159	21	120	25
	RP 353	503	197	134	8	109	12
	RP 354	311	106	118	2	72	4

Table 10C

After two winters, US 2 was scheduled to be restriped and the research was terminated for this roadway.

Summary

The objective of this project is to evaluate the performance of 3M All Weather Pavement Markings on PCC and Asphalt Pavements. The pavement marking types selected were standard water-based paint with standard glass beads as a control, 3M All Weather Paint (AWP) with AW Elements, standard preformed patterned tape as a control, and 3M All Weather Preformed Patterned Tape (AWT). Water-based paint was surface applied on the edge-lines and preformed patterned tape was placed in a 100 mil groove on the centerlines on a PCC pavement on I-29 south of Grand Forks. Water-based paint was also surface applied on the edge-lines and center lines on an asphalt pavement on US 2 west of Grand Forks.

Surface Applied Water-based Paint on PCC Pavement

ND 2010-01 I-29 Average Retroreflectivity of White Edge-line Paint (mcd/m2/lux)				
Date Tested	Control		AWP with AW Elements	
	Dry	Wet	Dry	Wet
Initial (Fall 2010)	390	22	534	219
Spring 2011	213	6	323	36
Spring 2012	109	2	183	13
Spring 2013	95	2	152	9
Spring 2014	62	4	120	10

ND 2010-01 I-29 Average Retroreflectivity of Yellow Edge-line Paint (mcd/m2/lux)				
Date Tested	Control		AWP with AW Elements	
	Dry	Wet	Dry	Wet
Initial (Fall 2010)	282	22	433	207
Spring 2011	213	18	343	123
Spring 2012	133	7	248	49
Spring 2013	98	9	170	40
Spring 2014	88	8	171	23

- Initial Retroreflectivity Tests
  - The white control section averaged 27% lower dry retroreflectivity and 90% lower wet retroreflectivity than the AWP with AW Elements.
  - The yellow control section averaged 35% lower dry retroreflectivity and 89% lower wet retroreflectivity than the AWP with AW Elements.
- After One Winter
  - The white control section retained 55% of its dry retroreflectivity (Control section wet retroreflectivity is minimal). White AWP with AW Elements retained 60% of its dry and 16% of its wet retroreflectivity.

  - The yellow control section retained 75% of its dry retroreflectivity (Control section wet retroreflectivity is minimal). Yellow AWP with AW Elements retained 79% of its dry and 59% of its wet retroreflectivity.

- After 4 Years
  - The white control section averaged 48% lower dry retroreflectivity than the AWP with AW Elements.
  - The control section retained 16% of its initial dry retroreflectivity. The AWP with AW Elements retained 23% of its initial dry and 5% of its initial wet retroreflectivity.
  - The yellow control section averaged 49% lower dry retroreflectivity than the AWP with AW Elements.
  - The control section retained 31% of its initial dry retroreflectivity. The AWP with AW Elements retained 40% of its initial dry and 11% of its initial wet retroreflectivity.
- The AWP was applied at a higher application rate than the control section (25 mils vs 16 mils). The additional paint thickness may have enhanced the durability of the marking.
- The bid price was $0.31 per Linear Foot (LF) for the AWP with AW Elements, and $0.19 per LF for the control section.

Grooved Preformed Patterned Tape on PCC Pavement

Average Retroreflectivity of White Center-Line Tape (mcd/m2/lux) [ND 2010-01 I-29]								
Date Tested	North Bound				South Bound			
	Control		AWT		Control		AWT	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Initial (Fall 2010)	832	66	766	406	338	46	302	376
Spring 2011	1005	68	831	514	1000	41	1107	333
Spring 2012	918	51	713	299	845	44	500	119
Spring 2013	871	72	611	236	698	40	203	40
Spring 2014	657	45	578	168	319	30	167	28

- Initial retroreflectivity tests were lower than the retroreflectivity tests after one winter. 3M has offered that sometimes free adhesive remaining on the marking collects dirt. Traffic and precipitation events over the first year remove this adhesive and the dirt. The highest recorded retroreflectivity values are used for the following comparisons.
    - The northbound control section averaged 21% higher dry retroreflectivity and 87% lower wet retroreflectivity than the northbound AWT.
    - The southbound AWT (Generation 1) performed similarly to the southbound control section, but Generation 1 AWT is no longer available from 3M; consequently, no useful data was obtained from a comparison of these sections.
- After 4 Years
    - The northbound control section averaged 14% higher dry and 73% lower wet retroreflectivity than the northbound AWT. The control section retained 65% of its initial dry retroreflectivity. The AWT retained 70% of its dry and 33% of its wet retroreflectivity.
- The bid price for both AWT and the control tape was $3.28 per LF.

Surface Applied Water-based Paint on Asphalt Pavement

Average Retroreflectivity of White Edge-line Paint (mcd/m2/lux) [ND 2010-01 I-29]				
Date Tested	Control		AWP with AW Elements	
	Dry	Wet	Dry	Wet
Initial (Fall 2011)	357	33	452	356
Spring 2012	165	6	226	21
Spring 2013	-	-	-	-

Average Retroreflectivity of White Center-line Paint (mcd/m2/lux) [ND 2010-01 I-29]				
Date Tested	Control		AWP with AW Elements	
	Dry	Wet	Dry	Wet
Initial (Fall 2011)	324	21	488	176
Spring 2012	125	9	190	19
Spring 2013	83	7	135	16

ND 2010-01 I-29 Average Retroreflectivity of Yellow Water-Based Paint (mcd/m2/lux)				
Date Tested	Control		AWP with AW Elements	
	Dry	Wet	Dry	Wet
Initial (Fall 2011)	265	18	372	247
Spring 2012	127	6	161	14
Spring 2013	76	5	108	11

- Initial Retroreflectivity Tests
  - The white edge-line control section averaged 21% lower dry retroreflectivity and 91% lower wet retroreflectivity than the AWP with AW Elements.
  - The white center-line control section averaged 34% lower dry retroreflectivity and 88% lower wet retroreflectivity than the AWP with AW Elements.
  - The yellow edge-line control section averaged 29% lower dry retroreflectivity and 93% lower wet retroreflectivity than the AWP with AW Elements.
- After One Winter
  - Snowplow operations heavily damaged the white edge-line in both the control section and the AWP with AW Elements. Retroreflectivity readings were collected where possible. The white edge-line was restriped following the evaluation.

  - The white center-line control section retained 39% of its dry retroreflectivity (Control section wet retroreflectivity is minimal). White center-line AWP with AW Elements retained 39% of its dry and 11% of its wet retroreflectivity.
  - The yellow edge-line control section retained 48% of its dry retroreflectivity (Control section wet retroreflectivity is minimal). Yellow edge-line AWP with AW Elements retained 43% of its dry and 6% of its wet retroreflectivity.
- After 2 Years
  - The white center-line control section averaged 38% lower dry retroreflectivity than the AWP with AW Elements.
  - The control section retained 26% of its initial dry retroreflectivity. The AWP with AW Elements retained 28% of its initial dry and 9% of its initial wet retroreflectivity.
  - The yellow edge-line control section averaged 29% lower dry retroreflectivity than the AWP with AW Elements.
  - The control section retained 29% of its initial dry retroreflectivity. The AWP with AW Elements retained 29% of its initial dry and 4% of its initial wet retroreflectivity.
- The bid price was $0.44 per LF for the AWP with AW Elements and $0.09 per LF for the control section.