INTERIM REPORT ON MEMBRANE SYSTEMS PERFORMANCE

as part of the

VTRANS RESEARCH PROJECT NO. SPR 961 BRIDGE DECK DURABILITY EVALUATIONS

April, 2005

State of Vermont
Agency of Transportation
Materials and Research

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Date: April 15, 2005

TECHNICAL REPORT STANDARD TITLE PAGE

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

4. Title and Subtitle	5. Report Date
INTERIM REPORT ON MEMBRANE SYSTEMS PERFORMANCE AS PART OF THE VTRANS RESEARCH PROJECT NO.: SPR 961 - BRIDGE DECK DURABILITY EVALUATIONS	April, 2005
	6. Performing Organization Code
7. Author(s) Alejandro Fuentes	8. Performing Organization Report No.
9. Performing Organization Name and Address Vermont Agency of Transportation Materials and Research Section National Life Building. Drawer 33 Montpelier, VT 05633-5001	10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Highway Administration Division Office Federal Building Montpelier, VT 05602	13. Type of Report and Period Covered October 2004–November 2004 14. Sponsoring Agency Code

15. Supplementary Notes

This report covers the first half of phase II – "*An Evaluation of Membrane System Performance*" of the Bridge Deck Durability Evaluations study

16. Abstract

This report describes the intent and procedures of phase II. The project's goal is to provide systematic research into the components affecting the superstructure durability in Vermont settings for consideration by VTrans designers. The work will build on existing research projects to provide a clearer picture of material stressors. Each phase of the project will be self supporting but will be suitable for compilation into an Agency position on design, construction and maintenance practices for durable superstructures. The project is anticipated to be subjected to periodic addition of phases to address emerging issues. Existing baseline research components already underway which are taken for incorporation into the project include: ASR Susceptibility of VT Aggregates, Corrosion Studies of VT Bridge Decks and three earlier studies of membranes suitable for updating with current products.

17. Key Words	18. Distribution Statement
Membrane, Sheet, Tar Emulsion, Epoxy, Torch	No restrictions

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

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

INDEX OF TABLES

“The information contained in this report was complied for the use of the Vermont Agency of Transportation. Conclusions and recommendations contained herein are based upon the research data obtained and the expertise of the researchers, and are not necessarily to be construed as Agency policy. This report does not constitute a standard, specification, or regulation. The Vermont Agency of Transportation assumes no liability for its contents or the use thereof.”.”

INTERIM REPORT ON MEMBRANE SYSTEMS PERFORMANCE AS PART OF THE VTRANS RESEARCH PROJECT NO. SPR 961 - BRIDGE DECK DURABILITY EVALUATION

INTRODUCTION

Since 1972 almost every concrete bridge deck in Vermont has been designed with a waterproofing protective membrane system and a bituminous overlay. Up until 1998, these membranes have been primarily pre-formed sheet products. However, other materials such as Tar Emulsion Membranes and Torch applied Membranes have also been used. The maintenance forces and construction personnel have usually reported in many states, including the State of Vermont, that the condition of the bridge deck when placing the membrane system is critical to the successful performance of the membrane and the deck's life. Thus it is hypothesized that chloride penetration is the greatest at the curb and at the negative moment areas over a pier while it is minimal at the centerline or highpoint.

Most old bridges in Vermont do not have significant negative moments due to their length and the thickness of the concrete decks. In some cases these decks have a thickness in excess of 7-1/2" above piers on longer bridges, with an expected life-span of 50 to 70 years. Today's engineering advances have improved the construction processes, materials and design techniques yet several of newer bridges show concrete deterioration. Some explanations include ASR (Alkali Silica Reactivity), Ettringite formation, Carbonation (loss of Alkali) or ACR (Alkali Carbon Reactivity) and corrosion of the reinforcement. The goal of this study is to quantify these conditions.

This report refers to the Phase II – "An Evaluation of Membrane System Performance" as part of the VTrans Research Project No. SPR 961- Bridge Deck Durability Evaluation. The study was initiated in 2002 by the Vermont Agency of Transportation (VTrans) Research Advisory Council (RAC) to provide systematic research into the components affecting the superstructure durability for consideration by VTrans' designers. This study proposes to evaluate the durability of bridge concrete decks according to the type of waterproofing membrane used as protection. The information will be used to improve on existing building methods and to aid in the selection of the most durable and cost effective deck protection systems. An effective system will lengthen the service life of the bridges and save in reconstruction and or repair costs.

PROJECT DESCRIPTION

This report describes the implementation of Phase II in the field and in the laboratory. The project consists on a systematic completion of research into components affecting superstructure durability in Vermont settings. The work builds on existing research projects to provide a clearer picture of the stresses that materials encounter. Each phase of the project is self supporting and suitable for compilation into an Agency position on Design as well as on Construction and Maintenance Practices for durable superstructures. This project is anticipated to be subjected to periodic addition of phases to address emerging issues. Existing baseline research components already underway which are planned for incorporation into the project include ASR Susceptibility of VT Aggregates, Corrosion Studies of VT Bridge Decks and three earlier studies of membranes suitable for updating with current products. The Sampling Protocol provides a detailed description of the sampling procedures. Phases of the Project are depicted in Table1 - Phase Descriptions.

Phase No.	Phase Description
I	A Supplemental Investigation of Bridge Deck Corrosion for the Distribution of Sodium and Chloride Ions
II	An Evaluation of Membrane System Performance
III	A Review of Cathodic Protection Systems for Reinforcing and Structural Steels in VT
IV	An Evaluation of Silanes and Other Chemical Sealers for Continuous Span Bridges
V	An Updated Report on the Performance of Membrane Systems for Bridge Decks (Lab and Field)
VI	A Review of Deicing Strategies for Long Span Structures

Table 1- Phase Descriptions

In addition, a nation wide survey was started. Twenty-eight (28) states have been contacted requesting them to provide information regarding their use of membranes, their specifications; material suppliers as well as their experience with epoxy coated concrete rebar, and epoxy overlays or other types of overlays. This survey will allow all states to address a common set of questions and provide a more comprehensive picture of the use and application of waterproofing membranes.

EXPERIMENT SETUP

The focus of this study is the various types of waterproofing membrane protection systems that have been installed as part of the bridge rehabilitation projects. The bridges selected were grouped by type of waterproofing membrane and then using a random log proportional selection. Other parameters such as bridge type, the weather on the day of deck pour/ membrane, sample location on the bridge deck, the AADT (Annual Average Daily Traffic), vehicle weights and age of bridge deck were also identified as factors for consideration in selecting bridges for this study.

Selection of Laboratory Tests

Initially only concrete strength testing was considered among the selected tests. However, it was later excluded on the grounds that it had no bearing on this part of the study. Table 2 shows the selected tests for the study.

Lab (L) or Field (F)	Type of Test Petrography (P), Chemical (C), Physical (f), Electrical (E)	Test Name
L	P	ASR Alkali Silica Reactivity
L	P	ACR –Alkali Carbon Reactivity
L	P	ETTRINGITE Formation
L	C	CHLORIDE Intrusion
F	E	REBAR Corrosion Potential
L	f	PERMEABILITY

Table 2- Selected Tests

Preliminary Sampling and Testing

A preliminary trial of the selected tests and sampling method was performed to ensure accurate conclusions overall. Initially the bridges for testing were selected using the following criteria; they must be state owned bridges within 15 miles of the AOT Materials & Research building, they must be over 20 feet long with concrete decks not containing epoxy rebar, and they must be neither railroad bridges nor interstate bridges. Sixty three bridges met these criteria. For the final selection, the type of membrane, type of bridge, year built, and average daily traffic counts were compared.

The bridges were narrowed down to ten which represented a cross section of the original sixty three bridges. The amount of traffic and size of the bridge were observed in order to ascertain which, if any, of the final ten bridges should not be used in the initial sample. The bridge condition was also looked at, however did not affect which bridges were selected for the initial sample. After visually inspecting the remaining ten, two bridges were selected for the initial sampling.

The two selected bridges for initial sampling are shown in Table 3 – Bridges Selected for initial Sampling.

Type of Membrane	County	Town	Route Name	Route Log Bridge No.	Year Built	Ave. Daily Traffic	Ave. Daily Truck Traffic	Year of Ave. Daily Traffic
None	Orange	Williamstown	VT 14	00060	1929	4400	6	1998
None	Washington	Duxbury	VT 100	00187	1937	3700	9	1996

Table 3– Bridges Selected for Initial Sampling

Core Location

The core locations on each of the sample bridges were determined by using random numbers. On each bridge three sites were designated as possible locations; over the centerline, at the curb, and over a pier. In the case of single span bridges, the third core site was located at a randomly determined point between the curb and centerline location.

This preliminary Sampling and Testing served to refine the protocol for a more accurate and feasible location of the cores. The centerline and curb cores are located at a random distance from the beginning of the bridge but they are always at the same station. In addition, the location of the core, initially planned to be 3" from the deck curb was not always feasible because of the difficulty of avoiding rebar at a location so close to the curb and because it would have allowed only one type of core drill at all times. This distance was recommended to be 9" allowing the operator of the drill to adjust the location ± 1ft in any direction and record the changes.

Final Selection of Bridges

Once the preliminary sampling and testing took place and the tests and sampling protocol was refined; the site locations were selected from all bridges in Vermont. Specific bridges were neglected to simplify the study.

The bridges were binned into membrane type. Random bridges from each bin, log-proportional to bin size, were selected with 55 bridges selected in total. From these bridges, sample locations were selected using random numbers. As with the sample bridges, each bridge had 3 possible core locations, near the centerline, near the curb and over a pier, if applicable or at a random location between the curb and the centerline.

The three core samples for each bridge will be taken from the same lane(s), on the same side of the centerline to minimize disruption of traffic and expedite the sampling process. Engineering judgment will be used when selecting the lane(s) taking into consideration, the traffic pattern, peak-hour directional traffic volume, and predominant type of vehicle, deck conditions, and the safety of the crew. The centerline core and the curb core will be collected at the same distance from the beginning of the bridge in order to establish a common variable between the two samples. These two samples will be studied to learn more about the difference in the Concrete Deck Deterioration Rate between the areas closer to the centerline versus areas closer to the curb.

After the first sixteen (15) bridges were sampled, it was decided to exclude bridges without membranes as it would not be proper to compare bridge decks without membranes with the rest of the population based on their condition or degree of deterioration. The majority of the bridges with no membrane are single span short bridges, too old and with a re-paving pattern not similar to the pattern found in bridges with membranes, since the application of membranes is a practice that started in the 1970's. There are also general geometrical differences such as their number of lanes, cross-slopes, shoulder width and condition of their drainage system. For that reason, this report includes only bridge decks with membranes for comparison of the incidence of membrane adhesion in relation to the core location as well as the incidence of membrane adhesion to either the concrete deck or the asphalt pavement.

Type of Membrane	County	Town Name	Route Name	Route Log Bridge No.	Year Built	Year Reconst.	Ave. Daily Traffic	Ave. Daily Truck Traffic	Year of Ave. Daily Traffic
No Membrane	Franklin	Bakersfield	VT108	00041	1952		1200	9	1998
	Essex	East Haven	VT114	00018	1929		1000	6	1998
	Franklin	Berkshire	VT118	00026	1934		1400	6	1998
Sheet	Orange	Bradford	TH3	0D62N	1973		300	2	1998
	Orange	Bradford	I91	0061N	1973		2800	13	1998
	Orleans	Irasburg	I91	0107N	1971		2800	13	1998
	Caledonia	St. Johnsbury	TH4	00D89	1975		120	2	1996
	Caledonia	Burke	VT114	00015	1990		1300	7	1998
Polymer Overlay	Caledonia	Waterford	TH4	000D8	1982		700	2	1998
Torch	Windsor	Hartford	I89	0011N	1967	1999	7550	13	1998
	Windsor	Hartford	I89	0011S	1967	2000	7550	13	1998
	Orleans	Barton	US5	00161	1939	1967	980	7	2000
Tar Emulsion	Franklin	Highgate	TH1	00D99	1965		340	2	1998
	Franklin	Swanton	I89	0094S	1967		4250	13	1998
	Franklin	Swanton	I89	0098S	1964		2150	13	1998

Table 4– Sampled Bridges

PERFORMANCE

Bridges with No Membrane

Three bridges with no membrane were sampled and showed no adhesion between the asphalt pavement and the concrete deck regardless of the core locations. However, this finding corroborates the hypothesis that the presence of a membrane, when properly installed, may in fact increase the adhesion of the asphalt pavement to the concrete deck.

Bridges with Membrane

As shown in Table 4 – Fifteen bridges with membranes were sampled. It was found that out of the 36 cores sampled, only 16 showed some adhesion, 3 at the curb, 5 at the centerline, 6 over the pier and 2 between the curb and the centerline.

The highest adhesion frequency occurs at or near the pier (75%) where there is also the highest incidence of adhesion of the membrane-to-concrete-deck interface. In addition, regardless of the core location, in 50% of the cores the membrane remained attached to the concrete deck.

A slightly different outcome was observed by analyzing the bridges according to their type of membrane.

Sheet Membrane

When looking at sheet membranes, it was found that in 80% of the samples the membrane remained attached to the asphalt for every core location, with 100% adhesion frequency at or near the piers. Such behavior leads to the argument that the installation process of the sheet membrane creates a stronger bonding between the membrane and the asphalt pavement due to the similitude of bituminous materials at such interface.

Town Name	Route Name	Route Log Bridge Number	Year Built	Membrane Attachment Pattern Showing the Axial force to separate the membrane bonding and the surface to which is it attached															
												3rd Core							
				Curb Core (lbs)	Attached to			C.L. Core (lbs)	Attached to			Pier Core (lbs)	Attached to			Rand. Core (lbs)	Attached to		
					Asp	Conc	None		Asp	Conc	None		Asp	Conc	None		Asp	Conc	None
St. Johnsbury	TH4	00D89	1975	>260	1	0	0	>440	1	0	0	>440	0	1	0				
Bradford	TH3	0D62N	1973	0	1	0	0	0	1	0	0					0	1	0	0
Bradford	I91	0061N	1973	0	1	0	0	340	1	0	0					380	1	0	0
Irasburg	I91	0107N	1971	0	1	0	0	0	1	0	0	>440	1	0	0				
Burke	VT114	00015	1990	80	0	1	0	90	1	0	0	310	0	1	0				
				40%	80%	20%	0%	60%	100%	0%	0%	100%	33%	67%	0%	50%	100%	0%	0%

Table 5 - Bridges with Sheet Membrane

Polymer Overlays

Bridge 000D8 was built in 1982 and it was protected with ½ inch polymer overlay directly applied on the concrete deck without any other type of membrane. Every core extracted from the deck of Bridge 000D8, built in 1982 on TH-4 in the town of Waterford, required more than 440 lbs. of axial pull-out force. These three samples leads to believe that polymer overlay are 100% satisfactory as far as waterproofing and adhesion, but the sample population consisted of only one sample and therefore it is not possible to arrive at any conclusion. However, bridge No. 10 located on TH – 1, in Franklin County in the town of Georgia, Vermont will be sample in the spring of 2005. This bridge was rehabilitated with a polymer overlay in 1994 and the site was revisited for evaluation again in 2002 and it was reported that the polymer overlay had performed well over the 7.5 year life of the deck up to the time of inspection.

Torch Membrane

Nine cores were collected. Of the 9 cores collected, 2 cores were from locations above or near a pier. The membrane remained attached to the concrete deck in 7 of the 9 cores. But there was no apparent adhesion of the membrane to the asphalt since only 2 out of 9 cores required a force to pull the core up from the deck. This behavior may imply that the mere installation process requiring the heating of the membrane to achieve its adhesion to the concrete, may be responsible for the higher incidence of adhesion at the interface membrane-concrete. But that at the same time, such an interface attempts to unite two very dissimilar materials. Dissimilar materials will not achieve the same strength found on the sheet membranes at the membrane-asphalt pavement interface.

Town Name	Route Name	Route Log Bridge Number	Year Built	Membrane Attachment Pattern Showing the Axial force to separate the membrane bonding and the surface to which is it attached															
												3rd Core							
				Curb Core (lbs)	Attached to			C.L. Core (lbs)	Attached to			Pier Core (lbs)	Attached to			Rand. Core (lbs)	Attached to		
					Asp	Conc	None		Asp	Conc	None		Asp	Conc	None		Asp	Conc	None
Hartford	I89	0011N	1967	0	0	1	0	0	0	0	1	380	0	1	0				
Barton	US5	00161	1939	0	0	1	0	0	0	1	0					>440	0	1	0
Hartford	I89	0011S	1967	0	0	1	0	0	0	1	0	0	0	1	0				
				0%	0%	100%	0%	0%	0%	67%	33%	50%	0%	100%	0%	100%	0%	100%	0%

Table 6 - Bridges with Torch Membrane

Tar Emulsion Membrane

In sections at or near the center line, the adhesion frequency of the membrane to the concrete deck was the highest (87%). The membrane remained attached to the asphalt with 100% frequency along the curb and 87% along the centerline. However, a detailed observation including all tar emulsion cores regardless of their location shows an incidence of 56% and 44% adhesion of the membrane to the asphalt pavement and the concrete respectively, which represents a more evenly distributed adhesion throughout the deck.

Town Name	Route Name	Route Log Bridge Number	Year Built	Membrane Attachment Pattern Showing the Axial force to separate the membrane bonding and the surface to which is it attached															
												3rd Core							
				Curb Core (lbs)	Attached to			C.L. Core (lbs)	Attached to			Pier Core (lbs)	Attached to			Rand. Core (lbs)	Attached to		
					Asp	Conc	None		Asp	Conc	None		Asp	Conc	None		Asp	Conc	None
Highgate	TH1	00D99	1965	0	1	0	0	0	1	0	0	0	1	0	0				
Swanton	I89	0094S	1967	0	1	0	0	420	0	1	0					0	0	1	0
Swanton	I89	0098S	1964	240	1	0	0	>440	0	1	0	140	0	1	0				
				33%	100%	0%	0%	67%	33%	67%	0%	50%	50%	50%	0%	0%	0%	100%	0%

Table 7- Bridges with Tar Emulsion Membrane

SUMMARY

At this time, with the limited lab results and the relatively small population sampled, it is wise to keep in mind that the final outcome of this report can differ as more information is available. However, it is apparent that polymer overlays and torch membranes show higher adhesion to the concrete than other types of membrane.

At this point there are not enough results from the chloride test to arrive at any conclusion regarding which type of membrane provides better protection against chloride intrusion. More meaningful conclusions will be drawn from the Rapid Chloride Penetration Test ASTM C 1202-97 that includes a larger population of specimens.

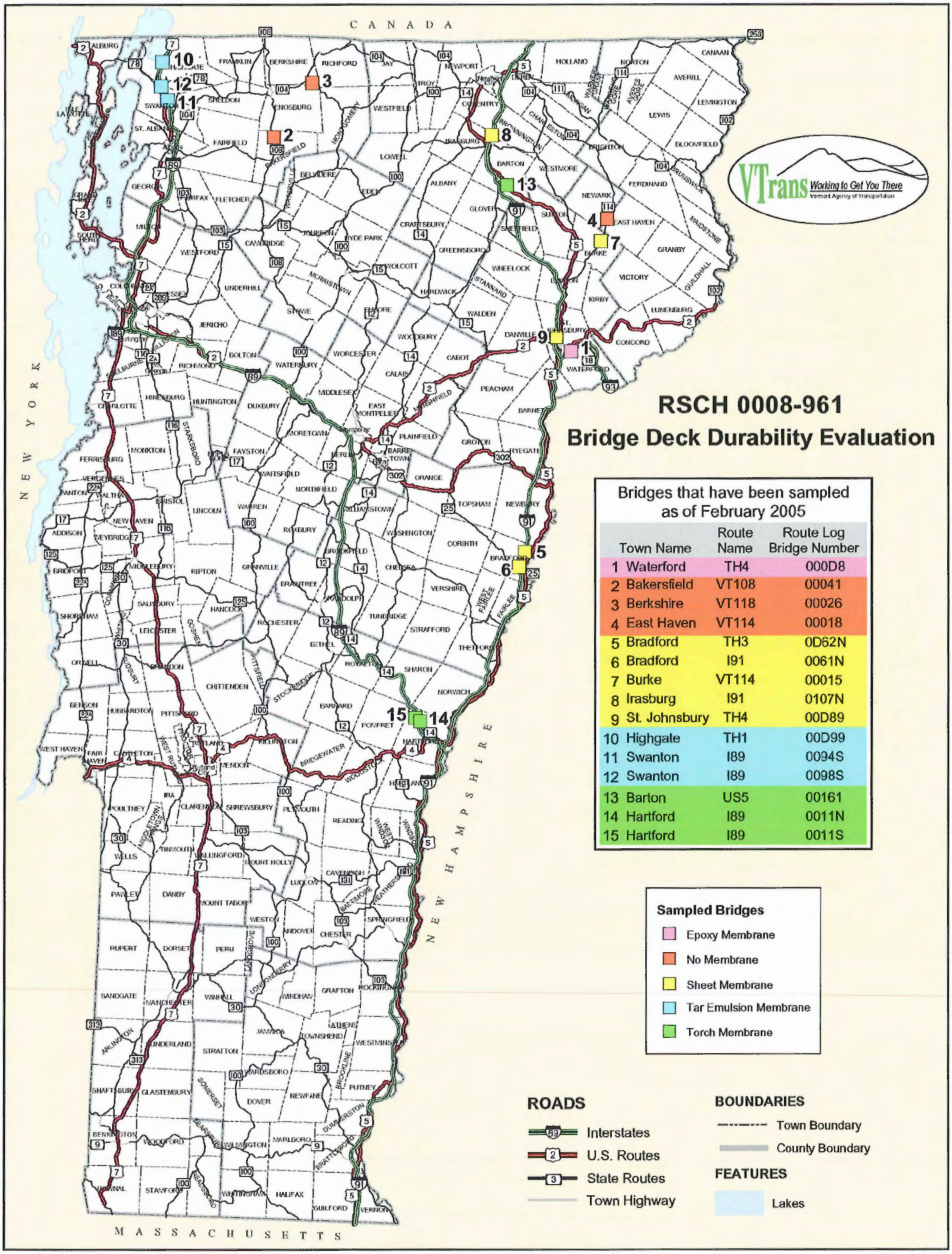
Chloride Intrusion in ppm					Chloride Sample Location Approximately Depth of Sample							
Membrane Type	Year Built	Year Reconstructed	Location	Bridge No.	Curb		Centerline		Above Pier		3RD Random	
					½"-1½"	1½"-2"	½"-1½"	1½"-2"	½"-1½"	1½"-2"	½"-1½"	1½"-2"
Torch	1967	1999	Hartford	BR0011N	180	90	80	50	230	30		
	1967	2000	Hartford	BR0011S	30	30	30	30	40	50		
Sheet	1990	No reconstruction performed	Burke	BR00015	280	120	80	100			200	110

Table 8- Chloride Intrusion in ppm

FOLLOW UP

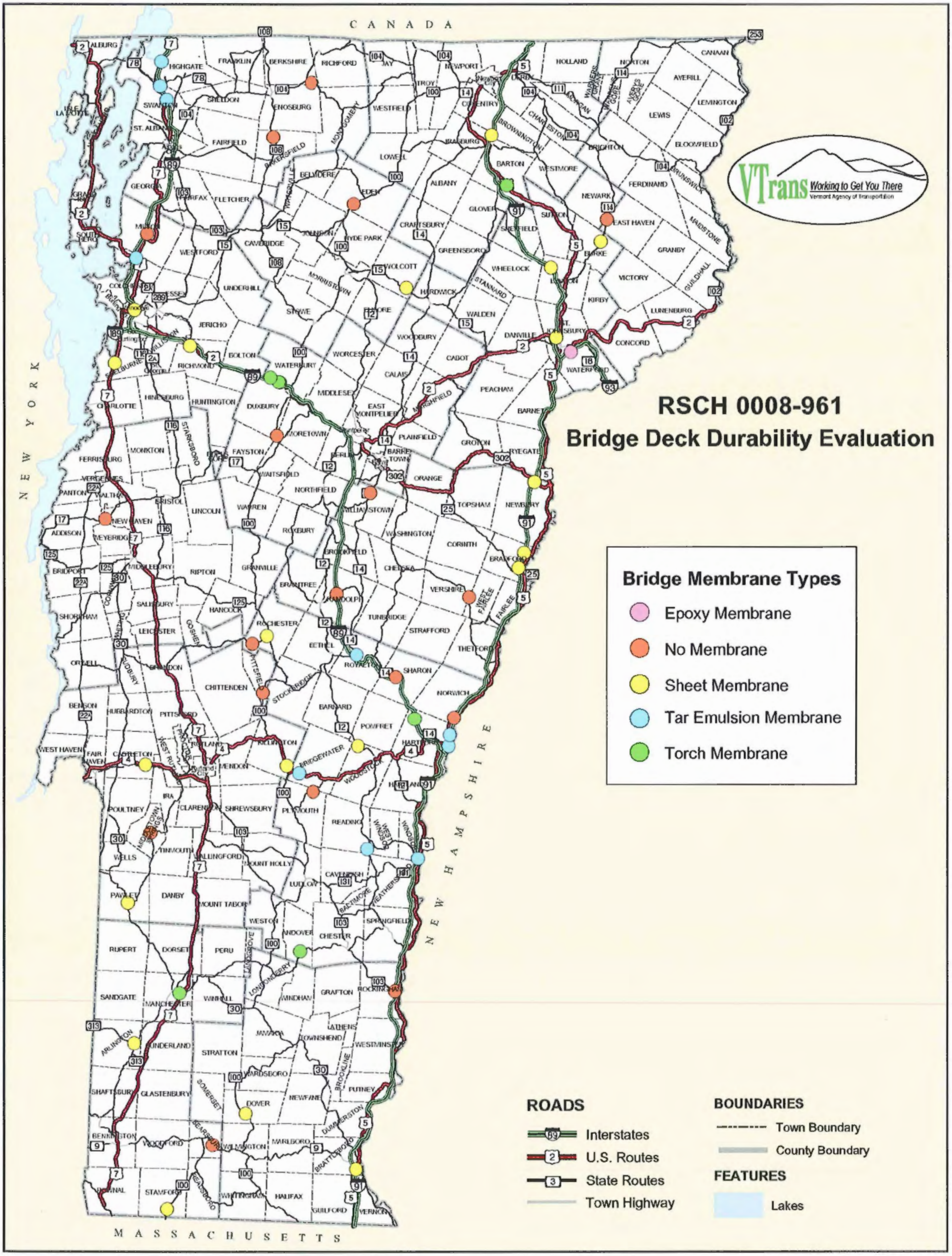
Bridge sampling will resume in the spring of 2005. It is expected that 42 bridges will be sampled, including bridges located in Windham, Bennington, Addison, Chittenden, Lamoille and Rutland counties. Upon completion, the analysis will be based on a larger population and the chloride test results will be available. Ultimately, a correlation may be established between the chloride intrusion, the type of membrane and the membrane adhesion frequency and pattern.

RSCH 0008-961
Bridge Deck Durability Evaluation



Bridges that have been sampled as of February 2005

	Town Name	Route Name	Route Log Bridge Number
1	Waterford	TH4	000D8
2	Bakersfield	VT108	00041
3	Berkshire	VT118	00026
4	East Haven	VT114	00018
5	Bradford	TH3	0D62N
6	Bradford	I91	0061N
7	Burke	VT114	00015
8	Irasburg	I91	0107N
9	St. Johnsbury	TH4	00D89
10	Highgate	TH1	00D99
11	Swanton	I89	0094S
12	Swanton	I89	0098S
13	Barton	US5	00161
14	Hartford	I89	0011N
15	Hartford	I89	0011S


RSCH 0008-961
Bridge Deck Durability Evaluation
Bridge Membrane Types
Epoxy Membrane
No Membrane
Sheet Membrane
Tar Emulsion Membrane
Torch Membrane
ROADS
Interstates
U.S. Routes
State Routes
Town Highway
BOUNDARIES
Town Boundary
County Boundary
FEATURES
Lakes
VTrans Working to Get You There
Vermont Agency of Transportation
CANADA
NEW YORK
NEW HAMPSHIRE
MASSACHUSETTS

VERMONT AGENCY OF TRANSPORTATION (VAOT)
RESEARCH ADVISORY COUNCIL (RAC)
RESEARCH, DEVELOPMENT AND TECHNOLOGY TRANSFER (RD&T)
FY2002 PROJECT SOLICITATION

PROJECT TITLE: Research Project No. SPR 961 as part of the VTtrans Research Project
Bridge Deck Durability Evaluations

Submitting Individual: William E. Ahearn Date: 7/13/01 Phone: 802 828 2561

Division/Section/Unit: Tech Services / Materials and Research / Research and Testing

Type of Activity (Mark most appropriate item):
__X__ *Applied Research* (To answer a question or solve a problem)
____ *Basic Research* (To increase knowledge)
__X__ *Development* (Translation of research into a prototype use)
__X__ *Technology Transfer* (Leads to adoption of a new technology)

Project Goal(s):
Provide systematic research into components affecting superstructure durability for consideration by VTrans designers

Brief Description of Project (Attach additional sheets if necessary):
Systematic completion of research into components affecting superstructure durability in Vermont settings. Work will build on existing research projects in order to provide a clearer picture of material stressors. Each element of the project will be self supporting but will be suitable for compilation into an Agency position on design, construction and maintenance practices for durable superstructures. This project is anticipated to be subjected to periodic addition of elements to address emerging issues. Existing baseline research components already underway which are planned for incorporation into the project include: ASR Susceptibility of VT Aggregates, Corrosion Studies of VT Bridge Decks and three earlier studies of membranes suitable for updating with current products.
*The **initial elements** of this project are:*
I) Supplemental Investigation of Bridge Deck Corrosion for the Distribution of Sodium and Chloride Ions
II) An Evaluation of Membrane System Performance (modified proposal considered earlier by the RAC)
III) A Review of Cathodic Protection Systems for Reinforcing and Structural Steels in VT
IV) An Evaluation of Silanes and Other Chemical Sealers for Continuous Span Bridges
V) An Updated Report on the Performance of Membrane Systems for Bridge Decks (Lab and Field)
VI) A Review of Deicing Strategies for Long Span Structures

Project Deliverable(s): *Each of these elements of the project will have a comprehensive workplan that details the research methodology [1], data collection strategy, evaluation and analyses[1], preliminary findings and corroborative investigative strategy phase and a final report[1]. If the study fails to meet research objectives then a revised research objective will be devised in the preliminary findings phase for acceptance by the Technical Research Advisory Committee.*

[1] *These tasks are subject to review and comment from a VAOT Technical Research Advisory Panel (TRAP)*

Estimated Project Duration/Phasing: *The completion of the elements in this project will take approximately*

16 months if completed concurrently with an estimated cost of $103,300 (I- $43,800; II- $15,000; III - $7500 and IV $30,000. IV Element II relies in data acquisition in Element I. See the task summary for further detail of each phase of work.

Estimated Cost: Total $ 103,300 Yearly Breakdown: FFY02 $75,000 FFY03 $28,300

Funding Other Than SPR (Matching Source(s) / Amount(s):

How the Agency's Vision/Mission is supported (Area(s) addressed): This projects supports accessibility through extending structure life and efficiency through selecting cost effective materials.

Describe the urgency of this project: Existing plans under construction are modified in the construction phase due to serious concerns about the performance of products and systems designed to provide durable superstructures. Many contracts are under revision to convert preformed membrane projects to Torch Applied membranes. VT experience with torch applied membrane prior to the 2000 construction season was less than 2000 square meters. Combined installations after the 2000- 2001 construction seasons are projected to exceed 400,000 square meters. This scale of change in materials used in the construction of our infrastructure requires factual support based on examination of the systems in-place.

What will happen if this project is not approved: There will continue to be significant variation in the selection of materials and systems that are purported to be cost effective solutions to superstructure design. Project managers will be forced to select materials and methods based on limited information sets with little direct information from Vermont's own structures.