Porous Pavement Paired Intersection Study

January 2014

Prepared for:

SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION
CITY OF ROBBINSDALE, MINNESOTA
MINNESOTA POLLUTION CONTROL AGENCY

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Shingle Creek

City of Robbinsdale

Minnesota Pollution Control Agency

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Acknowledgments

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Photo: Porous pavement construction, 41st and Abbot Avenue North, Robbinsdale, Minnesota, September 2010.

Cover: Porous pavement, 41st and Abbot Avenue North, Robbinsdale, Minnesota, Winter, 2010.

All photos and graphics: Wenck Associates, Inc., unless noted.

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1.0 Section 319 Final Report

1.1 GRANT SUMMARY REPORT

Grant Project Summary

Project title: Shingle Creek Porous Pavement Paired Intersection Study

Organization (Grantee): Shingle Creek Watershed Management Commission

Project start date: July 1, 2009 Project end date: August 30, 2013 Report submittal date:

Grantee contact name: Tina Carstens Title: Chair

Address: 3235 Fernbrook Lane

City: Plymouth State: MN Zip: 55359

Phone number: 763-553-1144 Fax: 763-553-9326 E-mail: judie@jass.biz

Basin (Red, Minnesota, St. Croix, etc.): Upper Mississippi County: Hennepin

Project type (check one):

- ☐ Clean Water Partnership (CWP) Diagnostic
- ☐ CWP Implementation
- ☐ Total Maximum Daily Load (TMDL) Development
- ☐ 319 Implementation
- ☒ 319 Demonstration, Education, Research
- ☐ TMDL Implementation

Grant Funding

Final grant amount: $248,308.40 Final total project costs: $504,238.40

Matching funds: Final cash: $30,000.00 Final in-kind: $225,930.00 Final Loan: $0

Contract number: B37348 MPCA project manager Barb Peichel

For TMDL Development or TMDL Implementation Projects only

Impaired reach name(s):

AUID or DNR Lake ID(s):

Listed pollutant(s):

303(d) List scheduled start date: Scheduled completion date:

AUID = Assessment Unit ID
DNR = Minnesota Department of Natural Resources

Executive Summary of Project **(300 words or less)**

This summary will help us prepare the Watershed Achievements Report to the Environmental Protection Agency. (Include any specific project history, purpose, and timeline.)

The Shingle Creek Watershed Commission and City of Robbinsdale, Minnesota completed a research project to investigate whether porous asphalt can be used as a physical substitute for road salt as an ice prevention method. Shingle Creek is an Impaired Water for excess chloride, and a TMDL showed that the primary source was road salt applied for ice control. A 71% reduction in chloride is needed to meet water quality standards. Two low-volume residential intersections in Robbinsdale were selected as test sites. One leg of each was reconstructed using porous asphalt pavement. An adjacent intersection at each served as control. During the two year monitoring period, the control intersections were plowed and salted as usual. The test sections were plowed, but no salt or sand was applied. Images taken by a closed circuit camera were processed to estimate bare pavement at each intersection at 9 am, noon, and 3 pm each day. This daily percent of bare pavement was evaluated against air temperature, pavement temperature, and solar radiation to assess which factors were more predictive of melting rate. Results suggest that unsalted porous asphalt pavement can have net bare pavement comparable to a salted traditional pavement section. Salted pavement starts melting sooner, and that lag can be anywhere from a few to several hours depending on temperature and solar radiation conditions, and that performance may be less acceptable to the public. However, slush and snowmelt infiltrates and does not refreeze on porous pavement, so the net amount of bare pavement is comparable. The pavement has been durable over three winters of snow plowing. The only maintenance has been to sweep with a regenerative vacuum sweeper in the spring and fall. Porous pavement at low-volume residential intersections shows promise as a potential ice control Best Management Practice

Goals (Include three primary goals for this project.)

1st Goal: Estimate the effectiveness of porous asphalt on residential streets in reducing the need for salt as a deicer.

2nd Goal: Determine whether porous asphalt is a BMP that can hold up to rigors of regular city street use

3rd Goal: Measure the water quality and quantity benefits of porous asphalt in a residential street application in both sandy and clay/loam subgrades

Results that count (Include the results from your established goals.)

1st Result: Unsalted porous asphalt pavement appears to result in similar net bare pavement to traditional, salted pavement, indicating porous asphalt may be a useful de-icing substitute for road salt

2nd Result: The porous asphalt withstood three winters of snowplowing and freeze-thaw cycles with minimal impact.

3rd Result: The porous pavement section constructed over a sand subgrade infiltrated all rain and snowmelt, which results in 100% removal of pollutants and runoff volume. Over the clay subgrade, there appears to have been some volume and thus load reduction, but it was difficult to measure.

Picture (Attach at least one picture, do not imbed into this document.)

Description/location:

Acronyms (Name all project acronyms and their meanings.)

TMDL: Total Maximum Daily Load

SC WMC: Shingle Creek Watershed Management Commission

MnDOT: Minnesota Department of Transportation

MAPA: Minnesota Asphalt Pavement Association

TAC: Technical Advisory Committee

Partnerships (Name all partners and indicate relationship to project)

City of Robbinsdale, Minnesota

Minnesota Department of Transportation

Minnesota Asphalt Pavement Association

1.2 WORK PLAN REVIEW

1.2.1 Approved Work Plan Changes

Change Order #1 reallocated budget and hours from tasks: Design Concepts; Preliminary Design; Prepare Plans and Specifications; and Monitoring tasks to the Construction; Project Management and Communication; and Final Report tasks.

1.2.2 Report by Activity/Task

Objective 1
Task 1.1 Develop Design Concepts. The Technical Advisory Committee (TAC) consulted with the Minnesota Asphalt Pavement Association (MAPA) and met at the MnROAD research facility in Monticello, Minnesota. Based on that input and a literature review the project team selected a pavement design and specification.
Task 1.2 Preliminary Design. The project engineer worked with City of Robbinsdale staff to select a sand subgrade site for one of the two test pavement sections, and City of Plymouth staff to select a clay subgrade staff. After the Plymouth site was selected, the City Council decided not to proceed with the street reconstruction project. The City of Robbinsdale volunteered another site that had been slated for mill and overlay and that had a clay subgrade. The project engineer also worked with MnDOT staff to select the appropriate instrumentation and to design the instrumentation layout.

Objective 2
Task 2.1 Prepare Plans and Specifications. The project engineer worked with City of Robbinsdale staff to prepare final plans and specifications for pavement work and instrumentation for both sites.

Objective 3
Task 3.1 Project Bidding. The sand subgrade site was completed as an add-on to a neighborhood street reconstruction project already in progress, and the project engineer negotiated a change order with the contractor. Quotes were solicited for the clay subgrade site. In both cases the project engineer reviewed the unit prices and made a recommendation to the City of Robbinsdale.
Task 3.2 Construction. Both segments were constructed.

Task 3.3 Construction Management. This task included both construction oversight and documentation of the pavement installations and installation and operation of the instrumentation. MnDOT staff fabricated and installed thermocouple trees in all four pavement sections.

Objective 4

Task 4.1 Monitoring. Project staff downloaded temperature data, and downloaded and digitized the CCTV photos. The pressure transducer froze in at the clay subgrade site, so no data was recorded. The sand site infiltrated so quickly that hardly any runoff was stored in the reservoir to trigger that transducer.

Objective 5

Task 5.1 Project Management and Communication. The project team made regular progress presentations to the Technical Advisory Committee. In addition, this project received significant regional and national interest. Presentations were made to a variety of audiences, including water resources professionals; pavement contractors; public works maintenance staff; and city and county engineers.

Table 1-1. Presentations of study interim and final results.

Conference	Date	Location
MAPA 54th Annual Asphalt Contractors Workshop	March 3, 2010	Brooklyn Center, MN
21st Annual Transportation Research Conference	April 28, 2010	St. Paul, MN
2010 Minnesota Water Resources Conference	October 19, 2010	St. Paul, MN
2011 Minnesota Water Resources Conference	November 19, 2011	St. Paul, MN
St. Paul Public Works staff	January 23, 2012	St. Paul, MN
11th Annual Road Salt Symposium	February 2, 2012	Chanhassen, MN
5th Annual LID Workshop	February 16, 2012	Dubuque, IA
Fall 2012 Conference, South Dakota Engineering Society	October 10, 2012	Sioux Falls, SD
2013 NASECA of Wisconsin 10th Annual Conference	February 7, 2013	Madison, WI
2013 International Low Impact Design Symposium	August 19, 2013	St. Paul, MN

Task 5.2 Final Report. This task required the collation and analysis of a considerable amount of monitoring data. In addition, a final pavement condition assessment was performed on all test and control segments. The results were summarized in a detailed final report.

1.3 GRANT RESULTS

1.3.1 Measurements

Results of monitoring data are presented in the following sections of this report.

1.3.2 Products

Project products were monitoring data, a final report, and numerous presentations.

1.3.3 Public Outreach and Education

This project did not include a specific public outreach and education component. However, the project has been publicized in the local papers and on the local Cable TV news.

1.3.4 Long-term Results

Capacity-Building. This research project raised awareness about the use of porous pavement as a chloride-reduction and infiltration BMP. Construction details and plans and specifications were developed and may be used by other road authorities implementing this BMP. It is estimated that several hundred water resources and other professionals have seen a presentation on this project.

Partnerships. The project forged partnerships between cities and MnDOT and the Minnesota Asphalt Pavement Association, and all parties shared information and expertise as well as learned from the results.

Dissemination of Project Results. The primary form of dissemination was presentations at various conferences, which are detailed in Table 1-1, and which included Midwestern regional conferences as well as one international conference.

Applicability to Other Audiences/Locations. The intent of the project was to explore whether porous pavement had utility in reducing the need to apply road salt. It also explored the impact of porous pavement on water quality and volume management and whether that BMP was applicable for use on residential streets. Other road authorities may take the project results and evaluate the cost-benefit of this BMP in their proposed application.

Lessons Learned. While this technology does appear to have some utility at reducing salt application and managing stormwater volume, it is an expensive BMP and there is a performance trade-off. The segments built with porous asphalt which were unsalted in winter had about the same net amount of bare pavement as traditional pavement that does received road salt. However, there is a lag time for the porous pavement to break through to pavement. That lag time can range from a few to several hours. The lesson may be that this technology is useful but only in certain, limited conditions.

1.4 FINAL EXPENDITURES

Funding Source	**Cost**
Section 319 Grant	$248,308.40
Shingle Creek WMC	30,000.00
In-kind (TAC, MnDOT, MAPA, Robbinsdale)	225,930.00
TOTAL	$504,238.40

2.0 Introduction and Purpose

The Shingle Creek watershed in Hennepin County, Minnesota in the Upper Mississippi River Basin is 44 square miles in area, and is almost entirely developed with urban and suburban land uses. Shingle Creek and its tributaries Bass, Eagle, and Ryan Creeks convey runoff from a watershed that is more than 25 percent impervious. Most of the lakes and streams in the watershed are listed as Impaired Waters- 13 of the 16 lakes for excess nutrients; Shingle and Bass Creek for impaired biota; Shingle Creek for low dissolved oxygen; and Shingle and Bass Creeks for excess chloride.

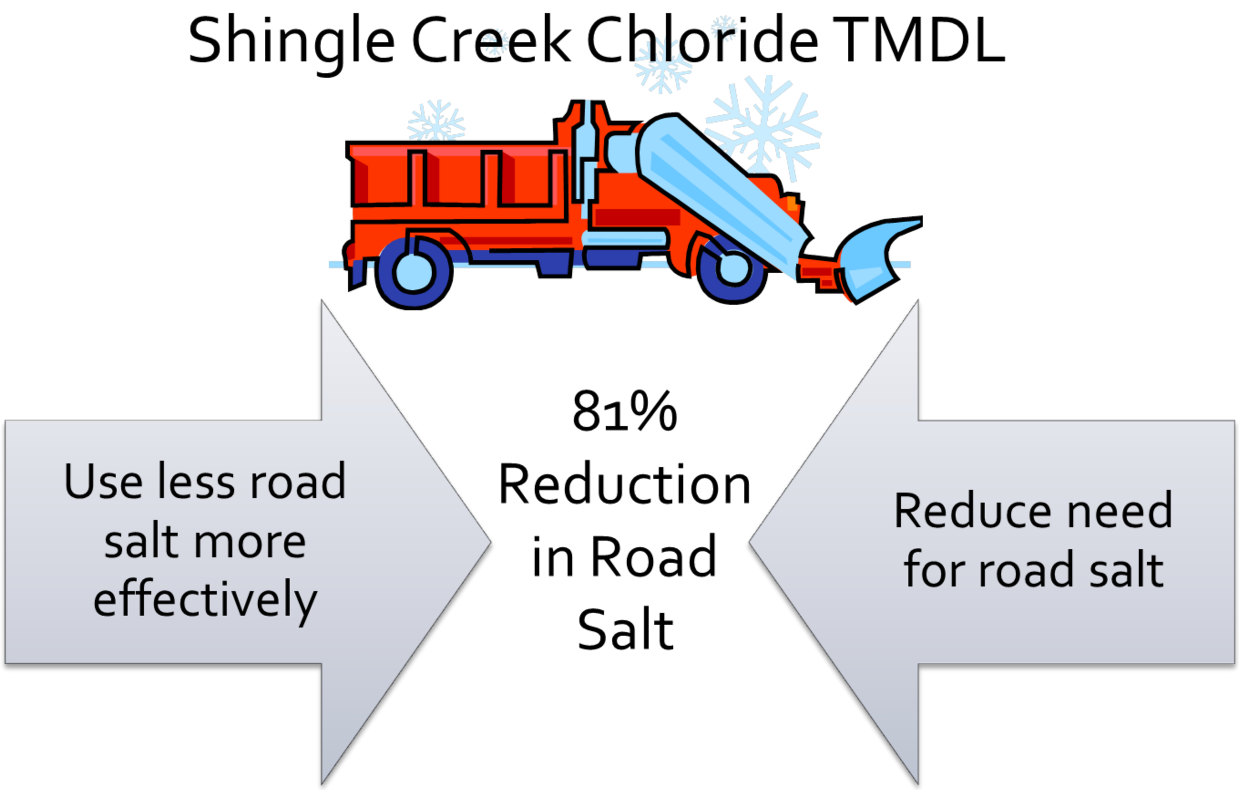
The United States Geological Survey (USGS) initially discovered the chloride impairment in Shingle Creek in the mid-1990s, when conducting intensive monitoring across the country as part of the National Assessment of Water Quality (NAWQA). Shingle Creek and another creek in Hennepin County were selected as representative of urban streams in the Upper Mississippi River Basin. Chloride is not a parameter that at the time was routinely monitored by watershed organizations in Minnesota, which are typically more concerned with nutrients, sediment, dissolved oxygen, bacteria, and biotic integrity. However, the USGS monitoring revealed elevated chloride concentrations in Shingle Creek and to a lesser extent in Nine Mile Creek in the southern Metro area. When Shingle Creek was added to the State of Minnesota's 303(d) list of Impaired Waters, more routine monitoring was performed on other waters across the Metro area, revealing a more extensive chloride problem. When combined with USGS and other monitoring across the northern tier of states, it became apparent that waters in the "Snow Belt" were more at risk of elevated chloride concentrations than waters to the south.

When the Shingle Creek Watershed Management Commission and the Minnesota Pollution Control Agency completed the Chloride Total Maximum Daily Load (TMDL) study for Shingle Creek, a source assessment found that over 85 percent of the chloride load to Shingle Creek originated in road salt – NaCl – used for winter ice control by public road authorities including the Minnesota Department of Transportation, Hennepin County, and nine cities. Much of the balance of the load was likely contributed by private salt use in parking lots, private roads, and sidewalks and trails. The TMDL calculated that the chloride load to Shingle Creek must be reduced by 81 percent to guarantee that the chloride concentration in Shingle Creek would not exceed the state's chronic exposure limit of 230 ug/L over four days or the acute limit of 860 ug/L.

Winter ice control is necessary to protect public health and safety and to assure the free flow of essential goods and services. In the past, road authorities relied on sand or a mix of salt-sand to provide ice control and traction. However, the use of sand had its own issues: spring rains washed the sand into receiving waters, requiring dredging to maintain flow and storage capacity. When swept up, the sand could not easily be reused, requiring landfilling. And the sand accumulated on boulevards, necessitating sod cleaning and repair in the spring. Many road authorities now use straight salt for ice control.

The road authorities in the watershed have set in place an implementation program that is focused on limiting the use of salt through pre-wetting salt; using temperature sensors and GPS-guided application to use the minimum amount of salt necessary for the road conditions; better training and equipment calibration; and pre-application of salt and salt brine in advance of expected ice events. The Watershed Commission and the MPCA have offered training in proper techniques and certification to both public and private applicators. These practices are reducing the amount of road salt applied, but to nowhere near the 81 percent reduction that is required by the TMDL.

The genesis of the Porous Pavement Paired Intersection Study was the observation that porous pavements used in parking lot applications appeared to need less wintertime plowing and salting than traditional pavements. Rather than reduce application of road salt to levels that may not be adequately protective of public safety, what if porous pavement could be used on roads to reduce the buildup of ice and thus the need to apply road salt?



2.1 THE PAIRED INTERSECTION STUDY

The purpose of the Porous Pavement Paired Intersection Study is to evaluate the use of porous pavement to reduce the need to apply road salt by constructing two test porous asphalt segments on residential streets, and to monitor the pavement condition compared to adjacent, control segments. The control segments would be salted and plowed as is routine on all residential streets, while the porous pavement would be plowed but receive no road salt.

The research questions to be explored in this study are as follows:

1. Estimate the effectiveness of porous asphalt in *reducing the need for salt* as a deicer.
2. Determine if porous asphalt can hold up to *rigors* of regular city street use.
3. Determine short term and likely long term *maintenance requirements*.
4. Measure the *water quality and quantity benefits* in both sandy and clay/loam subgrades

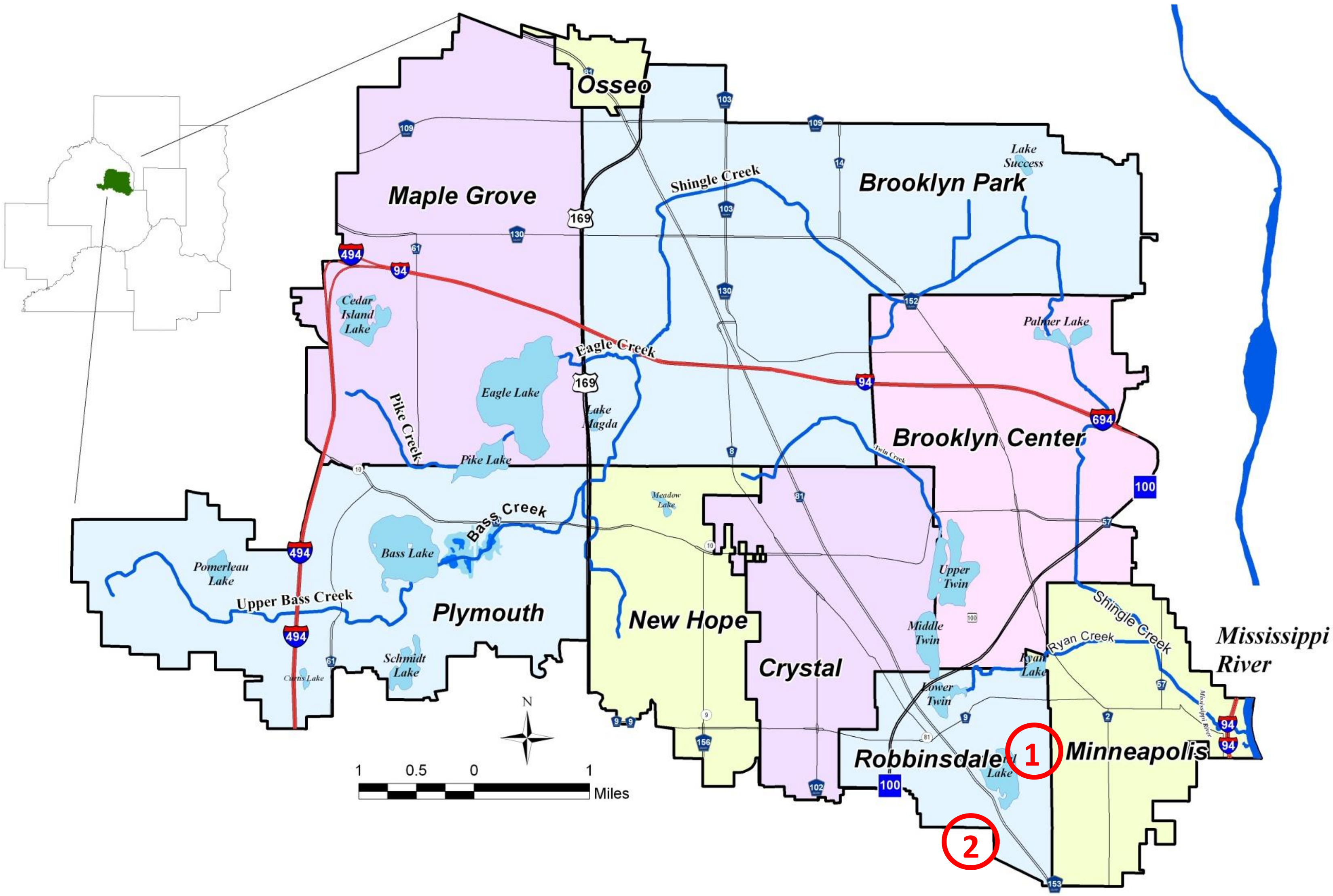


Figure 2.1. Project sites in the Shingle Creek watershed.

Two project sites were selected in the City of Robbinsdale, Minnesota (Figure 2.1). Site 1 is located near Crystal Lake, and has a sand subgrade with a measured infiltration rate of greater than 1.5" per hour (Figure 2.2). The control segment is the north leg of 41st and Zenith Avenues North, and the test segment is the north leg of 41st and Abbott Avenues North. 41st Avenue North is a through street, and drivers southbound on both Zenith and Abbott Avenues North must stop at a Stop sign. Streets in this neighborhood were being reconstructed during project establishment as part of the "Victory View Neighborhood" street and utility project.

Figure 2.2. Project Site 1: sand subgrade.

Site 2 is actually located just outside of the Shingle Creek watershed in the Bassett Creek watershed. Site 2 was initially to be located in the City of Plymouth as part of a neighborhood street and utility reconstruction project, but late in the planning process the Plymouth City Council decided not to go forward with the neighborhood project. Robbinsdale had a mill and overlay project planned in the Site 2 area, and volunteered two intersections in that project area, which has tight clay soils with minimal measured infiltration.

The control segment is the north leg of 27th and McNair Avenues North, and the test segment is the north leg of 27th and Ewing Avenues North. As with Site 1, 27th Avenue North is a through street, and McNair and Ewing both are controlled by Stop signs.

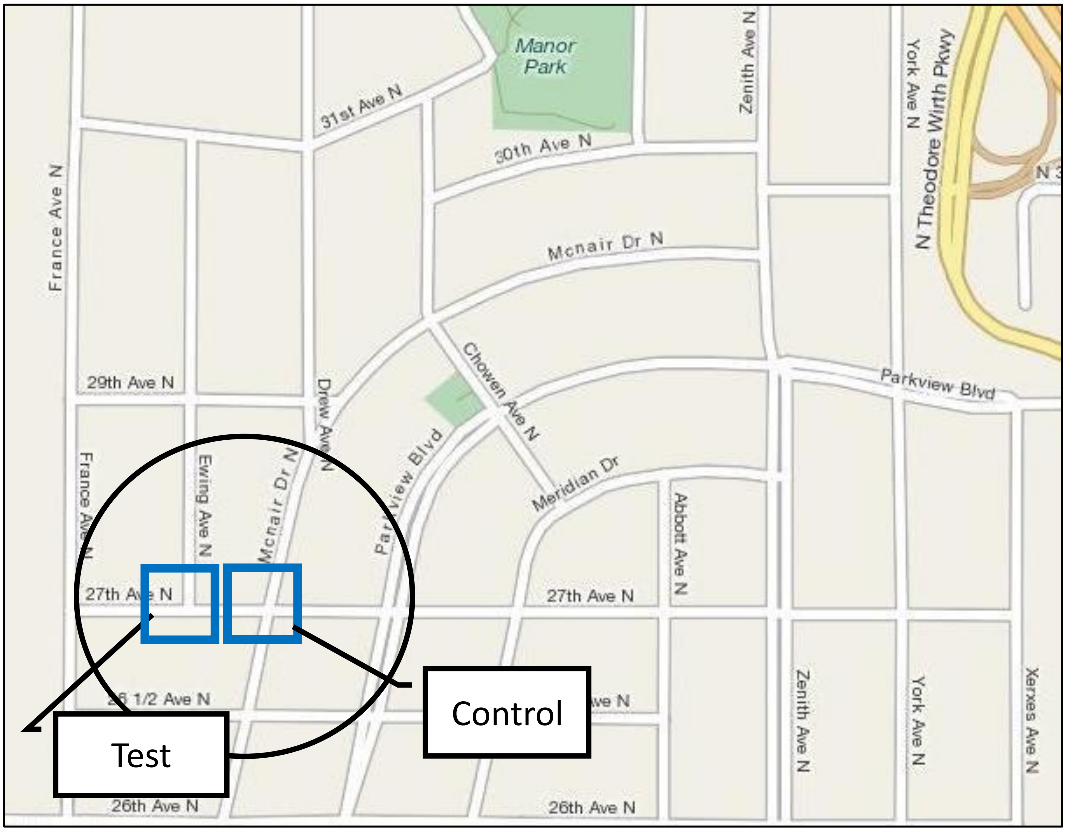


Figure 2.3. Project Site 2: clay subgrade.

These sites were deliberately selected to explore whether the type of subgrade makes a difference in the pavement performance. Otherwise, the two sites have very similar characteristics. Both have south-facing aspects, and have few coniferous trees shading the test and control pavement surfaces in the winter. Both are relatively flat. One difference between the two sites is that 27th Avenue North westbound from Parkview Boulevard to McNair is a steep hill, which will be discussed in later sections of this report presenting the data analysis.

3.0 Project Implementation

3.1 PAVEMENT DESIGN AND SPECIFICATION

As preparation for developing a final pavement design and specification, the team conducted a literature search on the use of porous pavements in cold climates. The Technical Advisory Committee (TAC) visited the Minnesota Department of Transportation's MnROAD Cold Weather Road Research Facility in Monticello, Minnesota, where an ongoing research project is studying permeable pavement performance.

The TAC made a site visit to the MnROAD Low Volume Road research facility, where porous asphalt and pervious concrete sections are being subjected to various traffic loads and monitored for performance. The TAC noted that the porous asphalt section, which had been installed the fall before the spring site visit, was raveling. MnROAD staff explained that they thought that the mix had been too hot and there had been excessive drawdown of the asphalt binder.

3.1.1 Asphalt Mix

With the literature review and MnROAD experience in mind, the project team worked together with the Minnesota Asphalt Pavement Association (MAPA) to modify MAPA's recommended specification. MAPA prepared that specification in consultation with asphalt industry members experienced with porous asphalt products.

The resulting specification emphasizes harder aggregates rather than softer shale to minimize moisture absorption in the aggregate, to lessen potential freeze-thaw heaving. Because the aggregate specification is more uniformly graded to maximize void spaces, porous asphalt mixes tend to hold heat longer. With minimal fines in the mix, binders are more prone to draw down in the truck and in place as the mix is waiting to be rolled. This is the likely cause of the raveling on the MnROAD site. To address that, performance asphalt binders with more viscosity were specified based on their availability to local asphalt producers, and synthetic cellulose fiber was added to the mix.

3.1.2 Pavement Section

Figure 3.1 shows the porous pavement cross section. The subgrade was covered with a geotextile fabric, and 12" of 1.5" – 2.5" granitic stones was placed to form a reservoir with an estimated 35-40% void space. This depth was designed to store the 2-year event of rain falling directly on the pavement. An overflow draintile was placed just below the top of the reservoir and directed to a nearby catch basin. That 12" depth reservoir was overlaid with a 2" choker course of 0.5" crushed stone to provide a more level surface for paving. Six inches of porous asphalt was laid in a single lift, and rolled to 4".

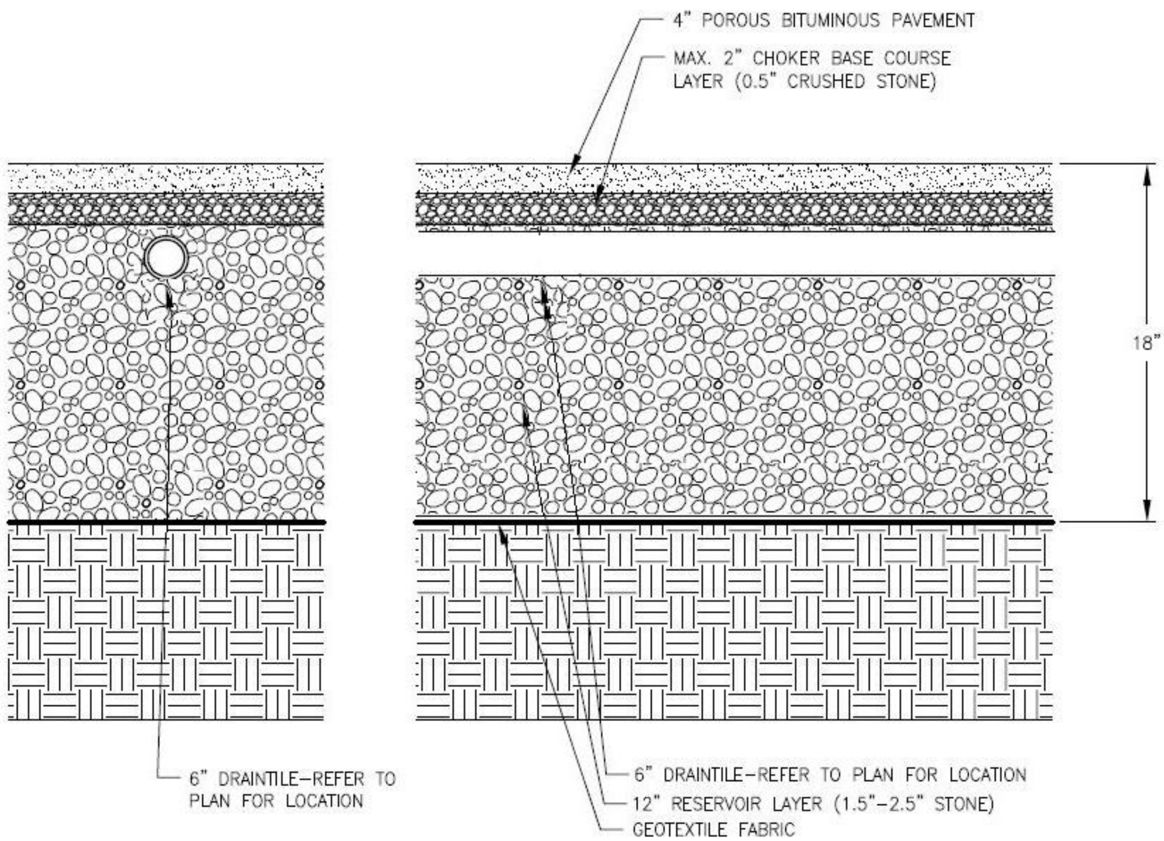


Figure 3.1. The porous asphalt pavement section used in the study.

3.2 INSTRUMENTATION

The instrumentation design for the project was prepared in consultation with MnDOT, building on their experience at the MnROAD pavement research facility in Monticello, Minnesota. The instrumentation was designed to measure pavement temperature, depth of water stored in the reservoir, runoff water quality, and snow and ice buildup and melt.

3.2.1 Pavement Temperature

Pavement temperature at various depths was recorded at 15 minute intervals at both the test and the control sites. A thermocouple tree was embedded in the pavement section in the center of the driving lane. MnDOT staff fabricated the devices by embedding eight pairs of thermocouple wires in a length of one inch PVC pipe filled with modeling plastic. Holes were drilled in the pipe for the sensors to extend into the pavement and base/subbase and reservoir at eight intervals (Figure 3.2). The cabling was routed to and through an adjacent catch basin and into a secured instrumentation box on the boulevard. Temperature data was periodically downloaded and compiled. Both winter and summer temperature data was recorded.

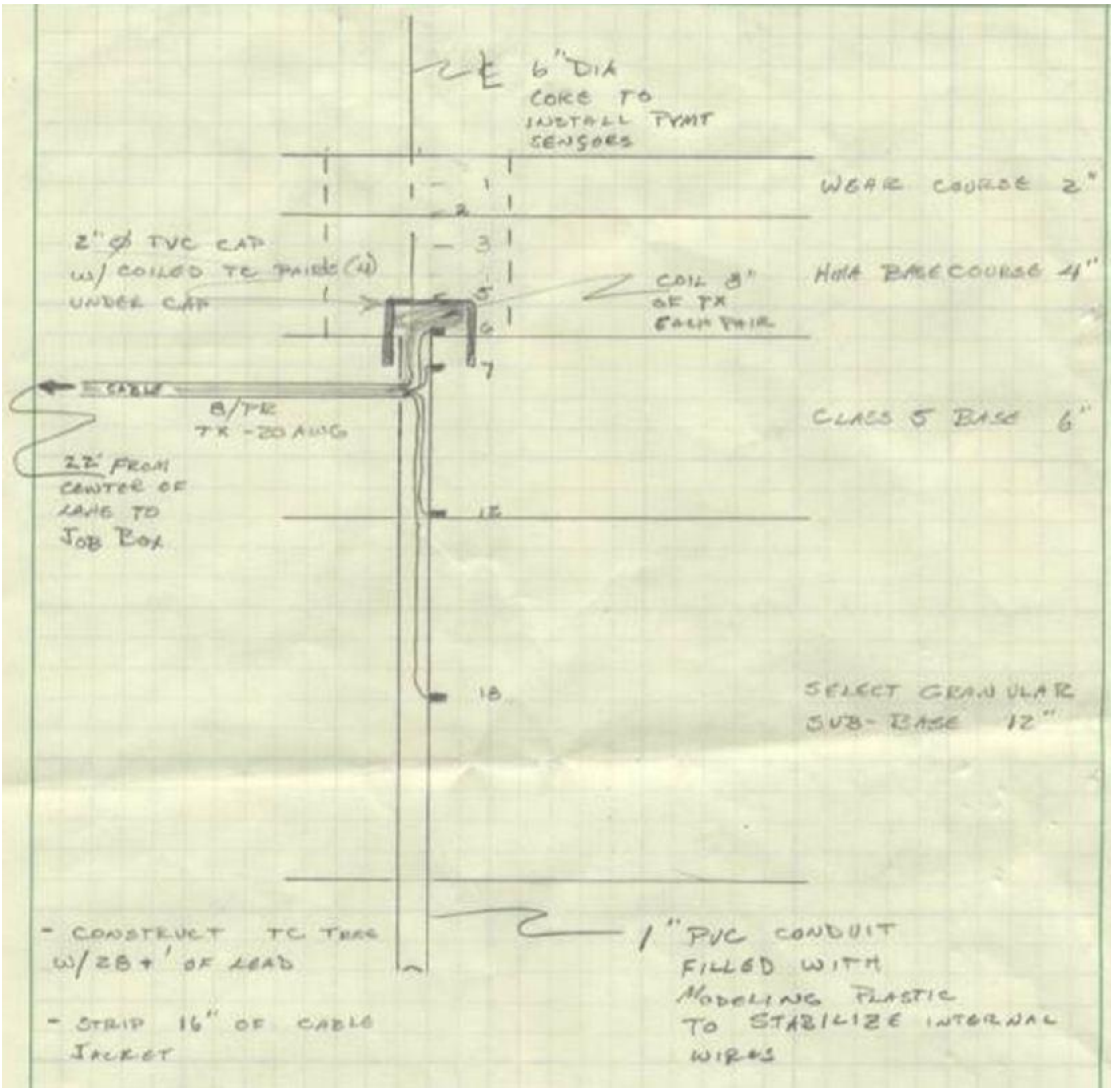


Figure 3.2. Thermocouple tree design by MnDOT engineers.
(Source: Len Palek, MnDOT)

3.2.2 Reservoir Volume and Water Quality

A pressure transducer was used to continuously record the depth of runoff stored in the reservoir. A standard valve box was modified so that the pressure transducer could be hung inside and cabling be routed out a hole drilled in the side of the box. The valve box was placed at the bottom of the reservoir and the cabling routed to the instrumentation box on the boulevard (Figure 3.4**Error! Reference source not found.**).

A drain tile was installed at the top of the reservoir (Figure 3.5 and Figure 3.6) and routed to a nearby catch basin, where an autosampler intake was set up to capture samples of runoff discharged from the reservoir. As with the thermocouple and pressure transducer cabling, the intake was routed through the catch basin and boulevard into a secured instrumentation box that housed the autosampler (Figure 3.7).

Figure 3.3. Installing the thermocouple tree on the Site 1 control section.

Figure 3.4. Pressure transducer installed in a valve box with conduit extended to catchbasin.
Note: The thermocouple tree was placed in the bottomless white bucket for protection until the reservoir rock was placed around it. At that point the bucket was removed.

Figure 3.5. Overflow pipe and instrumentation conduits routed through catchbasin.

Figure 3.6. 6" PVC overflow pipe routed to catchbasin and connected to autosampler intake.

Figure 3.7. Instrumentation conduits routed underground into a nearby instrumentation box.

3.2.3 Closed Circuit Cameras

To monitor the buildup and melt off of snow and ice, closed circuit cameras were mounted on adjacent power poles overlooking each of the four intersections. Images were captured every 12 minutes on a video server, and then transmitted by cable modem to a dedicated laptop computer. Images could also be viewed real-time over the Internet using viewing software.

Cameras at the 41st and Abbott & Zenith Avenues sites were mounted on power poles across the intersection from the porous pavement. The cameras at the 27th and Ewing & McNair Avenues sites were mounted on power poles at the intersection, which afforded a more restricted view of the sites.

Figure 3.8. CCTV camera, cable modem, and video server mounted on adjacent power pole.

3.3 CONSTRUCTION

Site 1 was constructed in 2009 and Site 2 in 2010. Both used the same section and specification, but were installed by different contractors. Both contractors were experienced pavement installers and were familiar with working with porous asphalt pavement.

In both cases, the existing bituminous pavement and base were removed and the subbase excavated to the desired depth. A geotextile fabric was placed over the subbase, and the 12” course of reservoir rock placed and graded. A 2” choker course of 0.5” gravel was placed on top of the reservoir to create a relatively smooth surface for paving. Six inches of porous bituminous was laid by paver.

Figure 3.9. (L) Preparing the sand subgrade. (R) Geotextile and reservoir rock.

Figure 3.10. Choker course graded and ready for paving.

The bituminous material registered between 285° and 310° in the truck and 250° and 275° when it was initially laid. It took about 2 hours to cool down enough to roll. The first roller pass on Site 1 had to be suspended because the material was too warm and viscous to effectively roll.

Figure 3.11. Laying the porous asphalt.

3.4 COST

The cost for installing the porous asphalt at Site 1 was negotiated as a $42,670 Change Order with the contractor reconstructing streets and utilities for the City of Robbinsdale as part of the larger 2009 Victory View Neighborhood Street Reconstruction project. Separate quotes were obtained to complete the work at Site 2, with the low bidder submitting a $32,200 quote.

Each section was approximately 150 feet long and 28 feet wide, or about 4,200 square feet (466.67 square yards). The upcost from a traditional bituminous pavement section to a porous section with a 12" reservoir is in both the price of the specialty porous asphalt and the cost of the reservoir rock. The unit price for the reservoir rock on this project was about 25% higher than the unit price for the corresponding volume of class 5 aggregate.

4.0 Monitoring Results

4.1 METHODS

The closed circuit cameras overlooking the four sites were programmed to take a photo every 0.2 hours (12 minutes). The video server software was configured to display all four images simultaneously (Figure 4.1). Each image was transmitted by cable modem to a dedicated laptop, where the images were stored for processing. Although a large quantity of images were available, only images taken at 9:00 am, noon, and 3 pm were initially processed.

The three daily images were converted into PDF format and a digital planimeter feature in Adobe Acrobat Pro was used to estimate the percent of bare pavement on each of the test and control sections.

Figure 4.1. Video server view showing Site 1 (top) and Site 2 (bottom).
Note: Digitized bare pavement is shown outlined in red.

Figure 4.2. Site 1 test section looking south.

During image processing, it became apparent that the camera at the Site 1 test section on Abbott Avenue was able to capture not only a good view of the porous pavement test section, but also the mid-block traditional pavement. Since typically the city only applies road salt at intersections, this provided an opportunity to not only contrast traditional, salted pavement to unsalted porous, but also to compare the performance of unsalted porous to unsalted traditional pavement. Unfortunately this comparison was not possible at Site 2 due to the angle of the camera.

Continued equipment problems, mainly with the cable modems, reduced the amount of usable data. The cable modem at Site 1 needed to be replaced twice, and in the third year of monitoring the video server at Site 1 stopped working and was unable to be repaired. As a result there are several gaps in the data record, but there is sufficient paired data to perform a statistical analysis.

4.2 FACTORS INFLUENCING MELTING

The instrumentation and subsequent analysis was designed to explore not only differences between pavement type and subgrade material but also the explanatory power of potential factors that influence snowmelt: pavement temperature; ambient air temperature; and solar radiation.

4.2.1 Pavement Temperature

Thermocouple trees embedded in the pavement and base recorded temperature at various depths. Figure 4.3 shows the temperature profile of the Site 1 porous pavement and base over winter 2009-2010. The temperature of the pavement itself (sensors at depths 0.5" to 5") was fairly uniform and varied throughout the winter, at one point dropping to -20° C (-4° F). However, the two sensors in the storage reservoir were consistently warmer than the pavement. The sensor at the bottom of the reservoir (17" in depth) recorded temperatures dropping to only a few degrees below zero C (28° F).

As can be seen on Figure 4.4 and Figure 4.5, the bottom of the Site 1 reservoir over the sand subgrade never got colder than a few degrees C below freezing, even when the air temperature fell to -15°C. In the springtime this reversed, and the bottom of the reservoir was slightly cooler than the pavement and the ambient air temperature. This pattern was similar but less pronounced at Site 2, the clay subgrade.

Figure 4.6 and Figure 4.7 focus in on the winter 2010-2011 season, where this relationship can be seen more clearly. Two-tailed t-tests of temperature data between 12/1/2010 and 2/28/2011 show that the difference between the test and control sections at 17"/18' below the surface are statistically significantly different at the 95% confidence interval.

It is likely that the air in the reservoir layer helps to insulate the reservoir and prevent freezing. This effect is magnified over the sand subgrade, where air in the pore spaces in the sand may also help to insulate the subgrade. This insulation may result in an updraft through the subgrade into the reservoir generated by heat transfer from the slightly warmer subgrade. This kept the subgrade and reservoir at or only slightly below freezing for most of the winter.

Research done in 2006-2008 by the Washington Conservation District, Dakota Soil and Water Conservation District, and the Ramsey Washington Metro Watershed District in the Twin Cities Metro Area (Davidson et al 2008) tracked four rain gardens over the course of three winters. Field staff used monitoring equipment to measure infiltration rates in the gardens throughout each winter and simulated large snowmelts by periodically flooding the gardens with 200-6,000 gallons of water. The study found that three of the four rain gardens infiltrated water into the ground 85% of the time. All three tended to stop infiltrating when air temperatures were well below freezing for extended periods of time. The fourth rain garden, which rarely infiltrated water during the winter, also performed poorly during the summer due to faulty design and construction. This research suggests that snowmelt percolating through the porous pavement may be able to infiltrate through the warm subgrade much of the winter.

Pavement temperature at the surface and at depth was examined to determine if there was a relationship between temperature and amount of bare pavement. Figure 4.8 graphs the amount of bare pavement by temperature one inch below the surface. While there is a positive relationship – the warmer the surface temperature the greater percent of bare pavement – the relationship is not statistically significant between the control and test sections. Figure 4.9 graphs the amount of bare pavement by temperature 18 inches below the surface. An ANCOVA test shows the relationship is significantly different between the control and test sections at the 99% confidence interval. The relative warmth of the reservoir beneath the porous pavement keeps the pavement from freezing, allowing snowmelt to infiltrate rather than pool on the surface and refreeze.

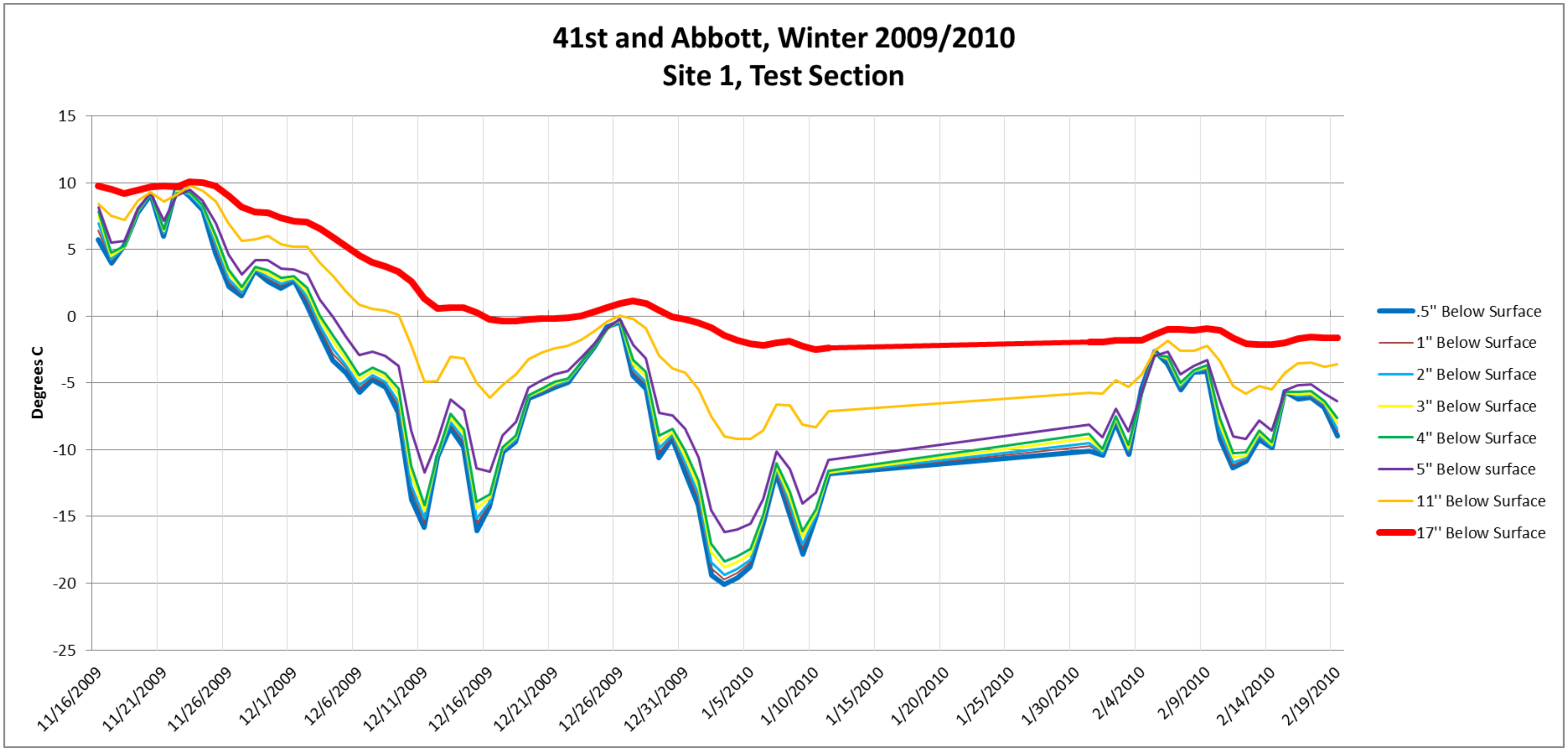


Figure 4.3. Site 1 porous pavement test section temperature at various depths.

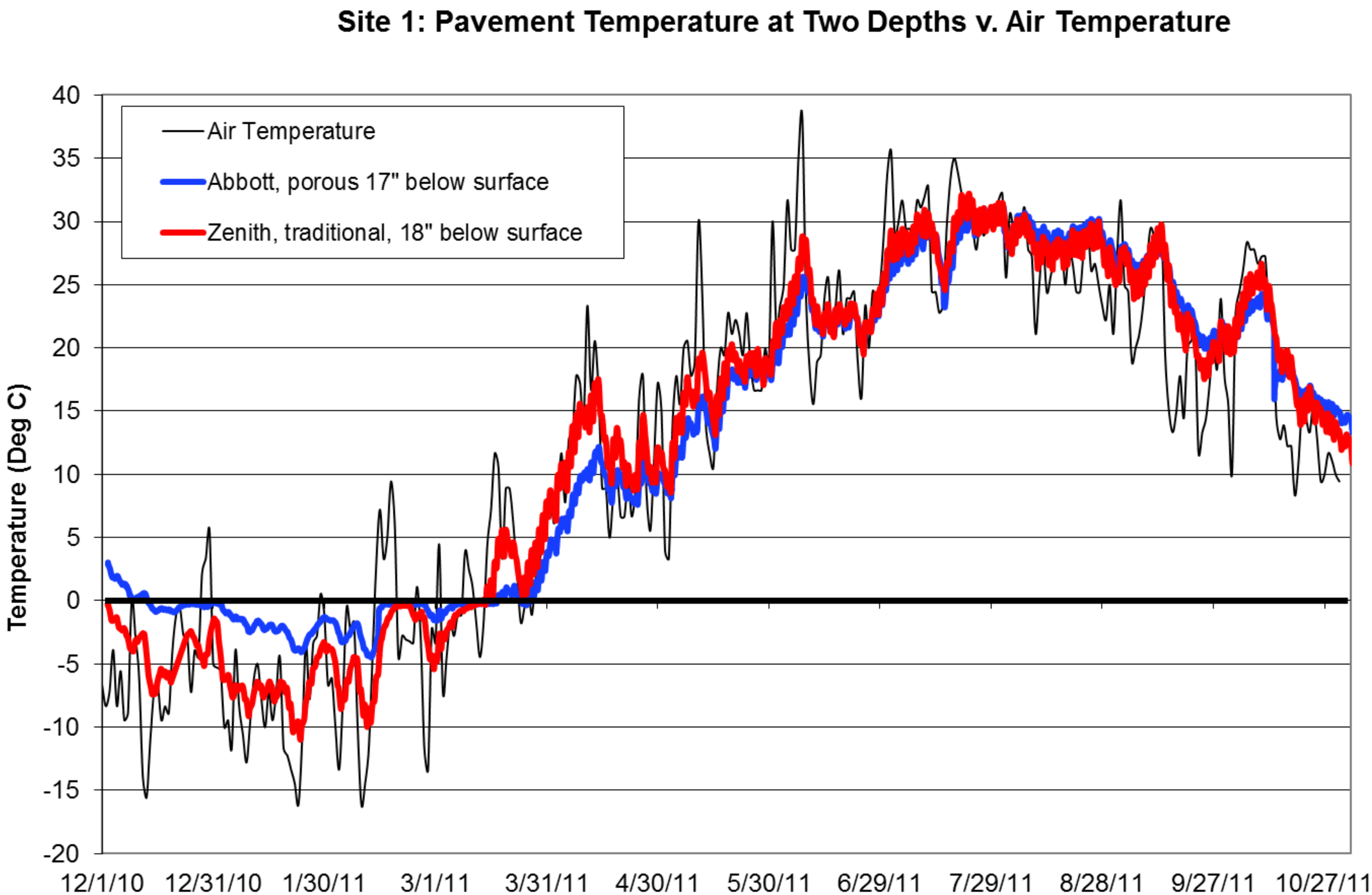


Figure 4.4. Site 1 pavement and reservoir temperatures compared to air temperature.

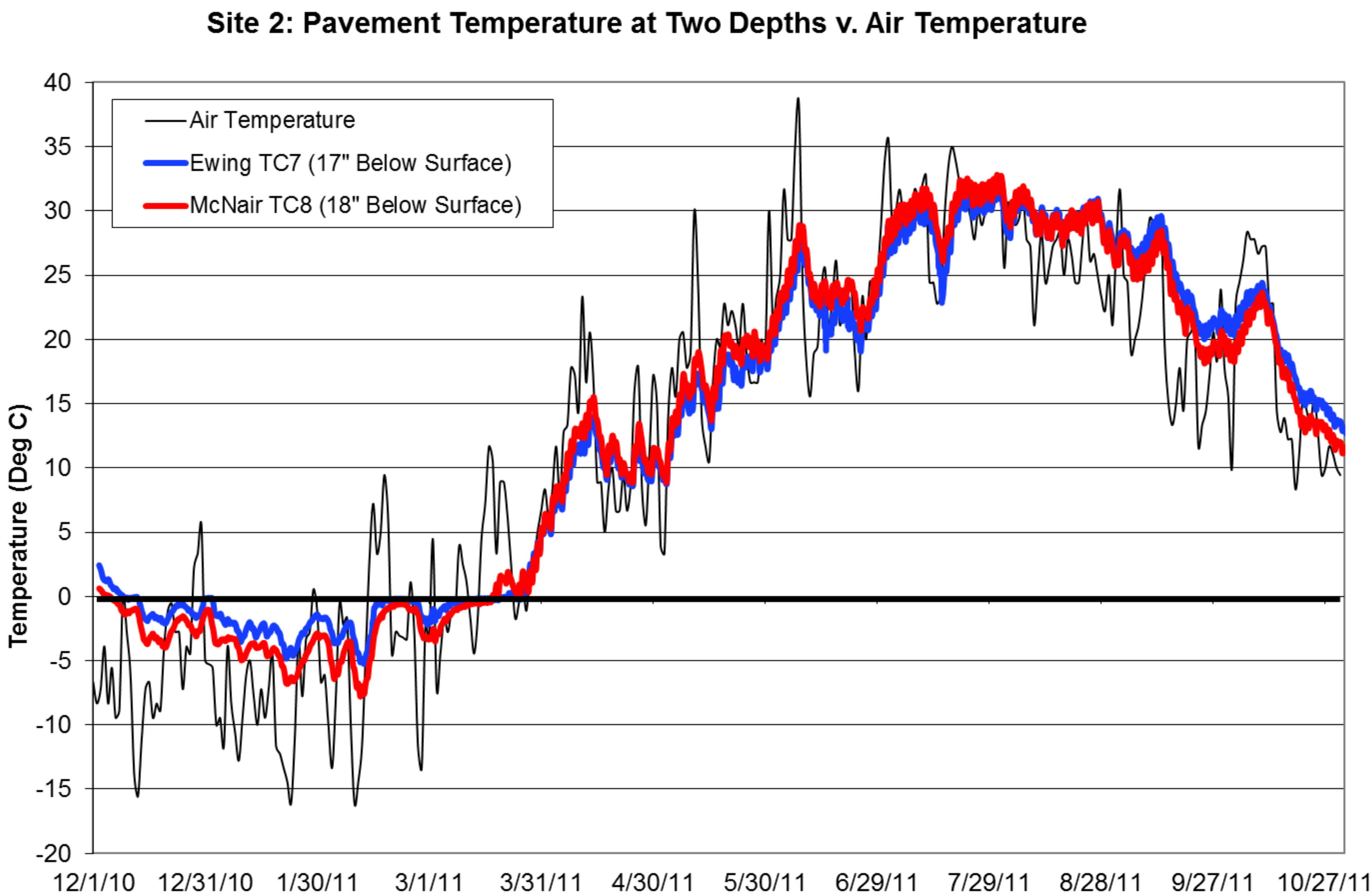


Figure 4.5. Site 2 pavement and reservoir temperatures compared to air temperature.

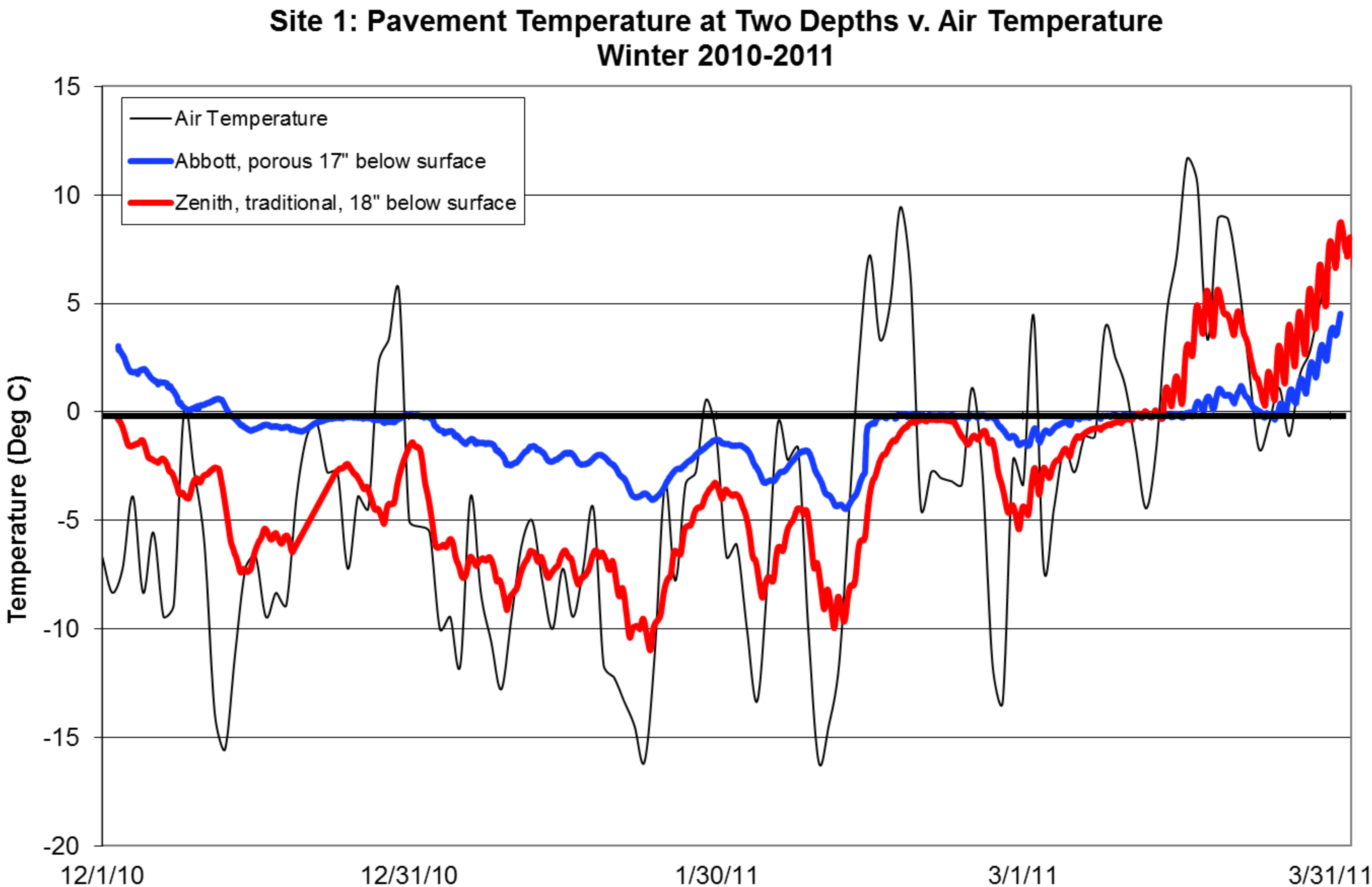


Figure 4.6. Site 1 pavement temperatures during Winter 2010-2011.

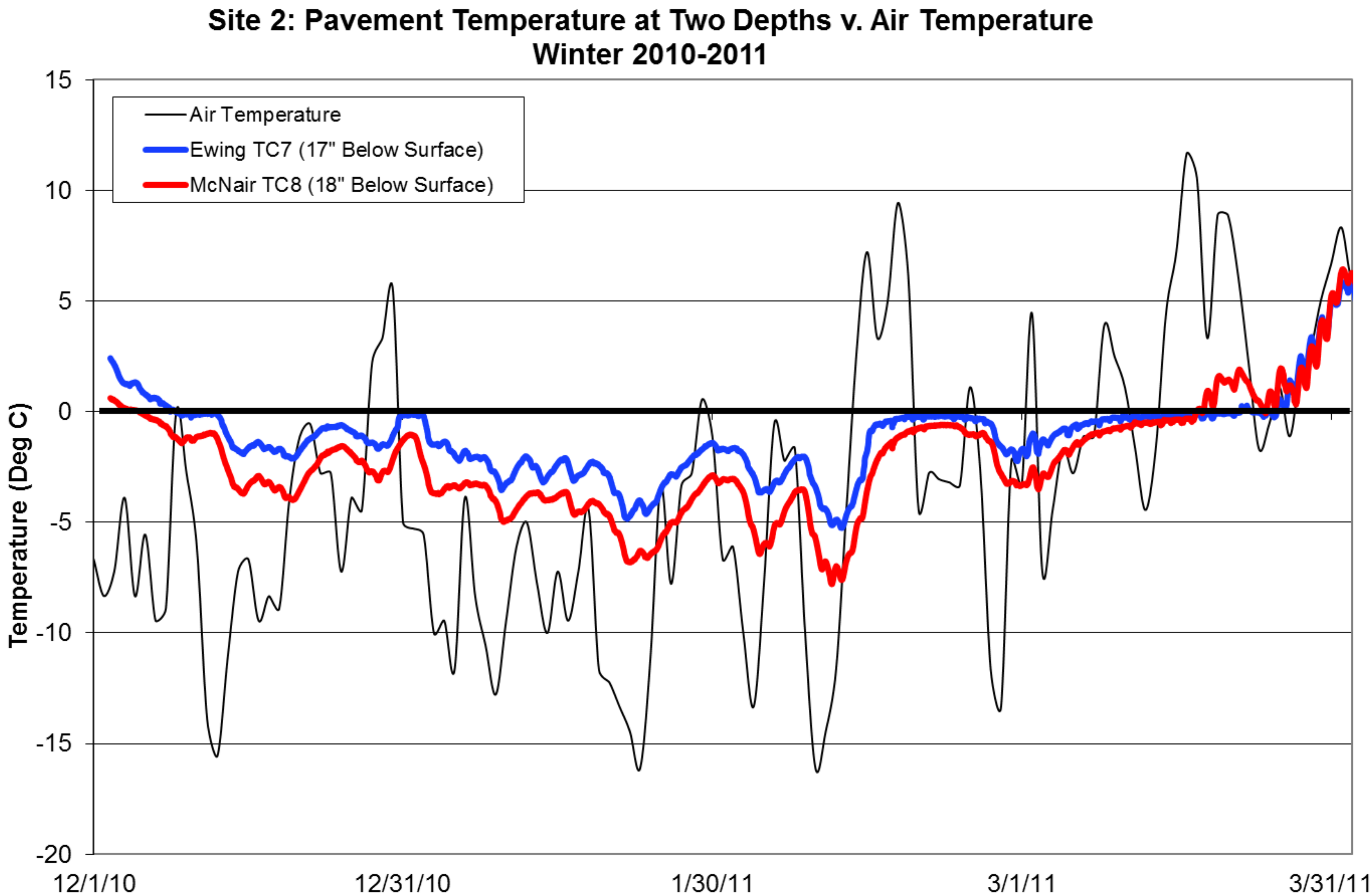


Figure 4.7. Site 2 pavement temperatures during Winter 2010-2011.

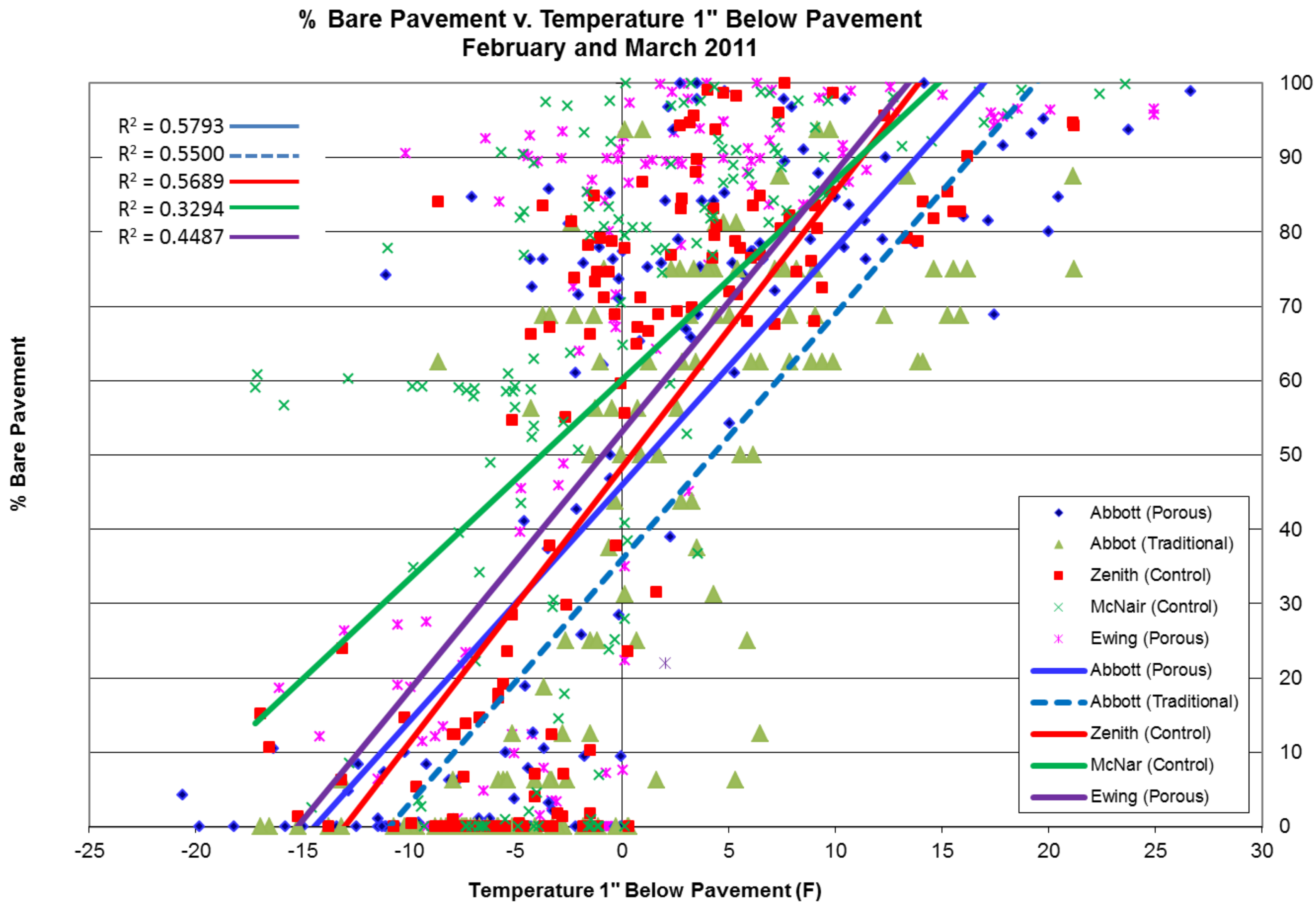


Figure 4.8. Percent bare pavement versus pavement surface temperature.

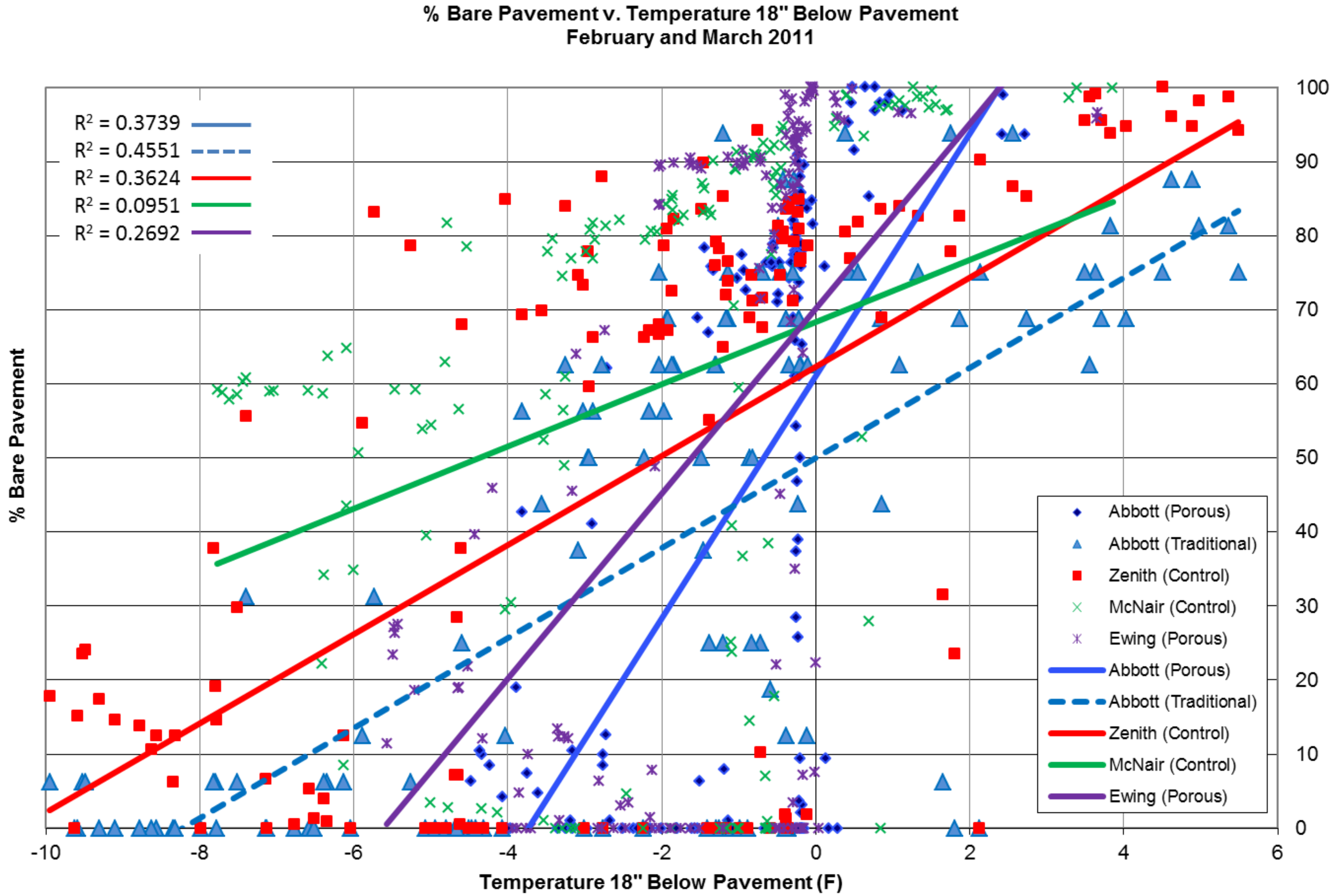


Figure 4.9. Percent bare pavement versus temperature at the bottom of the reservoir

4.2.2 Ambient Air Temperature

The relationship between the amount of bare pavement and ambient air temperature is shown in Figure 4.10. Ambient air temperature is defined as the daily heating degree days, or the average daily temperature subtracted from 65°F. This is a measure of generally how cold it is, with more heating degree days being colder than fewer heating degree days.

As noted above, in general the pavement temperature at the surface mimics the air temperature, and the pavement surface temperature did not appear to explain the difference in bare pavement between the two types of pavement. The relationship between ambient air temperature and amount of bare pavement is positive as shown on Figure 4.10, meaning that the warmer it is generally the more bare pavement there is. However, an analysis of covariance reveals the means of the two samples are not statistically different, suggesting that both traditional and porous asphalt have a similar melting response to ambient air temperature.

4.2.3 Solar Radiation

Solar radiation can also drive snow melt. The two paired sites were specifically chosen because they were relatively open with little canopy cover and had similar south-facing aspects. It can reasonably be assumed that each paired site received similar solar radiation, measured in Langleys. One Langley is one thermochemical calorie per square centimeter.

The relationship between solar radiation and bare pavement is shown in Figure 4.11. It is a positive relationship, that is, the more solar radiation is experienced per day, the more bare pavement there is. However, the means of the data for the test and control sections are not statistically significantly different. As with ambient air temperature, both traditional and porous asphalt have a similar melting response to solar radiation.

4.2.4 General Observations

Observations by city staff and the technical team were consistent with the data analysis. On average, it appeared that traditional, salted pavement tended to start melting before the unsalted porous pavement. However, the traditional pavement was slushier, and then refroze as the sun became lower in the sky and temperatures dropped. This can be seen in the sequence of photos following the figures below, comparing conditions between the traditional and porous pavements during a melt event.

The first photo shows melting on the traditional pavement, although it is slushy. The porous pavement has just broken through to bare pavement. The second photo shows pools of standing water on the traditional pavement, and less melt but drier conditions on the porous. Finally, as the sun is getting low in the sky, slush is starting to refreeze, while the porous pavement is dry.

The lag between snow and ice melt between the traditional and porous pavement ranged from a few to several hours. There was not enough data to explore the conditions that might drive that time lag and whether the short periods or longer periods were the norm. A lag of a few hours may not make a difference to many drivers, but several hours might be considered unacceptable to a public that is accustomed to a higher level of street clearance service. A longer time lag may make the use of porous pavement for ice control at intersections with busier streets less acceptable. If the use of porous pavement is to be seriously considered, this data gap should be further explored and quantified.

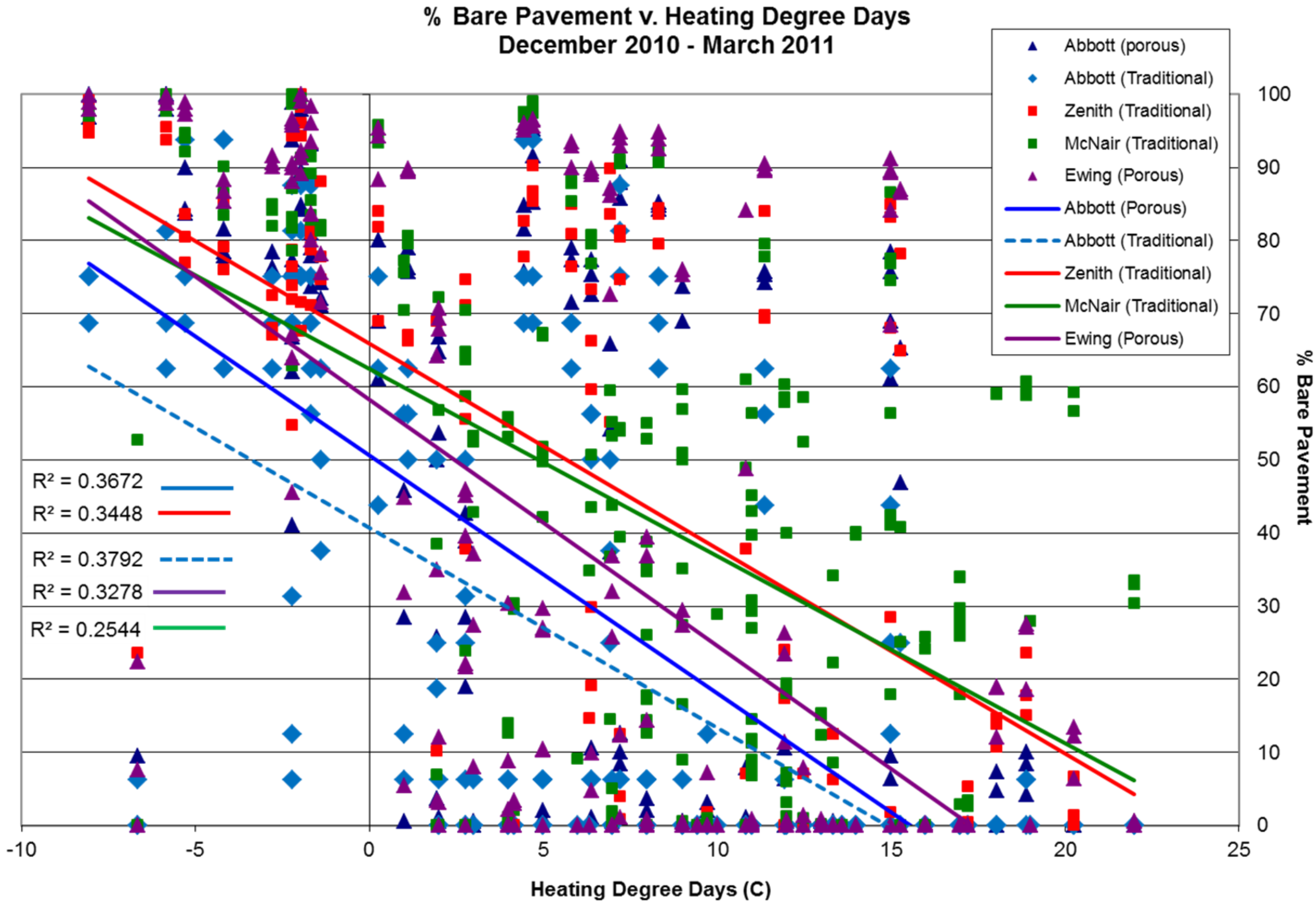


Figure 4.10. Percent bare pavement versus ambient air temperature.

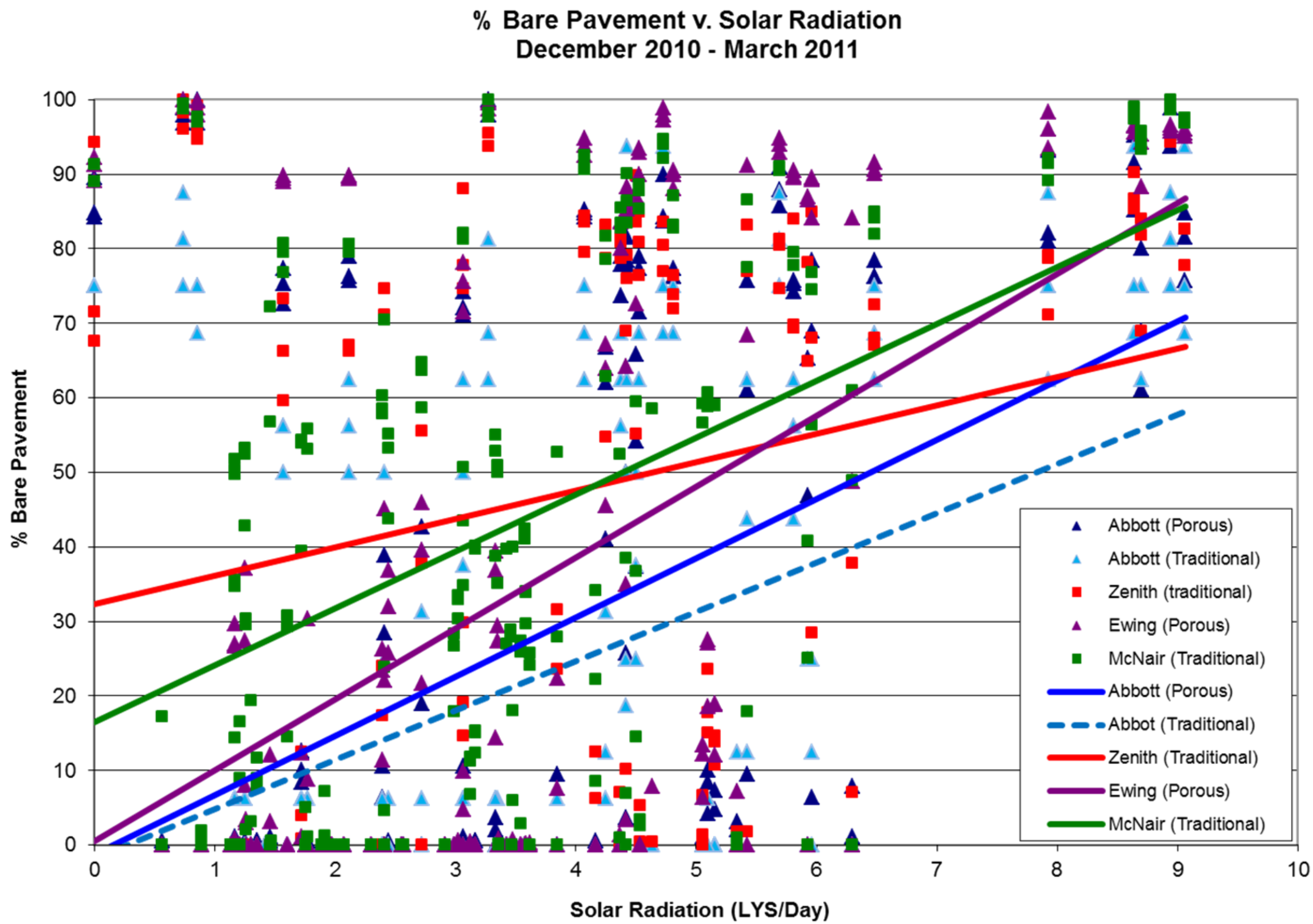


Figure 4.11. Percent bare pavement versus solar radiation.

Zenith, traditional

1/16/10

←

Abbott, porous

1/16/10

→

Zenith, traditional

1/17/10

Abbott, porous

1/17/10

Zenith, traditional

1/17/10

Abbott, porous

1/17/10

5.0 Conclusions

The research questions posed by the study were:

1. Estimate the effectiveness of porous asphalt in *reducing the need for salt* as a deicer.
2. Determine if porous asphalt can hold up to *rigors* of regular city street use.
3. Determine short term and likely long term *maintenance requirements*.
4. Measure the *water quality and quantity benefits* in both sandy and clay/loam subgrades

5.1 EFFECTIVENESS

How effective is porous asphalt in reducing the need for salt as a deicer? The test and paired intersections were selected so as to be very similar in slope, aspect and exposure. Overall, it appeared that there were similar amounts of net bare pavement between the salted, traditional pavement and the porous pavement. However, there was a lag time before the start of melting for the porous pavement. While there was not enough data to adequately quantify that relationship, during the period of the study it ranged from a few hours to several hours. This lag should be explored further to better understand the conditions defining its duration.

Reviewing the amount of bare pavement compared to ambient air temperature and solar radiation showed there were the expected positive relationships, but those relationships did not appear to be statistically different between the traditional and porous pavement. The factor that did appear to explain variability in the amount of bare pavement was temperature at depth. For the porous pavement, that was the temperature at the bottom or the rock reservoir, 17-18 inches below the surface compared to 18 inches in the traditional pavement subgrade. It appears that the thermal insulation of the rocky, porous reservoir provides an advantage at lower air temperatures, an effect that is more pronounced on the sand subgrade compared to the clay subgrade. In conclusion, porous pavement is most effective for ice control and water quality when it is on sand subgrade with open exposure.

5.2 DURABILITY

There have been few installations of porous asphalt pavement on residential city streets that have been in place more than ten years. Can this type of pavement stand up to the rigors of regular residential street use, including automobiles, delivery and garbage trucks, snow plows, etc.? Over three winters, the porous pavements have been very durable. Plow operators have not had to make an adjustment to their plowing techniques on the porous segment compared to traditional pavement.

Pavement condition was assessed using the standard Pavement Rating System for Asphalt Pavements published by the Minnesota Asphalt Paving Association (MAPA 2012). Both the test and control segments at Site 1 were rated 100 on a 100-point scale, meaning no signs of distress could be observed by eye. Both segments at Site 2 were rated 99, with the control section losing one point for some minor drainage deficiency, and the test section losing one point for some signs of excess binder.

While the pavements have been in place only for a few years, they show no signs of distress or winter damage, and with proper maintenance should maintain that usability and durability.

5.3 MAINTENANCE

In the short term, maintenance is limited to at least bi-yearly vacuum sweeping and patching as necessary. Since the pavements are so effective at infiltrating, it is likely that the drainage capacity would be maintained even if patches such as those necessary to make utility service repairs are necessary and are made with traditional rather than porous pavement. It would be an interesting exercise to calculate how much of the surface could be replaced with traditional pavement and still maintain not only infiltrative capacity but also the ability to maintain a dry surface in winter.

In Minnesota the typical traditional pavement maintenance cycle is to perform a seal coat six to eight years after the pavement is laid, and then perform a mill and overlay to refresh the wear course at the ten to twelve year mark. A final seal coat at fifteen to seventeen years would maintain the pavement until reconstruction at the 20-25 year mark. This pavement maintenance cycle could not be completed on porous pavement and maintain its porosity and infiltration capacity. Long-term maintenance may be limited to patching and crack sealing if necessary to maintain pavement integrity.

5.4 WATER QUALITY

Porous pavement infiltrates or filters stormwater runoff, providing a water quality benefit. Site 1 on the sand subgrade did not appear to discharge during the project, and may have infiltrated 100 percent of the rainwater falling on it and any runoff directed to it, eliminating any pollutants that runoff may have contained or conveyed. Site 2 on the clay subgrade did discharge quite frequently. Water quality samples taken were inconclusive as to the amount of pollutant load reduction that may have been gained as the runoff moved through the reservoir to the outlet pipe.

Where a sand subgrade is available to provide that high level of infiltration, porous pavement may have a beneficial water quality impact. Hypothetically, if porous pavement was placed on all four legs of the sixteen suitable intersections in the neighborhood surrounding Site 1, the following reductions might be expected:

- Annual volume reduction = 15.4 acre-feet
- TP annual load reduction = 10 lb/yr
- TSS annual load reduction = 356 lb/yr
- Prevented application of 1,920 pounds chloride

While the amount of chloride prevented would be small, the Site 1 neighborhood discharges to Crystal Lake, which is impaired by excess nutrients and needs to reduce its TP load from the watershed by just over 300 pounds per year. Given the fully built nature of the drainage area, that load reduction will have to occur through small reductions from implementing numerous BMPs in the watershed as opportunities arise.

5.5 SUMMARY

In summary, this study suggests the following conclusions:

- The porous, unsalted sections and the traditional, salted sections appeared to achieve *similar net bare pavement.*
- There is a time lag for porous to melt to dry pavement, from a few hours to 6+ hours.
- The rock reservoir underlying the porous sections appears to provide an *insulation* capability, which allows infiltration even in subfreezing weather and prevents refreeze of snowmelt.
- The porous pavement on sand subgrade appeared to *infiltrate 100%* of runoff and snowmelt, which has the benefit of reducing stormwater runoff volumes and pollutant loads.
- The porous pavement on clay subgrade discharged during warm weather rain; it is unknown whether discharge during snowmelt due to the level logger freezing in the reservoir layer.
- Given that Site 1 did not appear to discharge at all, it should be explored whether it is possible to *reduce the depth of* the large rock reservoir on sand subgrades with good infiltration, thus reducing cost.
- The porous sections appear *durable*, with no snowplow damage after two to three winters.
- The Shingle Creek watershed and City of Robbinsdale will be evaluating pavement condition and required maintenance yearly for next several years to continue to assess the utility of porous pavements on low-volume residential streets.
- Porous pavement intersections are promising as an ice-control BMP but may be limited in application.

6.0 References

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