Preventive Maintenance Study – Interim Report

WA-RD 871.1

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Special Project Report

Interim Report
Special Project

Preventive Maintenance Study

Washington State – Statewide Locations

Crack Seal

Chip Seal

Dig Out

Blade Patch

Washington State Department of Transportation
Engineering and Regional Operations
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16. ABSTRACT

This interim report details the performance of 69 test sites treated with various preventive maintenance treatments. The maintenance treatments applied included crack sealing, full lane chip sealing, wheel path chip sealing, dig outs (mill and fill), blade patching, and combinations of dig outs and crack sealing and dig outs and full lane chip sealing. The test sites are visited yearly to assess the condition of both the maintenance treatment and the pavements in which they were installed. The cost of the treatments ranged from $3.12 to $42.34 per square yard.

All of the treatments were found to be effective in stabilizing the condition of pavements a minimum of two years and as much as four years. The stabilization of the pavement's condition has allowed WSDOT to extend the time before rehabilitation and extend the pavement life.

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Executive Summary

Hot mix asphalt preventive maintenance techniques such as crack sealing, chip sealing, dig outs and blade patching are well-established maintenance practices. The goal of the study was to determine the effectiveness of each of the preventive maintenance treatments at extending pavement life and, using cost data, define which treatments are the most cost effective. This is a preliminary report that is being issued four years after the first test sites were installed. The study extends to June 30, 2018 at which time the final report will be published.

Sixty-nine test sites are being evaluated on a yearly basis since initiation of the study in 2012. The oldest sites are approaching the age of five years, the newest two years. The test sites are located in all of the Regions with the exception of the Northwest Region, with the majority located in the Eastern and Olympic Regions. The preventive maintenance techniques applied are crack sealing (12 sites), chip sealing (4 sites), wheel path chip seal patching (2 sites), wheel path chip seal rut filling (5 sites), dig outs (21 sites), dig outs plus crack sealing (4 sites), dig outs plus chip sealing (6 sites), blade patching (9 sites), and four control sites that received no treatment.

At the initiation of this study, it was assumed that the performance of the various preventive maintenance treatments would be differentiated by the failure of some treatments as contrasted with the good performance of others. This has not been the case as virtually all of the treatments are performing equally well in preserving the pavements for extended periods of time. In fact, there is very little change in the condition of any of the preventive maintenance treatments over the four-year evaluation period. The one exception is the pavements that received the combination treatment of dig outs plus chip sealing. Flushing of the chip seal over the dig out locations is common to all of these sites.

The pavements that received the preventive maintenance treatments are in excellent condition with 95 percent receiving no additional treatment. Only three test sites needed additional treatment, two that required additional dig outs due to the very poor condition of the original pavement and one that required crack sealing of a longitudinal crack that reflected through a blade patch. Three of the four control sites that received no treatment required emergency attention due to complaints from the public.

The costs of the various treatments were compared by calculating the cost to treat a strip of pavement one foot in length and one lane wide (12 feet). This allows treatments that do not cover an entire lane, such as wheel path chip sealing, to be compared side by side with treatments that do cover the full lane. The costs ranged from the cheapest treatment (crack sealing at $1.14) to the most expensive (dig outs plus chip sealing at $19.57 for the one foot by 12 foot strip). The unit costs of the treatments, in order, were wheel path chip seal rut filling ($2.76), wheel path chip seal patching ($4.44), full lane chip sealing ($7.08), blade patching ($10.00), dig outs ($12.49) and dig out plus crack sealing ($13.63).

The best practice in choosing a maintenance strategy to fix a particular pavement distress is to choose the option that will provide the lowest annual cost. In general, the least expensive

techniques of crack sealing and wheel path chip sealing are very effective treatments when the distress is confined to the wheel paths. The slightly more expensive full lane chip sealing could be used more frequently than currently utilized because it can mitigate a number of pavement distress conditions, but must be constructed correctly. Dig outs are recommended when the distress is severe but generally confined in a small area. The very expensive dig outs plus crack sealing is necessary when the pavement is in very poor condition and the adjacent pavements needs crack sealing. The use of dig outs plus chip sealing is not recommended due to the problems with flushing or chip loss and high cost of the combined treatment of dig outs and chip sealing. Blade patching is a necessary practice to address specific types of distress such as settlement or a rough ride.

The conclusions below are from the performance of the treatments and the pavements that received the treatments. These may change depending on the performance data collected prior to the end of the study in 2018.

- The findings in this study show that the guidance in WSDOT's Instructional Letter and Integrated Pavement Preservation Plan is successfully extending pavement life. For these test sites pavement life has been extended two to four years as noted below.

- Crack sealing, full lane chip sealing and dig outs are capable of extending pavement life a minimum of four years (oldest test site has been in place for 50 months); wheel path chip sealing a minimum of three years (oldest test site has been in place for 38 months); and blade patching a minimum of two years (oldest test site has been in place for 27 months). This extension of life is the result of stabilizing the structural condition of the pavement.

- The Preventive maintenance work done in this study maximizes the time before a Capital Preservation Project must be completed (that is a reconstruction or resurfacing project) providing that the right treatment is done at the right time.

- Early treatment using crack sealing or chip sealing is more cost effective than allowing the pavement to deteriorate into a condition that requires the use of the more expensive treatments like dig outs or combinations of dig outs plus crack sealing or dig outs plus chip sealing.

Background

Hicks et al, 2000 defined pavement preventive maintenance as "planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without increasing the structural capacity)." Preventive Maintenance differs from traditional maintenance in that it addresses pavement distress at an earlier point in the life of a pavement. This maintenance is designed to be performed before the pavement shows significant distress and to forestall the need for reactive maintenance. For example, the sealing of cracks when they first reach 1/4 inch in width will likely forestall the need for dig outs of complete sections of pavement at a later date. The result is cost savings because pavements last longer before needing complete rehabilitation.

Study Purpose

Hot mix asphalt (HMA) preventive maintenance techniques such as crack sealing, chip sealing, dig outs and blade patching are well-established maintenance practices. The purpose of this study is to determine the effectiveness of these preventive maintenance treatments at extending pavement life. The study will use cost data to determine which treatments are the most effective in maintaining pavements in a safe and serviceable condition.

Integrated Approach to Pavement Preservation

The Washington State Department of Transportation (WSDOT) has adopted a policy for pavement preservation called the Integrated Pavement Preservation Plan (IPPP). IPPP encompasses the entire life-cycle of the pavement from initial construction to eventual reconstruction (see Figure 1). During the life of a pavement, WSDOT uses various preservation activities to mitigate the effects of traffic, climate and studded tires and to extend the life of a pavement to the maximum extent possible. The primary goal of the IPPP is to extend pavement life a minimum of two years by performing strategic maintenance.

The IPPP can be broken down into three primary categories consisting of Capital Preservation Projects, Preventive Preservation, and Reactive Preservation. Preventive Preservation is divided into two categories: Strategic Preservation and Emerging Needs Preservation. Each of these categories is part of the integrated process.

A. Capital Preservation Projects (initial construction, reconstruction or resurfacing)
B. Preventive Preservation (preventive maintenance treatments)
    1. Strategic Preservation
    2. Emerging Needs Preservation
C. Reactive Preservation (emergency preventive maintenance treatments)

Capital Preservation Projects are delivered at the proper time to minimize the overall life-cycle cost of the pavement, Preventive Preservation is performed as needed throughout the pavement life-cycle to extend pavement life (the time between Capital Preservations Projects), and Reactive Preservation is performed to address emergency needs that typically occur late in the pavement life-cycle or due to unforeseen circumstances.

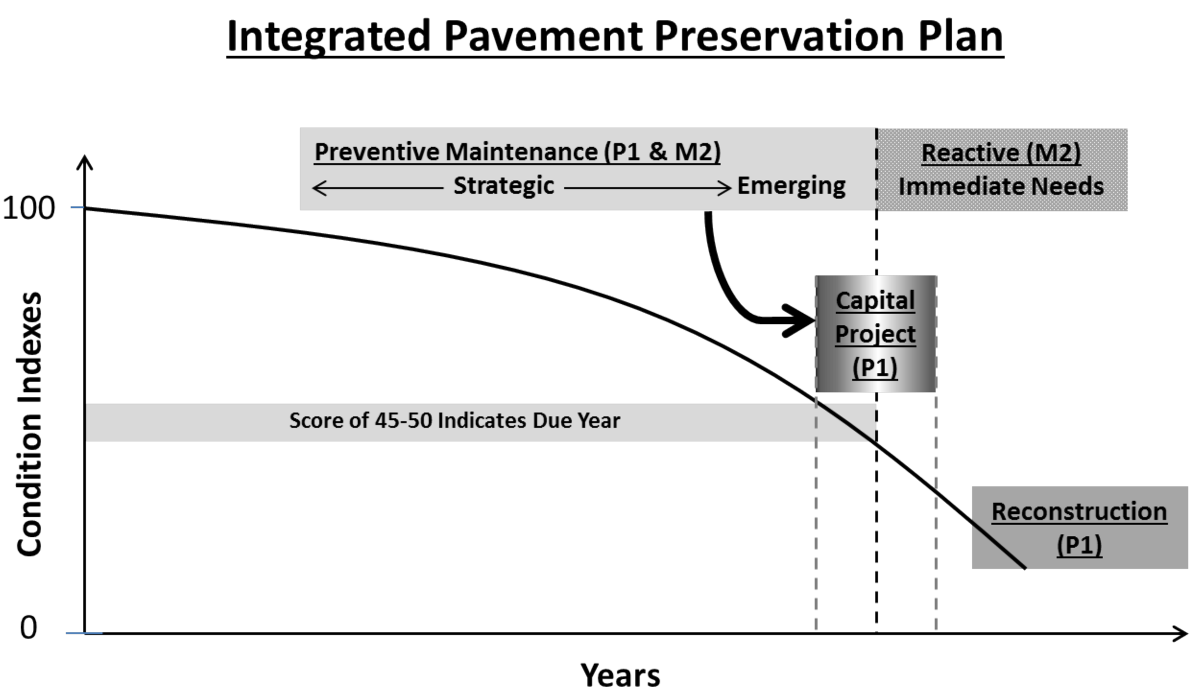

Figure 1. Integrated pavement preservation plan.

Relationship of IPPP to WSPMS

The IPPP is related to the Washington State Pavement Management System (WSPMS) through the changes that occur in the pavement structural condition (PSC) over time. The WSPMS conducts a pavement condition survey on the entire State highway system over a two year cycle (high traffic routes every year and lower traffic routes every other year). The survey rates the pavement condition based on a scale of 0-100 in three areas: a) pavement cracking and patching, b) rutting, and c) roughness. The amount of cracking and patching determine the pavement structural condition (PSC). The PSC relates to the pavement's ability to carry loads. A cracked pavement will be weaker and have less ability to carry a heavy truck than a pavement without cracks. The curved line in Figure 1 is the PSC of a pavement over time. Pavements begin life with a PSC score of 100, which declines over time as cracking occurs. Pavements are scheduled for capital preservation projects when their PSC reaches a value of 45-50. Preventive maintenance treatments are used to extend the time between initial construction and the point when a capital preservation project needs to be scheduled. Preventive maintenance treatments may also improve the pavement rutting condition (PRC) and pavement profile condition (PPC).

This study has classified sections of pavement with PSC scores between 60 and 100 to be in the Strategic Category of the Preventive Maintenance portion of the curve. Pavement sections with PSC scores between 40 and 59 are in the Emerging Category of the Preventive Maintenance portion of the curve. Pavements with PSC scores less than 40 fall into the Reactive Category portion of the curve.

Capital Preservation Projects

Capital Preservation Projects are pavement resurfacing and reconstruction projects funded by the Highway Construction Program (P1 subprogram). Capital Preservation Projects are contracted out and account for the bulk of the P1 subprogram budget. Extending the life of Capital Preservation Projects would result in significant savings to WSDOT. Reconstruction of bituminous pavement is rarely necessary so most of the savings from preventive preservation is due to increasing time between capital preservation projects. The contracted resurfacing work includes; (1) thin HMA inlays or overlays (about 1.8 inches) designed to restore the HMA surface and protect the underlying pavement structure, and (2) chip seals designed to seal and protect the underlying pavement. HMA inlays and overlays need to be performed every 12 to 17 years and chip seals every 6 to 10 years.

It is expected that under the IPPP, no Capital Preservation Project will be funded on a section of pavement that has not had one or more Preventive Preservation treatments. This initial treatment, sometimes referred to as the "first touch" has been shown to be a very cost-effective strategy to extend pavement life (WSDOT Instructional Letter #4077.02). The first touch treatments are described in the following sections on Preventive Preservation. First touch does not apply to Reactive Preservation, which addresses urgent pavement repairs necessary to preserve pavement integrity.

Preventive Preservation

Preventive Preservation is work designed to maximize the time between Capital Preservation Projects (that is reconstruction or resurfacing). Examples of this type of work include crack sealing, dig outs, chip sealing, and blade patching. Strategic Preservation and Emerging Needs Preservation are the two components of Preventive Preservation.

Strategic Preservation

This is planned work performed early in the pavement life cycle, usually at least two years prior to a scheduled Capital Preservation Project. The work may be performed by maintenance crews (Maintenance) or it may be performed as a construction project (Contract) if the size or complexity of the work goes beyond the Maintenance crews. Highway Construction (P1) funds are used for Strategic Preservation (PSC of 60 to 100).

Emerging Needs Preservation

Emerging Needs Preservation (PSC of 40 to 59) is planned work that focuses on pavement areas predicted to fail in the next several months to a year. Its goal is to reduce the need to perform Reactive Preservation in the future, with a secondary goal of extending pavement life. Maintenance (M2) funds are used for Emerging Needs Preservation and WSDOT maintenance crews perform the repairs.

Reactive Preservation

Reactive Preservation is urgent pavement repair used to address failing pavements and to mitigate the impacts of visible pavement deterioration. By its nature, Reactive Preservation (PSC of 0 to 39) is unplanned and must be performed immediately. The intent is to correct the problem and restore the road surface to a serviceable condition. Maintenance (M2) funds are used and the work is done by maintenance crews.

Study Design

The study was designed to mimic the real world of pavement maintenance so that the data collected would be valid. WSDOT Regions were asked to provide the research team with locations that were scheduled for preventive maintenance in the upcoming year. Many of the locations submitted in the initial years of the study were pavements that had reached their due year (sites in the Emerging and Reactive categories), but funding was not available for complete rehabilitation. Site visits were made by the research team to document the existing condition of the pavements with photos and written comments. The Region maintenance crews would then apply the preventive maintenance technique they determined was the best choice for the condition of the pavement at each location. Next, the research team would make a second visit to each location and document the type of treatment applied and its condition. This process was repeated for each year of the study for the new test sites for that year as well as the older sites. The process provided documented evidence of the condition of the treatments at each test site as well as the condition of the untreated pavement that surrounds the area that was treated. It is important to note that the research team did not dictate the locations or types of treatments used by the maintenance crews.

Test Site Summary Information

A total of 69 preventive maintenance test sites are currently being monitored using photographs and visual inspections (see Appendix A for test site descriptions). In addition, the Washington State Pavement Management System (WSPMS) is being used to document the PSC of the pavements at each test site. The preventive maintenance techniques that have been used include crack sealing, chip sealing, dig outs, blade patching and various combinations of more than one technique. The test sites vary in length from 0.10 miles to over 11 miles with an average of 1.74 miles. The most common test site length is 0.50 miles.

The project began in 2012 with additional sites added in 2013, 2014, 2015 and 2016. The following bullets summarize the year of treatment, the WSDOT Region where the treatment was applied, the type of treatment, the pavement type and the preservation category of the treatments. Figure 2 shows the location of the Regions, rainfall averages, and test site locations.

Year of Treatment

- 16 treated in 2012
- 14 treated in 2013
- 9 treated in 2014
- 21 treated in 2015
- 9 treated in 2016

Region

- 30 Olympic Region
- 29 Eastern Region
- 3 South Central Region
- 4 Southwest Region
- 3 North Central Region

Treatment Type

- 12 - Crack Seal
- 4 - Chip Seal
- 2 - Wheel Path Chip Seal Patching
- 5 - Wheel Path Chip Seal Rut Filling
- 2 - Crack Seal + Chip Seal
- 21 - Dig Outs
- 4 - Dig Outs + Crack Seal
- 6 - Dig Outs + Chip Seal
- 9 - Blade Patch
- 4 - Control (no treatment)

Pavement Type

- 52 HMA
- 17 BST

WSPMS Condition Category

- 48 - Strategic (PSC 60-100)

- 7 - Emerging (PSC 40-59)
- 14 - Reactive (PSC <40)

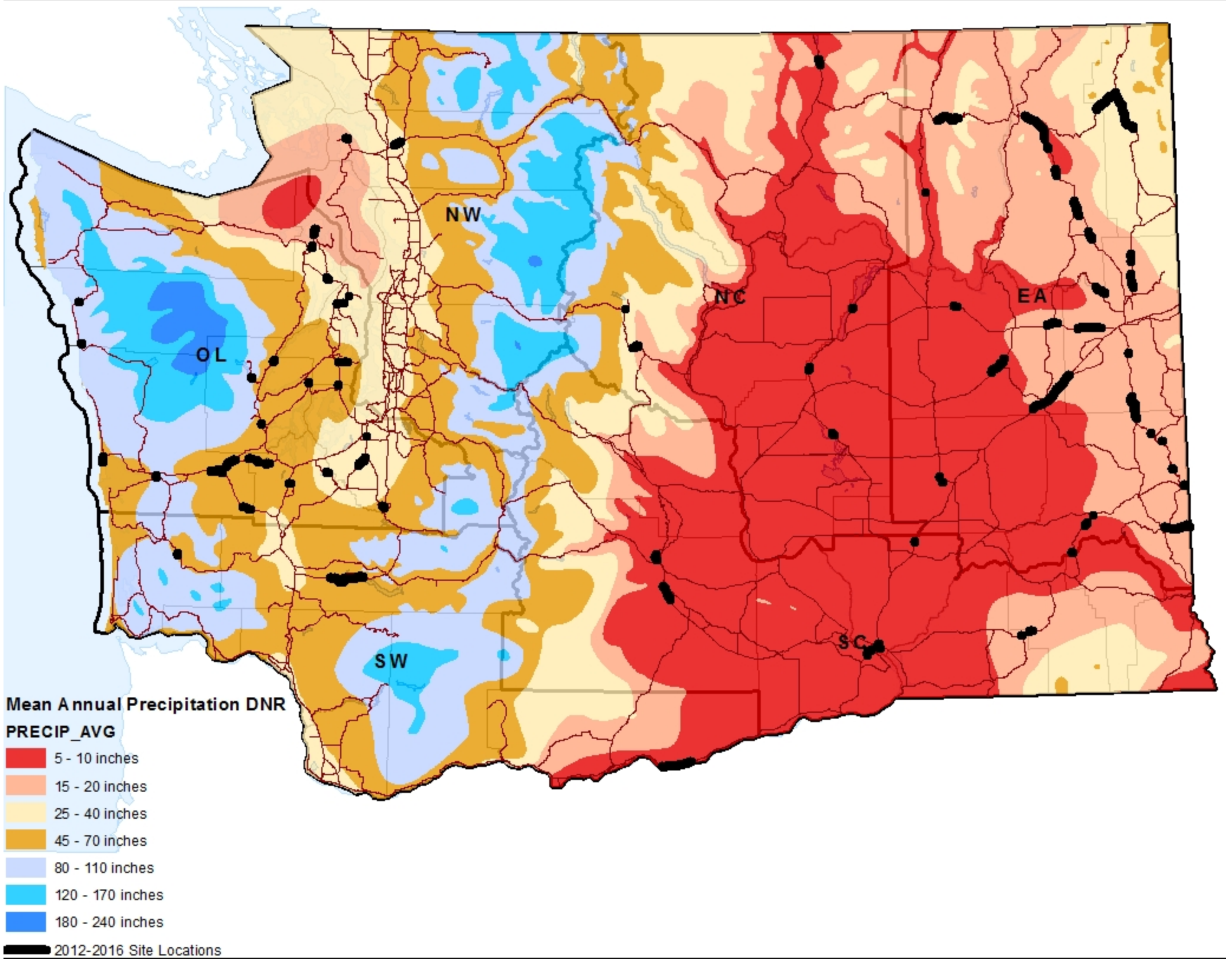

Figure 2. Map showing WSDOT Regions, rainfall averages, and test site locations.

Performance Review Data

The following section uses a photo to represent the current condition of each of the 69 test sites. The sites are organized by the type of treatment applied to the pavement and in order from the oldest to the youngest. The caption on each photo identifies the Region and site number, followed by the State Route location and the PSC category. An example of a given site would be

(OR1, SR-101, Reactive) which would be a site in the Olympic Region on State Route 101 with an average PSC putting it in the Reactive category. The ages noted on the photos are the time in months between installation and the last physical review in the fall of 2016.

A second series of photos illustrate the condition of the maintenance treatments over time for selected test sites in each category. Yearly photo at approximately the same location in these test site show the change or lack of change in the condition of the treatments.

Crack Sealing

The twelve crack sealing test sites ranged in age from three to 50 months at the 2016 inspection. The photos illustrate that the crack sealant is preventing further deterioration of the crack with no spalling or potholing present. Some traffic wear on the over banded sealant is noticeable on the older test sites. Cracking continues to increase in extent and severity in the cracks that did not receive sealant. This is especially true on sites where cyclic segregation cracking and/or raveling is present. Figures 3-14 show the condition of the 12 test sites at the most recent inspection.

Figure 3. OR1, SR101, Reactive, age 50 months.

Figure 4. OR6, SR8, Strategic, age 39 months.

Figure 5. OR8, SR8, Ramp Reactive, age 39 months.

Figure 6. OR9, SR105, Strategic, 39 months.

Figure 7. NC2, SR2, Strategic, age 26 months. No spalling or potholes.

Figure 8. SC1, SR97, Strategic, age 14 months. No spalling or potholes.

Figure 9. ER41, SR395, Strategic, age 2 months.

Figure 10. OR20, SR12, Strategic, age 3 months.

Figure 11. OR21, SR12, Strategic, age 3 months.

Figure 12. OR31, SR115, Strategic, age 3 months.

Figure 13. OR32, SR160, Strategic, age 4 months.

Figure 14. OR34, SR302, Strategic, age 3 months.

One of the older crack sealing sites, OR1, on SR101 in the Olympic Region is a good example of the effectiveness of crack sealing as a preventive maintenance technique. The photos (Figures 15 through 19) show the same location, at different angles, in the area that was sealed. This was a Reactive category pavement prior to treatment. The age of the site was 50 months at the 2016 inspection.

Figure 15. OR1, SR101, prior to treatment. Cracks exceed 1/4 inch in width in places.

Figure 16. OR1, SR101, one year after installation. Slight wear of sealant over banding.

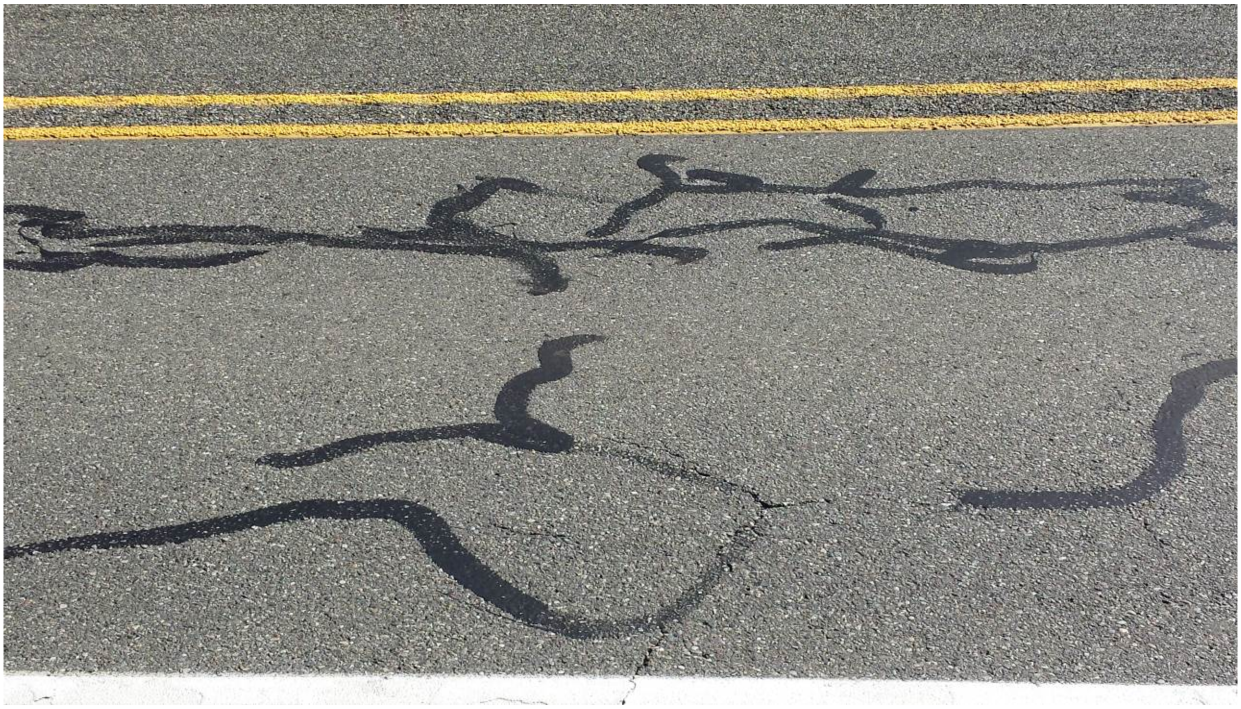

Figure 17. OR1, SR101, two years after installation. There is not much change from year one.

Figure 18. OR1, SR101, three years after installation. There is not much change from year one.

Figure 19. OR1, SR101, four years after installation. There has not been much change in the condition of the crack sealant since year one.

Test site OR1 is in excellent condition with no spalling of the cracks or potholes forming after 50 months of traffic and environmental exposure. The over banding of the crack sealant is wearing in the wheel paths; however, this is typical of the older crack sealing sites. There is virtually no change in the crack sealant itself. Additional cracks have formed and cracks have become longer in the areas not sealed. It might be argued, based on the relatively unchanged condition of the cracks that were not sealed, that the pavement would have performed equally as well if maintenance had not been performed. It might also be argued that the width and depth of all of the cracks would have increased if the sealant had not been there to prevent this from occurring. Also, the addition of moisture entering the pavement structure through the cracks may have increased the rate of deterioration of the pavement had the cracks not been sealed.

Full Lane Chip Sealing

The four full lane chip seal test sites ranged in age from 14 to 50 months at the 2016 inspection. Longitudinal reflection cracks have been observed on two of the four projects, occurring at 14 months after installation on one site and at 21 months on the other; however, these cracks do not currently have an adverse impact on the overall performance of the roadway. Delamination and spalling is occurring on one of the remaining sites and the other is suffering from a partial loss of aggregate. Slight flushing was noted on one site. In general, the performance of the full lane chip seals has been lower than expected. Figures 20-23 show the condition of the chip seals at the four test sites.

Figure 20. OR1b, SR101, Reactive, age 50 months. Longitudinal cracking noted at 21 months. Slight flushing in the wheel paths.

Figure 21. OR3b, SR101, Reactive, age 50 months. Delamination and spalling noted.

Figure 22. OR16, SR16, Strategic, age 38 months. Longitudinal crack and pumping of fines noted at 14 months.

Figure 23. OR22, SR101, Strategic, age 14 months. Loss of aggregate at bottom of superelevation.

One of the older full lane chip sealing test sites, OR1b on SR101 in the Olympic Region provides visual evidence of the effectiveness of chip sealing as a preventive maintenance technique. Figures 24 through 28 show the same relative location in the test site over a 50-month period.

Figure 24. OR1b, SR101, prior to treatment. Alligator cracking was noted over the entire lane, but especially severe in the wheel paths.

Figure 25. OR1b, SR101, one year after installation. Slight flushing in the wheel paths, one longitudinal crack in the left wheel path.

Figure 26. OR1b, SR101, two years after installation. Longitudinal crack appears to have "healed". There is slight flushing in the wheel paths.

Figure 27. OR1b, SR101, three years after installation. Longitudinal crack is getting longer and wider. The flushing in the wheel paths is about the same.

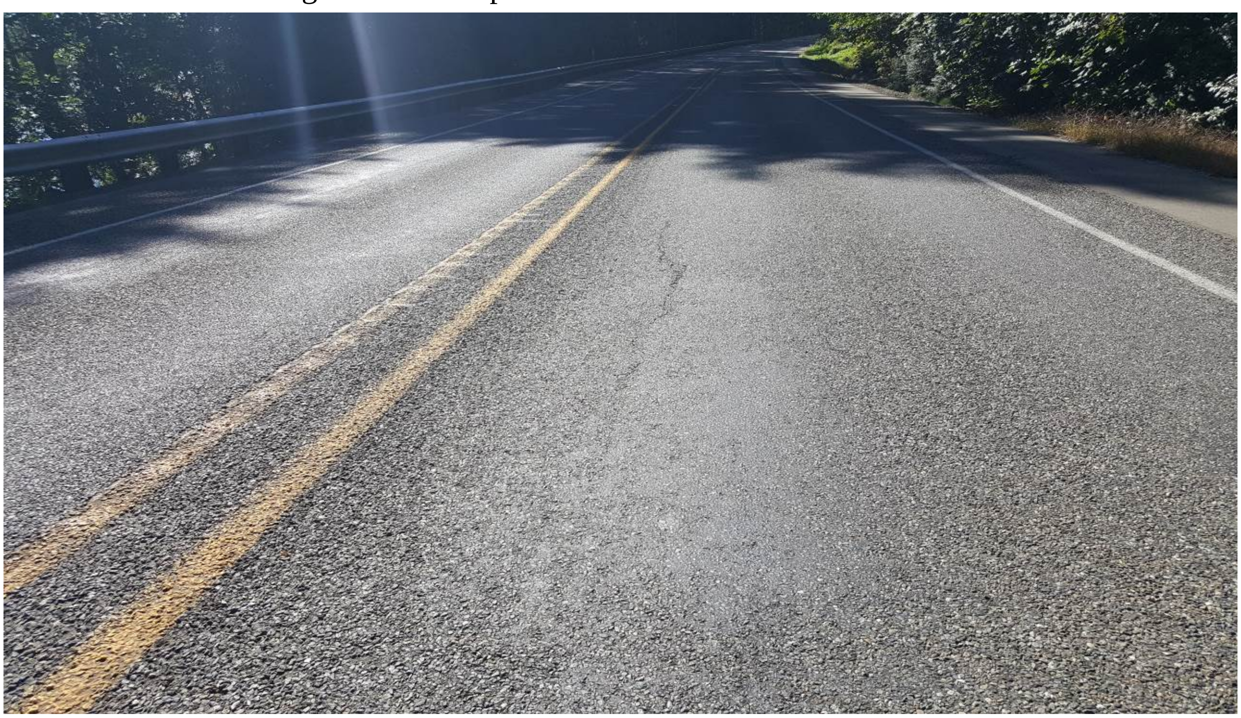

Figure 28. OR1b, SR101, four years after installation. Longitudinal crack condition is about the same, slight rutting and flushing in the wheel paths.

The wheel paths show some flushing and rutting after 50 months of service. The single longitudinal reflection crack became more evident with age, but did not affect the overall performance of the pavement. This is the typical performance of all four of the test sites even though the quality of the chip seal was not what was expected.

Wheel Path Chip Seal Patching

The two wheel path chip seal patching test sites ranged in age from 13 to 38 months at the 2016 inspection. Both are located in the Olympic Region where the wheel path chip sealing is done primarily to address alligator or longitudinal cracking. A longitudinal reflection crack was noted at 10 months on one of the two sites. Some loss of chips was noted along the edges of the seals of the other site. Figures 29 and 30 show the condition of the two test sites at the 2016 site visit.

Figure 29. OR12, SR20, Strategic, age 38 months. Longitudinal reflection crack and flushing noted at 10 months.

Figure 30. OR23, SR104, Strategic, age 13 months.

OR12 on SR 20 was selected as an example of wheel path chip seal patching. The pavement prior to treatment was in the Strategic category. Figures 31 through 35 show the same location in the test site that was installed in 2013.

Figure 31. OR12, SR20, prior to treatment. Longitudinal and alligator cracking is present in the wheel paths.

Figure 32. OR12, SR20, immediately after installation. Wheel path chip seal patching was well constructed.

Figure 33. OR12, SR20, one year after installation. No change to the wheel path chip seal patching.

Figure 34. OR12, SR20, two years after installation. Some loss of aggregate but no reflection cracking.

Figure 35. OR12, SR20, three years after installation. Some loss of aggregate but no reflection cracking.

OR12 represents the typical performance of the wheel path chip seal patching sites. The chip seals are still in good condition after three years in spite of some reflection cracking and the loss of aggregate on one of the two sites.

Wheel Path Chip Seal Rut Filling

The five wheel path chip seal rut filling sites ranged in age from two to 37 months at the 2016 inspection. These sites, located primarily in the Eastern Region, are done to fill ruts formed by studded tires. This work consisted of one shot chip seals using aggregate from existing stockpiles. A finer choke aggregate was usually applied after the initial application of larger chips. A full lane chip seal, constructed in 2015, covered one of the sites thus eliminating it from this category of treatment. The remaining sites are performing very well. A transverse crack was noted at 12 months on one site. Figures 36-40 show the condition of the five test sites at the 2016 inspection.

Figure 36. ER7, SR20, Strategic, age 37 months. Full lane seal applied in 2015.

Figure 37. ER10, SR2, Strategic, age 24 months. Cracking noted at 12 months.

Figure 38. ER15, SR395, Strategic, age 12 months.

Figure 39. ER18, SR31, Strategic, age 14 months.

Figure 40. ER40, SR270, Strategic, age 2 months.

ER7 was selected to demonstrate the placement of a wheel path chip seal rut fill site. The chip seal on ER7 was placed in 2013 on SR20 and is the oldest of all of the rutting wheel path sites. The Eastern Region overlaid the site with a full lane chip seal in 2015, thus ending further evaluation of this site. Figures 41-45 show the condition of the wheel path chip seals for the two years following installation and the site after the full lane chip seal was applied. The full lane chip seal applied in 2015 showed no signs of rutting, which was the reason for the initial wheel path chip seals.

Figure 41. ER7, SR20, prior to installation. Rutting is visible in the wheel paths.

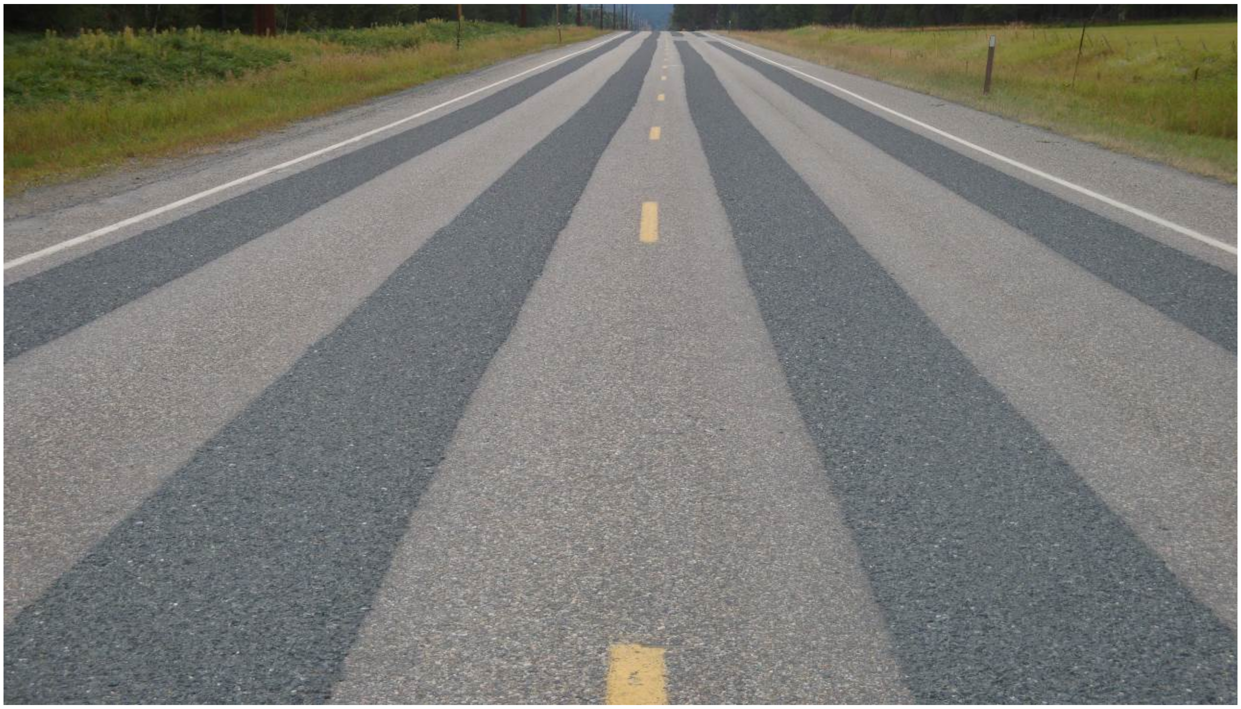

Figure 42. ER7, SR20, a few months after installation. Excellent looking wheel path chip seal rut filling.

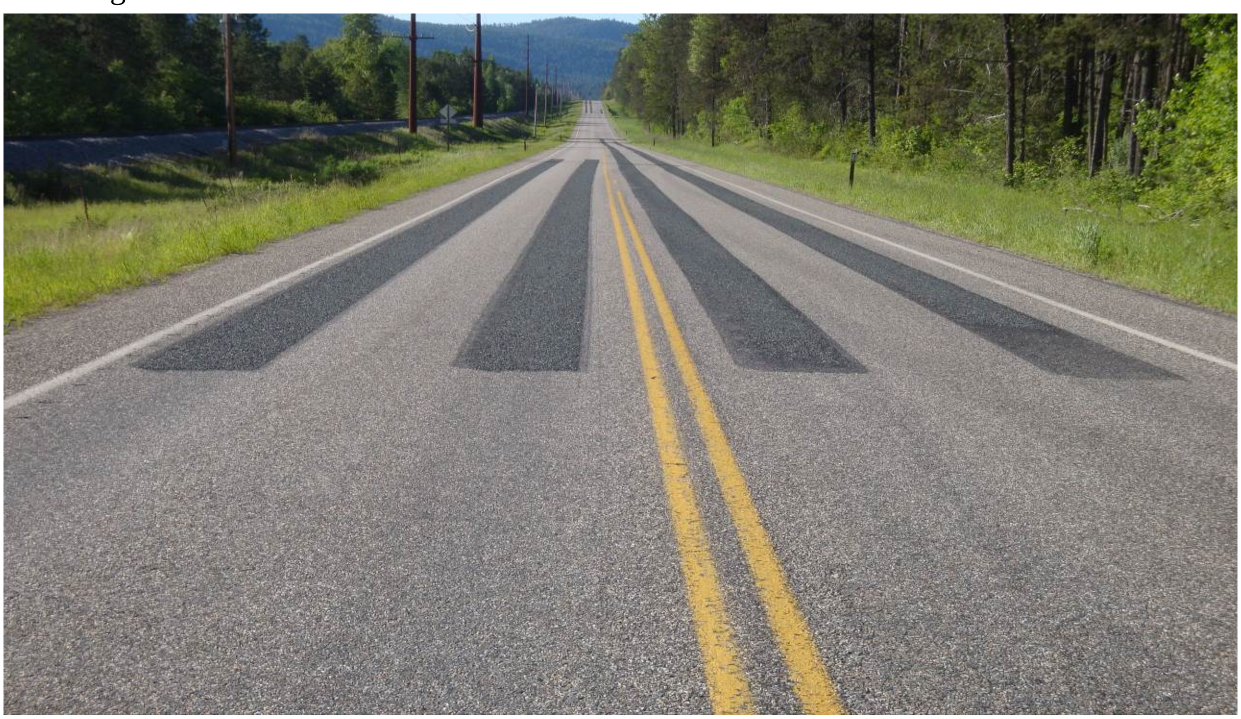

Figure 43. ER7, SR20, one year after installation. Wheel path chip seal rut fills are in excellent condition.

Figure 44. ER7, SR20, two years after installation. No change in chip seals.

Figure 45. ER7, SR20, three years after installation. Full lane chip seal installed under Contract 8728, US 2 ET AL 2015 Eastern Region Chip Seal.

These photos represent the typical good performance that was noted for the wheel path chip seals rut fill sites. The ruts have been filled and the chip seals show no signs of flushing or excessive chip loss.

Crack Sealing Plus Chip Sealing

The two test sites that combined crack sealing with chip sealing ranged in age from 26 to 50 months at the 2016 inspection. Cracks on the SR101 project were wide block cracks. The sealed cracks can be seen as shadowing under the seal, but none have reflected through the seal. The cracks on SR155 were very wide and deep transverse thermal cracks. The cracks were sealed with a special sealant called Nuvo Gap. The chip seal was applied one year after the Nuvo Gap was installed. In both cases crack sealing prior to a chip seal prevented reflection cracking although on the SR155 project it appears that there may be cracks forming adjacent to the filled cracks. Figures 46 and 47 show the condition of the two test sites in 2016.

Figure 46. OR1a, SR101, Reactive, age 50 months. Underlying crack sealant can be seen as shadowing.

Figure 47. NC1, SR155, Strategic, age 26 months. Transverse crack locations are visible.

OR1a on SR101 was selected to provide visual evidence of the effectiveness of this combination of preventive maintenance techniques. Figures 48 through 52 show the same location in the test site. This is a Reactive category test site.

Figure 48. OR1a, SR101, prior to treatment. Alligator and longitudinal cracking noted.

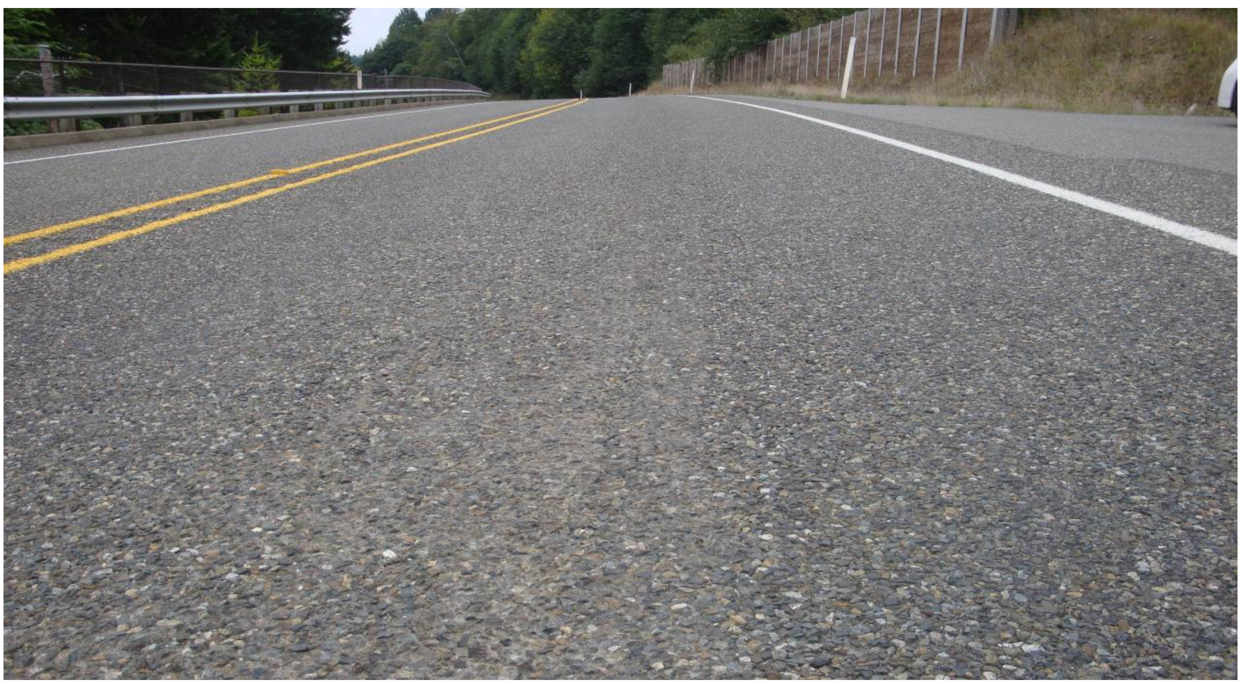

Figure 49. OR1a, SR101, one year after installation. Chip seal looks excellent.

Figure 50. OR1a, SR101, two years after installation. Shadowing of the sealed cracks visible.

Figure 51. OR1a, SR101, three years after installation. Very slight flushing and shadowing of the sealed cracks.

Figure 52. OR1a, SR101, four years after installation. Slight amount of rutting beginning to appear. Flushing does not seem to be a big issue.

Performance of the chip seal placed over the crack sealed pavement is excellent. The appearance of the chip seal changes over time to show a shadowing of the underlying crack sealing, but this has not been detrimental to the performance of the chip seal.

Dig Outs

The twenty-one dig out test sites ranged in age from 2 to 50 months at the 2016 inspection. The patches are performing very well on most of the projects. Reflection of transverse cracks from underlying PCCP was noted on two projects, one at age 10 months after installation and the other at age 12 months. Three test sites required the installation of additional dig out patches adjacent to the existing patches due to continued deterioration of the surrounding pavement. The patches themselves vary in workmanship with some well compacted, others with segregated areas around the edges or throughout and some with high and low areas that collect water; however, despite these inconsistencies the patches themselves have performed very well. Figures 53-73 show the condition of the 21 test sites at the 2016 inspection.

Figure 53. OR2, SR8, Emerging, age 50 months. Excellent performance.

Figure 54. ER3, SR291, Emerging, age 50 months. Additional dig outs added in 2015. Transverse reflection crack noted at 10 months after treatment. More dig outs are scheduled for installation in 2017.

Figure 55. ER2/4, US2, Emerging, age 50 months. Additional dig outs installed in 2013 and 2015.

Figure 56. ER5, SR2, Reactive, age 38 months. Transverse reflection crack noted at the age of 10 months after treatment.

Figure 57. OR5, SR7, Strategic, age 39 months. No problems with patches, pavement continues to deteriorate adjacent to the patches.

Figure 58. OR8a, SR101, Reactive, age 39 months. Excellent performance.

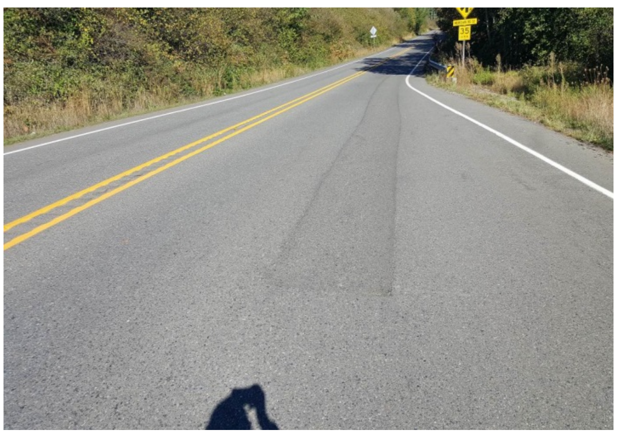

Figure 59. OR10, SR510, Strategic, age 39 months. Excellent performance.

Figure 60. OR11, SR20, Strategic, age 38 months. Raveling of patch edges noted at 25 months.

Figure 61. OR15, SR12, Emerging, age 38 months. Full lane chip seal in 2016.

Figure 62. ER9, SR395, Strategic, age 25 months. Additional dig outs installed in 2015.

Figure 63. ER11, SR270, Emerging, age 25 months. Transverse crack at 12 months after installation.

Figure 64. SW5, SR6, Strategic, are 14 months. More dig outs added in 2015.

Figure 65. ER17, SR395, Strategic, age 14 months. Excellent performance.

Figure 66. ER24, SR127, Strategic, age 13 months. Excellent performance.

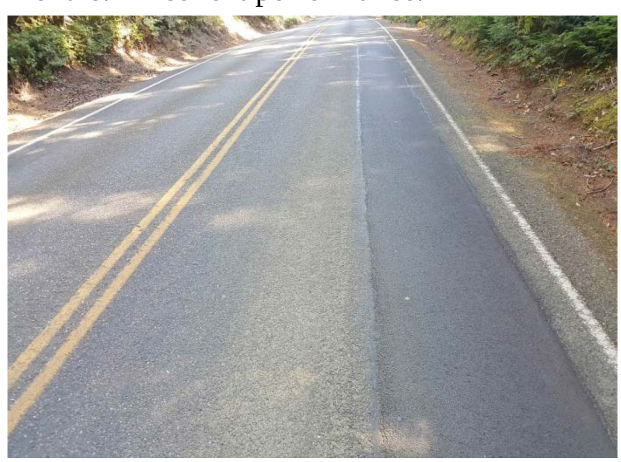

Figure 67. ER29, SR27, Strategic, age 14 months. Excellent performance.

Figure 68. OR24, SR119, Strategic, age 14 months. Excellent performance.

Figure 69. OR28, SR507, Strategic, age 14 months. Excellent performance.

Figure 70. SC5, SR12, Strategic, age 15 months. Excellent performance.

Figure 71. SW6, SR6, Strategic, age 3 months. Excellent performance.

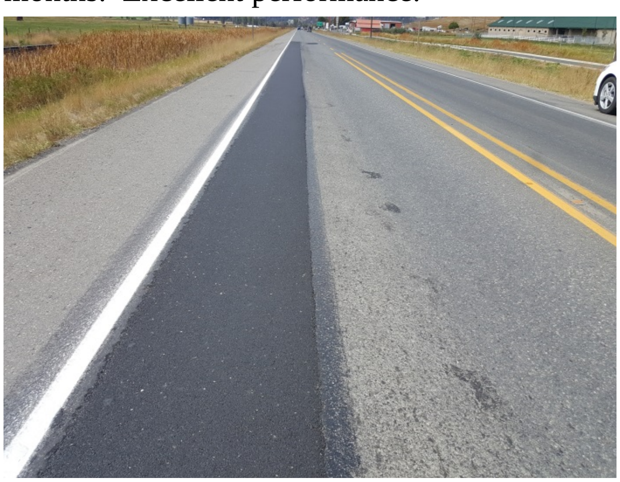

Figure 72. ER42, SR20, Strategic, age 2 months. Excellent performance.

Figure 73. ER43, SR395, Strategic, age 2 months. Excellent performance.

OR2 located on SR8, one of the oldest sites, is shown in the following series of yearly photos. Figures 74 through 78 show the same location over a four plus year span of time. OR 2 was an Emerging category site prior to treatment.

Figure 74. OR2, SR8, prior to treatment. Alligator cracking in the left wheel path. This is not the same location as the following photos which had alligator cracking in both wheel paths.

Figure 75. OR2, SR8, one year after installation. Dig out patch looks excellent.

Figure 76. OR2, SR8, two years after installation. No change in condition of patch.

Figure 77. OR2, SR8 three years after installation. Slight rutting in the patch.

Figure 78. OR2, SR8 four years after installation. No change in past year.

The dig out patch shown in the photos has not changed in appearance for 50-months except for some slight rutting. The workmanship on the dig out patches varies from site to site, but the performance is uniform across all sites.

Another example was selected due to the large number of dig out test sites. Figures 79 through 83 show the condition of the dig outs on test site OR5 located on SR7. OR5 was a Strategic category pavement prior to treatment.

Figure 79. OR5, SR7, prior to treatment. Not at same location as following photos.

Figure 80. OR5, SR7, immediately after installation. Dig out patches look good. They appear to be related to utility cuts in original pavement.

Figure 81. OR5, SR7, one year after installation. No change in the dig out patches.

Figure 82. OR5, SR7, two years after installation. No change in the dig out patches.

Figure 83. OR5, SR7, three years after installation. No change in the dig out patches.

The appearance of the dig out patch does not change as it ages. Rutting in the wheel paths is the only visible change in the patch after 37 months. The two examples that were shown are typical of the dig out test sites, each with excellent performance.

Dig Outs Plus Crack Sealing

A total of four test sites combined dig outs and crack sealing. The age of the sites ranged from 13 to 50 months at the 2016 inspection. Both the crack sealing and dig out patches are performing very well at all test sites. Reflection cracking through the patches on one site was noted at 38 months after installation. It does not appear to be reflecting from the underlying PCCP. The oldest site, ER1 is a Reactive category pavement that was in very poor condition. Additional dig outs and crack sealing were installed to keep the pavement in a serviceable condition. Figures 84-87 show the condition of the five test sites at the last inspection.

Figure 84. ER1, SR2, Reactive, age 50 months. Additional dig outs and crack sealing done in 2015.

Figure 85. OR4, SR3, Strategic, age 39 months.

Figure 86. OR27, SR307, Strategic, age 14 months.

Figure 87. SC4, SR395, Strategic, age 13 months. Portions of the test site are in the Reactive category.

The site selected to represent dig outs plus crack sealing was OR4 located on SR3 that was installed in 2013. Figures 88 through 92 show the same location in the test site over a span of three years. OR 4 was a Strategic category pavement prior to treatment.

Figure 88. OR4, SR3, prior to treatment. Longitudinal, transverse and alligator cracking.

Figure 89. OR4, SR3, a few months after installation. Crack sealing looks good, dig out patches appear under filled in spots.

Figure 90. OR4, SR3, one year after installation. Dig out patch and crack sealing look unchanged.

Figure 91. OR4, SR3, two years after installation. No change in dig out patch or crack sealing.

Figure 92. OR4, SR3, three years after installation. No change in dig out patch or crack sealing.

The appearance of the dig out patch and the sealed cracks do not change over the 39 months on this test site.

Dig Outs Plus Chip Sealing

There are six test sites with a combination of dig outs and chip sealing. They ranged in age from 26 to 51 months at the 2016 inspection. Reflection cracking was noted on two of the sites, one at 9 months after installation and the other at 12 months. Flushing over the underlying dig out patches is present on five of the six test sites. It is possible that no dig outs patches were installed on OR3 and that the site only received a full lane chip seal, which did not flush. Figures 93-98 show the condition of the six test sites at the 2016 inspection.

Figure 93. OR2a, SR8, Strategic, age 50 months. Flushing over the dig out patches.

Figure 94. OR3, SR101, Reactive, age 50 months. Excellent performance.

Figure 95. SW1, SR14, Reactive, age 51 months. Transverse reflection cracking and flushing noted at 9 months after installation.

Figure 96. SW1a, SR14, Reactive, age 51 months. Transverse and longitudinal reflection cracking and flushing noted at 12 months after installation.

Figure 97. OR14, SR7, Strategic, age 39 months. Dig out patches flushing through the chip seal at 27 months.

Figure 98. NC3, SR207, Strategic, age 26 months. Dig out patches flushing through the chip seal after 12 months.

OR2a on SR8 was selected as representative of the dig outs plus chip seal sites. Figures 99 through 103 show the same location in the test site over a span of four years. OR2a was a Strategic category pavement prior to treatment.

Figure 99. OR2a, SR8, prior to treatment.

Figure 100. OR2a, SR8, one year after installation. Slight flushing in the wheel paths over the dig out patches.

Figure 101. OR2a, SR8, two years after installation. Increased flushing in the wheel paths over the dig out patches.

Figure 102. OR2a, SR8, three years after installation. Increased flushing in the left wheel path throughout the length of the chip seal.

Figure 103. OR2a, SR8, four years after installation. Flushing has remained about the same as in 2015.

The type of flushing observed on this site was typical of five of the six sites. The flushing was caused by an excess of asphalt binder that results from a combination of the binder from the patch and the new binder used for the chip seal process. The common practice used to prevent this type of flushing is to wait for a period of time before applying the chip seal. One year is advisable, but shorter periods of time may also work.

Blade Patch

The nine test sites with blade patches ranged in age from 12 to 27 months at the 2016 inspection. A summary of the test sites follows. Most of the patches are only one year old so are in good condition although surface roughness and raveling along the edges is common. One of the older blade patches had cracking reflecting through the patch after only 13 months which was sealed in 2016. A 2015 site has a transverse crack reflecting through the patch. Figures 104-112 show the condition of the nine test sites at the 2016 inspection.

Figure 104. ER8, SR195, Strategic, are 27 months. Blade patch used to fill wheel path ruts.

Figure 105. ER9a, SR395, Strategic, age 25 months. Transverse and longitudinal cracking reflecting through the patch at 13 months. It is possible that this could have been a paver and not a blade patch.

Figure 106. ER20, SR272, Strategic, age 12 months. Transverse crack reflecting through the patch.

Figure 107. ER26, SR127, Strategic, age 13 months. Good Performance.

Figure 108. ER31, SR21, Strategic, age 13 months. Good Performance.

Figure 109. ER32, SR20, Strategic, age 12 months. Fair performance.

Figure 110. ER33, SR270, Strategic, age 12 months. Good performance.

Figure 111. ER34, SR271, Strategic, age 12 months. Good performance.

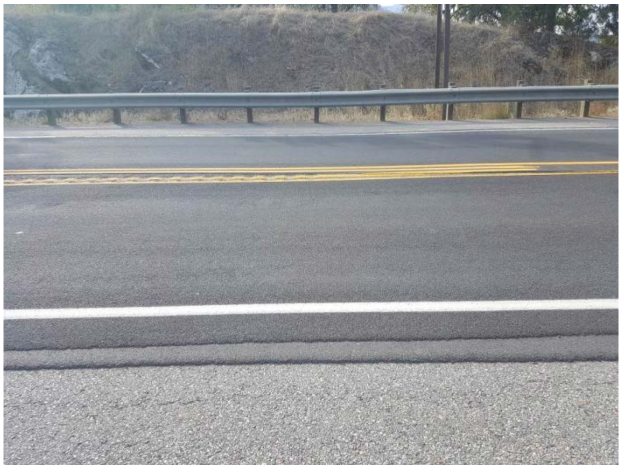

Figure 112. ER37, SR395, Emerging, age 13 months. Excellent performance.

One of the older blade patch sites in the Eastern Region ER9a on SR395, a Strategic category pavement, provides visual evidence of the performance of this preventive maintenance technique. Figures 113 through 116 show the same location over a span of two years.

Figure 113. ER9a, SR395, prior to treatment. Longitudinal, transverse and alligator cracking.

Figure 114. ER9a, SR395, a few months after installation. Blade patch looks excellent.

Figure 115. ER9a, SR395, one year after installation. Some wear of the blade patch at each end. Transverse cracks reflected through the blade patch after only one year.

Figure 116. ER9a, SR395, two years after installation. Longitudinal reflection cracking has been sealed. Note slight flushing in the left wheel path.

It was only one year before reflection cracking required crack sealing of the blade patch. The cracking is the result of the underlying cement treated base. Other common issues with blade patches are raveling at the ends where it is feathered into the existing pavement and raveling on the surface of the patch due to low density. The patches have preserved the pavement in a condition that allows safe travel and prevented further deterioration of the underlying pavement for a short period of time, but typically needs to be removed when performing rehabilitation.

Control Sections

Four test sites that were set aside in 2012 as control sections where no preventive maintenance treatments would be applied. All of the control sites continued to deteriorate with three of the four receiving emergency maintenance due to complaints from the public. The only control site not receiving attention was OR3a where the cracking continues to increase in both extent and severity. Control sections were not included beyond year 2012 due to the rapid deterioration of the pavement that often required an emergency fix. Figures 117-120 show the condition of the four control sections at the 2016 inspection.

Figure 117. OR3a, SR101, Reactive, at 2016 inspection.

Figure 118. ER1a, SR2, Reactive, at 2016 inspection. Dig outs, crack sealing and patching were necessary to preserve the roadway.

Figure 119. ER2a, SR2, Reactive, at 2016 inspection. Dig outs, crack sealing and patching were necessary to preserve the roadway.

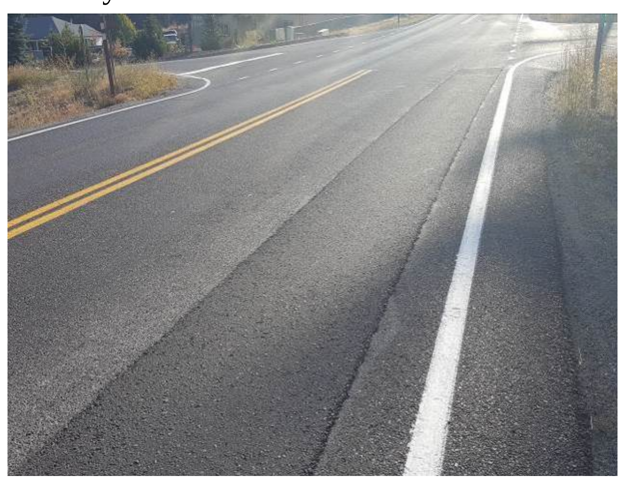

Figure 120. ER3a, SR291, Emerging, at 2016 inspection. Dig outs, crack sealing and patching were necessary to preserve the roadway.

The one site in the Olympic Region on SR101 that did not receive preventive maintenance during its life (OR3a) is shown over a span of four yours (Figures 121-125). This is a Reactive category pavement.

Figure 121. OR3a, SR101, condition in 2012, the year that the other sections were treated.

Figure 122. OR3a, SR101, one year after the other sections were treated. Cracking looks severe due to moisture in the cracks.

Figure 123. OR3a, SR101, two years after the other sections were treated. Vegetation growing in the wider cracks.

Figure 124. OR3a, SR101, three years after the other section were treated. Cracks are wide but not spalling.

Figure 125. OR3a, SR101, four years after the other sections were treated. Cracks are wide and beginning to spall.

There was no maintenance applied to this particular control section and, as a result, the cracks get wider becomes more extensive. It should be noted that this is a very low traffic roadway as compared to the other control section test sites. Close examination of the last photo shows some spalling of the pavement on the sides of the wider crack.

Performance

There are two performance factors addressed in this study. The first is the performance of the preventive maintenance treatment. The second is the performance of the pavement that received the treatment. Table 1 summarizes both performance factors for each test site. The treatment performance column describes the condition of the treatment and the years it has been in place. The pavement performance column indicates whether the pavement required additional treatment and when it was applied. If no treatment was required, it is indicated that pavement life was extended for a certain period of time. Test sites that required additional treatment are tinted purple.

Table 1. Preventive maintenance treatment and pavement performance of the test sites.

Site	Year	PSC Category	Treatment Performance	Pavement Performance
Crack Sealing (12 Test Sites)				
OR1	2012	Reactive	Cracks are still sealed after 4+ years.	No additional treatment required, pavement life extended 4+ years.
OR6	2013	Strategic	Cracks are still sealed after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR8	2013	Reactive	Cracks are still sealed after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR9	2013	Strategic	Cracks are still sealed after 3+ years.	No additional treatment required, pavement life extended 3+ years.
NC2	2014	Strategic	Cracks are still sealed after 2+ years.	No additional treatment required, pavement life extended 2+ years.
SC1	2015	Strategic	Cracks are still sealed after 1+ year.	No additional treatment required, pavement life extended 1+ year.
ER41	2016	Strategic	New site in 2016, no performance rating to date.	
OR20	2016	Strategic	New site in 2016, no performance rating to date.	
OR21	2016	Strategic	New site in 2016, no performance rating to date.	
OR31	2016	Strategic	New site in 2016, no performance rating to date.	
OR32	2016	Strategic	New site in 2016, no performance rating to date.	
OR34	2016	Strategic	New site in 2016, no performance rating to date.	
Full Lane Chip Sealing (4 Test Sites)				
OR1b	2012	Reactive	Chip seal is in poor condition after 4+ years due to rutting and flushing a longitudinal reflection crack.	No additional treatment required, pavement life extended 4+ years.
OR3b	2012	Reactive	Chip seal is in fair condition after 4+ years due to delamination and spalling of section placed on a patch.	No additional treatment required, pavement life extended 4+ years.
OR16	2013	Strategic	Chip seal is in fair condition after 3+ years due to flushing in the wheel paths.	No additional treatment required, pavement life extended 3+ years.
OR22	2015	Strategic	Chip seal is in good condition after 1+ year. Minor chip loss and flushing.	Pavement life extended 1+ year.

Table 1. (Continued).

Site	Year	PSC Category	Treatment Performance	Pavement Performance
Wheel Path Chip Seal Patching (2 Test Sites)				
OR12	2013	Strategic	WP seals in good condition after 3+ years. Minor chip loss. No flushing	No additional treatment required, pavement life extended 3+ years.
OR23	2015	Strategic	WP seals in good condition after 1+ year. No flushing	No additional treatment required, pavement life extended 1+ year.
Wheel Path Chip Seal Rut Filling (5 Test Sites)				
ER7	2013	Strategic	WP seals in good condition after 3+ years. Minor chip loss, no flushing. Full lane chip seal applied in 2016.	No additional treatment required, pavement life extended 3+ years.
ER10	2014	Strategic	WP seals in good condition after 2+ years. No flushing.	No additional treatment required, pavement life extended 2+ years.
ER15	2015	Strategic	WP seals in good condition after 1+ year. Slight flushing.	No additional treatment required, pavement life extended 1+ year.
ER18	2015	Strategic	WP seals in good condition after 1+ year. No flushing.	No additional treatment required, pavement life extended 1+ year.
ER40	2016	Strategic	New site in 2016, no performance rating to date.	
Crack Seal Plus Chip Seal (2 Test Sites)				
OR1a	2012	Reactive	Chip seal in good condition after 4+ years with only no cracking reflecting through the chip seal.	No additional treatment required, pavement life extended 4+ years.
NC1	2014	Strategic	Chip seal in good condition after 2+ years. Sealed cracks (Nuvo Gap sealant) are visible but not cracked.	No additional treatment required, pavement life extended 2+ years.
Dig Outs (21 Test Sites)				
OR2	2012	Emerging	Dig out patches in good condition after 4+ years. Transverse reflection cracking.	No additional treatment required, pavement life extended 4+ years.
ER2/4	2012	Emerging	Dig out patches in good condition after 4+ years. Transverse reflection cracking	Additional dig out patches required after 1 and 3 years.
ER3	2012	Emerging	Dig out patches in good condition after 4+ years Transverse reflection cracking.	No additional treatment required, pavement life extended 4+ years.

Table 1. (Continued).				
Site	**Year**	**PSC Category**	**Treatment Performance**	**Pavement Performance**
Dig Outs (21 Test Sites continued)				
ER5	2013	Reactive	Dig out patches in good condition after 3+ years. Transverse reflection cracks.	No additional treatment required, pavement life extended 3+ years.
OR5	2013	Strategic	Dig out patches in very good condition after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR8a	2013	Reactive	Dig out patches in very good condition after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR10	2013	Strategic	Dig out patches in very good condition after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR11	2013	Strategic	Dig out patches in very good condition after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR15	2013	Emerging	Dig out patches in very good condition after 3+ years. Full lane chip seal applied in 2016.	No additional treatment required, pavement life extended 3+ years.
ER9	2014	Strategic	Dig out patches in very good condition after 2+ years.	No additional treatment required, pavement life extended 2+ years.
ER11	2014	Emerging	Dig out patches in very good condition after 2+ years. One reflection crack.	No additional treatment required, pavement life extended 2+ years.
SW5	2014	Strategic	Dig out patches in very good condition after 2+ years.	No additional treatment required, pavement life extended 2+ years.
ER17	2015	Strategic	Dig out patches in very good condition after 1+ year. Transverse reflection cracks just beginning to show	No additional treatment required, pavement life extended for 1+ year.
ER24	2015	Strategic	Dig out patches in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
ER29	2015	Strategic	Dig out patches in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
OR24	2015	Strategic	Dig out patches in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
OR28	2015	Strategic	Dig out patches in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.

Table 1. (Continued).

Site	Year	PSC Category	Treatment Performance	Pavement Performance
Dig Outs (Continued)				
SC5	2015	Strategic	Dig out patches in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
SW6	2015	Strategic	Dig out patches in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
ER42	2016	Strategic	New site in 2016, no performance rating to date.	
ER43	2016	Strategic	New site in 2016, no performance rating to date.	
Dig Outs Plus Crack Sealing (4 Test Sites)				
ER1	2012	Reactive	Dig outs and crack sealing in good condition after 4+ years.	Additional dig outs and crack sealing required after 3 years.
OR4	2013	Strategic	Dig outs and crack sealing in good condition after 3+ years.	No additional treatment required, pavement life extended 3+ years.
OR27	2015	Strategic	Dig outs and crack sealing in good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
SC4	2015	Strategic	Dig outs and crack sealing in good condition after 1+yrs.	No additional treatment required, pavement life extended 1+ year.
Dig Outs Plus Chip Sealing (6 Test Sites)				
OR2a	2012	Strategic	Chip seal flushing in wheel paths over dig out patches after 4+ years. Longitudinal reflection crack.	No additional treatment required, pavement life extended 4+ years.
OR3	2012	Reactive	Chip seal in good condition after 4+ years. Minor loss of chips, but no flushing. Wider crack reflecting through chip seal.	No additional treatment required, pavement life extended 4+ years.
SW1	2012	Reactive	Chip seal flushing in wheel paths and cracks reflecting through after 4+ years.	No additional treatment required, pavement life extended 4+ years, however roadway is still in very poor condition due to lack of structure.
SW1a	2012	Reactive	Chip seal is flushing in the wheel paths and cracks are reflecting through the seal after 4+ years.	No additional treatment required, pavement life extended 4+ years, roadway is in very poor condition. due to lack of structure.

Table 1. (Continued).

Site	Year	PSC Category	Treatment Performance	Pavement Performance
Dig Outs Plus Chip Sealing (Continued)				
OR14	2013	Strategic	Chip seal is flushing in the wheel paths at 3+ years but not as a result of dig out patches.	No additional treatment required, pavement life extended 3+ years.
NC3	2014	Strategic	Chip seal is flushing in wheel paths over the dig out patches after 2+ years.	No additional treatment required, pavement life extended 2+ years.
Blade Patch (9 Test Sites)				
ER8	2014	Strategic	Patch is in fair condition after 2+ years.	No additional treatment required, pavement life extended 2+ years.
ER9a	2014	Strategic	Patch is in fair condition after 2+ years. Longitudinal reflection cracks were sealed in patch.	Additional maintenance was required after 1 year to seal a longitudinal reflection cracking.
ER20	2015	Strategic	Patch is in fair condition after 1+ year. Transverse reflection cracks.	No additional treatment required, pavement life extended 1+ year.
ER26	2015	Strategic	Patch is in good condition after 1+ year. Some raveling noted.	No additional treatment required, pavement life extended 1+ year.
ER31	2015	Strategic	Patch is in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
ER32	2015	Strategic	Patch is in fair condition after 1+ year. Raveling and flushing noted.	No additional treatment required, pavement life extended 1+ year.
ER33	2015	Strategic	WP patches are in poor condition after 1+ year. Flushing and reflection cracking noted.	No additional treatment required, pavement life extended 1+ year.
ER34	2015	Strategic	Patch is in very good condition after 1+ year.	No additional treatment required, pavement life extended 1+ year.
ER37	2015	Emerging	Patch is in poor condition after 1+ year. Delamination and raveling noted.	No additional treatment required, pavement life extended 1+ year.

Table 1. (Continued).				
Site	**Year**	**PSC Category**	**Treatment Performance**	**Pavement Performance**
Control Sections (4 Test Sites)				
OR3a	2012	Reactive	Block and alligator cracking has increased in severity after 4+ years. Vegetation growing in wider cracks.	No additional treatment required, pavement life extended 4+ years.
ER1a	2012	Reactive	Multiple installations of dig out patches throughout the 4+ years.	Additional maintenance was required to maintain the serviceability of the pavement.
ER2a	2012	Reactive	Multiple installations of dig out patches throughout the 4+ years.	Additional maintenance was required to maintain the serviceability of the pavement.
ER3a	2012	Emerging	Multiple installations of dig out patches throughout the 4+ years.	Additional maintenance was required to maintain the serviceability of the pavement.

Maintenance Treatment Performance

A discussion of the performance of the individual preventive maintenance treatment categories follows.

Crack Sealing - The sealants are performing well with some wear showing in the wheel paths. The sealants have not cracked or pulled away from the edges of the crack in any of the test sections.

Chip Sealing - The full lane chip seals are not performing up to expectations. Three of the four sites are flushing in the wheel paths and one has a small area that is delaminating due to an underlying patch that was not addressed prior to the chip seal. Additional maintenance may be required to address the flushing and delamination issues. The performance of the test sites in the study do not compare with the majority of chip seals placed in the state under contract which last from 6-8 years without the early flushing problems noted in the test sites.

Wheel Path Chip Seal Patching – The chip seals placed to fix cracking confined to the wheel paths are performing very well with only minor chip loss and no flushing.

Wheel Path Chip Seal Rut Filling – The chips seals placed to fill ruts are performing very well with only one exhibiting slight flushing.

Crack Sealing Plus Chip Sealing – The chip seals on both of the sites are performing very well. On one site, the crack sealing can be seen as shadowing in the surface of the chip seal, but no cracks have reflected through the chip seal. On the other site, a special sealant (Nuvo Gap) was used to fill very wide transverse thermal cracks in a bituminous surface treatment (BST) pavement prior to the chip seal. The transverse cracks are visible in the chip seal as a slight depression. It appears that a crack has formed at the edge of the sealant; however, it is impossible to be sure that there is an actual crack in the chip seal.

Dig Outs – The performance of the dig outs was outstanding with no flushing or significant distress noted. On a few of the test sites, the patches have transverse cracks whose origin appears to be joints or cracks in the underlying concrete pavement. The compaction of the HMA in the dig outs varies from site to site from poor to good, which allows the accumulation of moisture; however, it does not appear that this has resulted in distress detrimental to their performance.

Dig Outs Plus Crack Sealing – The performance of the dig outs plus cracking sealing was excellent. One of the sites required additional dig outs and sealing due to the very poor condition of the original pavement.

Dig Outs Plus Chip Sealing – Flushing is a major problem on most of the chip seals placed over dig out patches. Some of the flushing is a result of an excess of asphalt binder due to the underlying fresh patch and, in other cases, the origin of the flushing is the chip seal. For the sites where the chip seal is the origin of the flushing the patches seem to intensify the flushing, but the flushing problem is more likely related to the materials and techniques employed to place the seals. Two of the projects had chip sealed pavements with significant structural deficiencies that resulted in widespread transverse cracking reflecting through the chip seal.

Blade Patch – The blade patches are performing adequately to cover deficiencies in the roadway. The condition of the patches ranged from very good to poor. Longitudinal cracks reflected through the blade patch on one test site. Raveling was also noted on several test sites where the patch feathers into the existing pavement.

Control Sections - The control sections continued to deteriorate over time, as expected, with three of the four receiving emergency treatment to fix the escalating distresses.

In summary, the observations indicate that the primary treatments, that is, crack sealing, chip sealing, wheel path chip seal patching, wheel path chip seal rut filling, dig outs and blade patching, are all performing very well with only minor problems. The yearly photos at the same location in the test sites show very little change in the condition of the treatments over time. The combination treatment of dig outs plus chip sealing is the one category of treatment that is not exhibiting good performance. The flushing problems on a majority of these test sites would indicate that placing a chip seal over dig out patches in the same year is not a strategy that should be encouraged. The excellent performance of dig outs without a chip seal supports this observation.

Pavement Performance

The performance of the pavements that were treated with the various preventive maintenance techniques is overall excellent with 95 percent receiving no additional treatment. Only three test sites needed additional treatment, two that required additional dig outs due to the very poor condition of the original pavement and one that required crack sealing of longitudinal cracks that reflected through a blade patch. Two of the three sites that required additional treatment were in either the Emerging or the Reactive category with only one in the Strategic category. Note that the four control section sites are not included because it was known that they would probably require treatment due to condition of the pavements; however, it should be noted that the three control sections that required emergency treatment were in the Reactive and Emerging categories. The statistics for the period of time with no additional treatment are shown in Table 2.

Table 2. Pavement performance statistics (excluding control section test sites).

Test Site Age (years)	Sites With No Additional Treatment Required	Total Number of Sites	Percent of Sites
4+	10	12	83
3+	14	14	100
2+	8	9	89
1+	21	21	100
New Test Sites in 2016	9	9	100
Total for all Test Sites	62	65	95

In summary, the performance of the pavements was overall excellent; however, the pavements in the Reactive or Emerging category were the ones that often required additional treatment or, in the case of the control sections, emergency treatment.

WSPMS Performance

The PSC data for each test site were collected to see if the application of the various maintenance treatments made any improvement to the structural condition of the pavements in the test sections (see Appendix B). The data for each year is plotted on a line chart to show the changes in the PSC from one year to the next.

Figure 126 shows the yearly PSC data for the test sites that received preventive maintenance in 2012. The Strategic, Emerging and Reactive categories are delineated on the left side of the graph to show the initial condition of each test site. Patching and crack sealing reduce the PSC, but not as much as unsealed cracks or severe alligator cracking. When preventive maintenance treatments are applied such as crack sealing and dig outs the PSC value is increased if the pavement is in poor condition and stay at a relative constant rate if the pavement is in good condition. The PSC of pavements in the Reactive category may increase into the Emerging category and remain relatively constant year after year if the pavement condition does not change. Conversely, the PSC of a pavement in the Strategic category may decrease into the Emerging category as the pavement continues to deteriorate, but preventive maintenance will maintain it at that level for year after year.

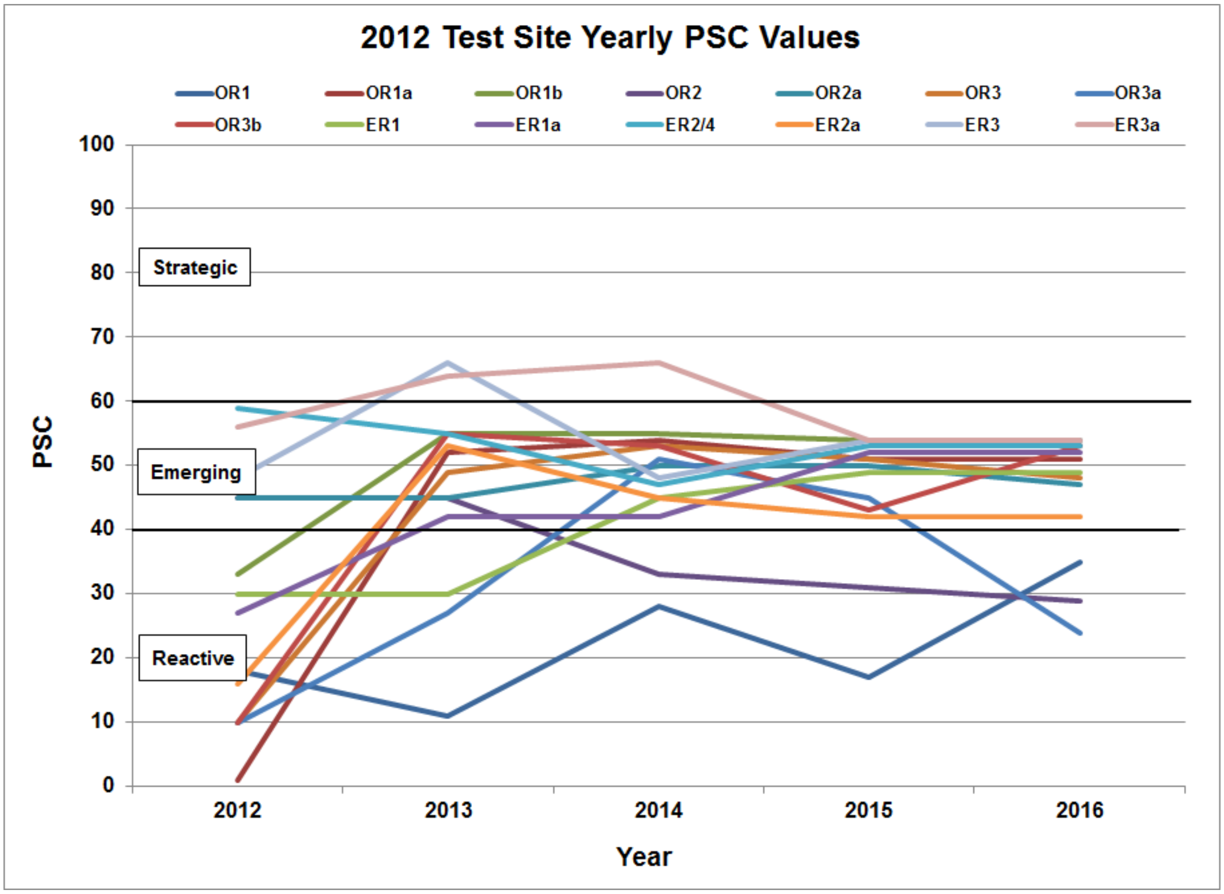

Figure 126. Yearly PSC values for the 2012 test sites.

The preventive maintenance for 2012 would have been installed after the 2012 ratings; therefore, the ratings for 2013, 2014 and 2015 reflect any changes resulting from the treatments. Ignoring the general up-trend from the 2012 to the 2013 ratings, the curves are generally flat for the ratings from 2013 to 2015. The up-trend from 2012 to 2013 can be attributed to the application of the preventive maintenance treatments. All of the 2012 pavements for the 2012 test sites were in the Reactive or Emerging categories, therefore, the improvements in PSC scores is much greater than if the pavements were in the Strategic category. The largest changes are for the test sites that were in the Reactive Category prior to treatment (OR1, OR1a, OR1b, ER1, ER1a, ER2a, ER3a, OR3, and OR3b). These test sites are indicted on the chart and have 2012 PSC values below 39.

The sites in the Emerging category (OR2a, ER3, ER2/4, and ER4) had relatively flat curves showing little improvement in PSC. These test sites are the lines that begin with 2012 PSCs between 40 and 60. This is also reasonable since preventive maintenance is not designed to improve structural condition, but rather preserve it. In summary, the preventive maintenance treatments applied in 2012, generally speaking, preserved Emerging category pavements and improved Reactive category pavements.

Figure 127 shows the yearly PSC data for test sites that received preventive maintenance in 2013.

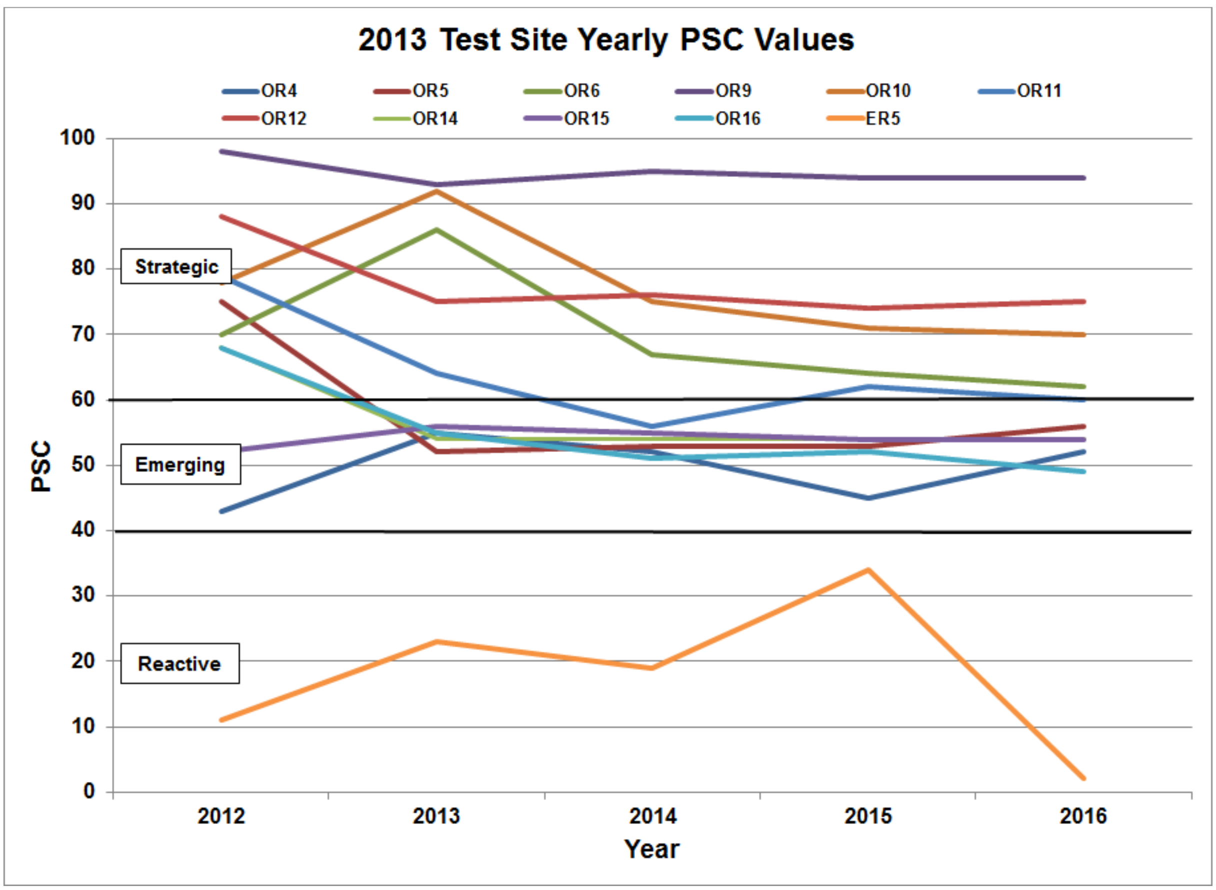

Figure 127. Yearly PSC values for the 2013 test sites.

The preventive maintenance treatments would have been applied after the 2013 ratings, therefore, the 2014 and 2015 values are the ones that reflect the changes due to preventive maintenance and these values are essentially flat. The PSC values for a majority of the test sites decreased slightly between 2014 and 2015. In summary, the preventive maintenance treatments did very little to change the structural condition of the pavement in the test sites, but did preserve the condition of the pavements at the pre-treatment levels.

Figure 128 shows the yearly PSC data for the sites that received preventive maintenance in 2014.

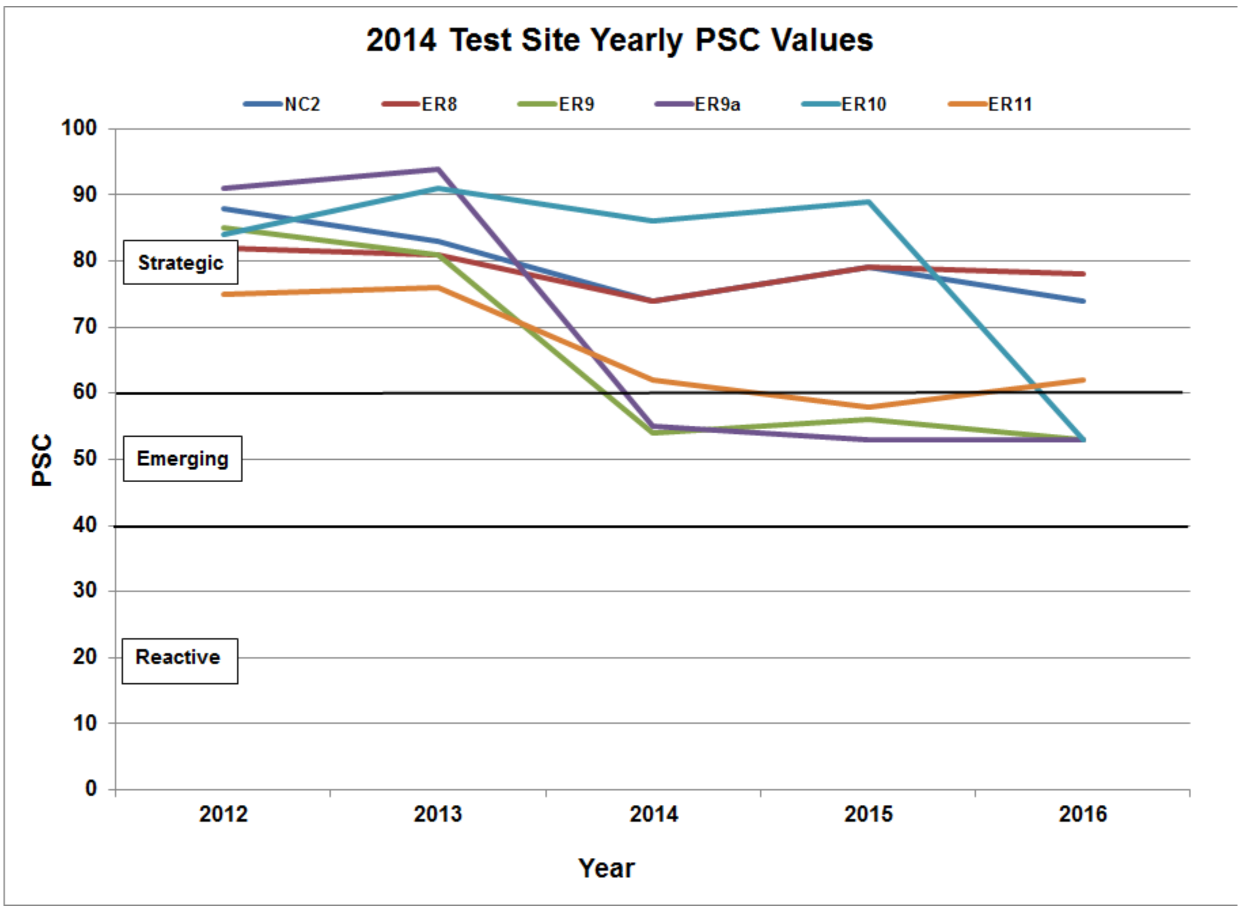

Figure 128. Yearly PSC values for the 2014 test sites.

The PSC ratings for the 2014 test sites were done in the spring of 2014 and the preventive maintenance treatments were applied in the summer of 2014, therefore only the 2015 ratings reflect changes resulting from the treatments. The trend in PSC values is slightly up for four of the sites and slightly down for the other three sites. In summary, the preventive maintenance treatments maintained the PSC values of the pavements prior to treatment.

The 2016 WSPMS ratings are currently not available; therefore, there are no charts for the 2015 test sites.

In summary, the PSC values did not increase for the test site pavements after the treatments were applied except for those test sites with pavements in the Reactive category. The PSC scores for test sites with pavements in the Emerging and Strategic categories generally stay at the same level as they were prior to treatment, indicating that the structural condition of the pavements were stabilized by the maintenance treatment.

Effect of the Condition of the Original Pavement

The original condition of the pavement does not seem be a controlling factor in the performance of the treatments for the majority of the test sites. There are eight test sites with pavements in the Reactive category and five sites in the Emerging category that were not control sections. No additional treatment was required on seven of the eight Reactive category sites and four of the five Emerging category sites. The three test sites that required additional treatment had one site in each of the three pavement structural condition categories. Unfortunately, the small number of Reactive and Emerging category sites does not allow a statistical analysis to determine if the numbers are significant. The PSC charts illustrate that no matter what the original condition of the pavement, treating the parts that are falling apart will delay the need for immediate rehabilitation and extend pavement life.

Two exceptions deserve special mention. Test sites, SW1 and SW1a are BST sites that were in very poor structural condition prior to receiving a large number of dig outs and a chip seal. The current condition of these sites is still very poor with flushing and numerous transverse and longitudinal cracks. No additional treatment has been necessary; however, it is very apparent that additional work is needed to address the structural deficiencies of this roadway. These two plus others such as ER1 and ER2/4 (all Reactive category sites) illustrate that there is a limit to how much preventive maintenance should be done to a section as compared to the cost of complete rehabilitation.

Side by Side Performance Comparisons

The study design did not allow for a comparison of the various treatments one against the other, except for three test locations in the Olympic Region that place several treatment side by side on the same roadway. Below is a discussion of each of these locations.

OR1 – OR1a – OR1b

OR1, OR1a and OR1b were all located side by side on SR 101 along Hood Canal between Eldon and Lilliwaup. It is a two lane roadway (one lane in each direction) classified as a rural-principal arterial. OR1 was treated with crack sealing, OR1a was also crack sealed, but in addition received a chip seal, and OR1b received just a chip seal with no crack sealing (see Figure 129). The site with only crack sealing performed very well with no deterioration of the crack sealant except where traffic had worn down the over-banding. Additional cracking and growth of the existing cracks was noted in the section, but no additional work was required on the site during the four plus years of observation. The site with the crack seal followed by a chip seal was in very good condition with no flushing and no cracks reflecting through from the underlying pavement. No additional work was required on the section for four plus years. The section with only the chip seal did not perform as well as the other two sections with rutting and flushing in the wheel paths and a longitudinal crack reflected through the chip seal. No additional work occurred on the section for four plus years; however, it could be argued that the flushing, rutting and reflection crack may have warranted some additional attention. It could also be argued that crack sealing was the best treatment solution for this particular location knowing that the cost of crack sealing would be much less than the other two treatment choices. The choice depends on how long the pavement needs to be delayed until the next rehabilitation cycle.

Figure 129. OR1, OR1a and OR1b on SR 101. OR1 has crack sealing, OR1a has crack sealing and chip sealing, and OR1b has a chip seal with no crack sealing.

OR2 – OR2a

The next location with multiple treatments was OR2 and OR2a, located on the westbound lanes of SR 8 approaching McCleary. It is a four lane divided roadway (two lanes in each direction) classified as a rural-principal arterial. OR2 received dig outs and OR2a received dig outs and a chip seal (Figure 130). The section with dig outs performed very well with no deterioration of the dig out patches and minor transverse reflection cracks. The dig out patching was only installed in the inside wheel path. The outside wheel path had severe longitudinal cracking that was beginning to show some spalling they intersected transverse cracks. The section that received the chip seal over the digs outs had flushing present in the wheel paths throughout the section with severe flushing over the dig out patches. Longitudinal cracking was also reflecting through the chip seal in the outside wheel path, the same longitudinal cracks not addressed in the section with only the dig outs. Dig outs without the chip seal performed much better than the section with the chip seal due to the flushing of the chip seal; however, both sites lasted four plus years without additional treatment. The application of the chip seal was apparently due to a misunderstanding between the Olympic Region Materials Engineering and Maintenance. The Materials Engineering indicated that the dig outs and chip sealing were alternatives for the treatment and were not meant to be applied in combination. It was difficult to make the right choice on this site. Crack sealing the outside wheel path and omitting the chip seal followed by the chip seal the next summer may have been the optimum fix

Figure 130. OR2 and OR2a on SR8. OR2 received dig outs and OR2a received dig outs and a chip seal.

OR3 – OR3a – OR3b

The final location is OR3, OR3a and OR3b located on SR 101 south of the Queets River Bridge. It is a two lane roadway (one lane in each direction) classified as a rural-principal arterial. OR3 received dig outs and a chip seal, OR3b a chip seal with no dig outs, and OR3a was a control section with no treatment (Figure 131). It is evident that the dig outs and chip seal section is performing much better than the section with only the chip seal; however, this may be due in part to the poor condition of the original pavement in the chip seal only section. The control section is also performing fairly well, although the cracks have grown in length and become wider with vegetation growing in the cracks. The best treatment solution for this location appears to be no treatment since the section survived for four plus years without potholes or excessive spalling of the cracks; but now is the time to perform preventive maintenance before the cracks turn into potholes. The mild climate and low traffic volumes (ADDT of 870) were contributing factors to the slow deterioration of this section of pavement.

Figure 131. OR3, OR3a and OR3b on SR101. OR3 received dig outs and a chip seal, OR3a is a control section with no treatment and OR3b received a chip seal with no dig outs.

In summary, the application of only one treatment, whether it is crack sealing, chip sealing or dig outs, is the best choice for all three of the side-by-side test sites.

Following is a discussion of the cost of each of the treatments that may enable a better decision regarding the best treatment choice for a particular pavement.

Cost Data

Cost information on the treatment types is very difficult to gather from maintenance records. The data generally included the cost of labor, equipment and materials, the amount of materials used, and the length of the roadway treated. The available data and methods used to arrive at a cost for each treatment type are explained in the following paragraphs.

Crack Sealing

The data for crack sealing included costs for labor, equipment, materials, amount of crack sealant used in boxes or blocks, and the length of the roadway that was sealed in total miles. The length and width of the sealed cracks was not recorded. The process of calculating the cost involved measuring the crack lengths from WSPMS photo logs and using a Crafco table giving the amount of sealant required for cracks of different widths and lengths. The costs ranged from $0.42 to $1.34 per lineal foot of pavement treated. The mid-point of $0.88 per lineal foot was selected as an average cost for crack sealing. The average length of cracking in a one mile section for a large number of projects was 1.3 miles.

Chip Sealing

Chip sealing was the easiest cost to calculate because the data included the cost of labor, equipment, and materials for a stated square foot of coverage. The total costs ranged from $0.45 to $0.72 with an average of $0.59 per square foot.

Dig Outs

The data for dig outs included labor, equipment and materials cost, plus the tons of HMA, the length of the roadway treated, and the average depth of the dig outs. No information was provided on the number or size of the dig outs. The cost per ton of mix was calculated for 26 maintenance projects in the Eastern Region built in 2014 and 2015. The cost included labor, equipment and materials (HMA and tack coat). The average cost per ton of the 26 projects was $227.00. The average depth of the dig outs from a large number of projects was three inches.

Blade Patching

The cost for placing blade patches was the most difficult to calculate because there was no data provided on the square footage of the patch. The cost per ton of HMA including labor and equipment was the only data available. The cost per linear foot was calculated using an average depth of 1.5 inches and an average density of 145 pounds per cubic foot (pcf). The costs range from $5.00 to $15.00 per linear foot. The mid-point of $10.00 per lineal foot was chosen as an average cost.

Comparison of Treatment Costs

It was thought that it would be possible to calculate the cost of the various maintenance techniques on a unit basis such as square feet or square yards of treatment. This would work for crack sealing (using the average length of cracks sealed in a mile as 1.3 miles), chip sealing and blade patching, but not for dig outs and wheel path chip sealing which are only applied in strips. Another thought was to calculate the cost of one lane mile of each treatment. This would work for crack sealing, chip sealing and wheel path chip sealing, but not for dig outs or blade patching.

In the case of dig outs, the amount of dig outs in a lane mile varies depending on roadway conditions. The same holds true for blade patches, the length of the patch is dependent on roadway conditions.

The solution was to calculate the cost of the treatment of one lineal foot of a 12-foot wide lane (Table 3). This size was chosen as a way to differentiate between a wheel path chip seal and a full lane chip seal. This approach allowed dig outs cost to be calculated as a dig out in one wheel path that was three feet wide by one foot in length. One dig out in one wheel path was chosen based on observation of the 21 dig out test sites, which generally had dig outs in only one wheel path.

Table 3. Cost comparison of the various treatments.

Treatment	Cost for treating 1 Foot of Pavement on a 12 Foot Wide Lane
Crack Sealing	$1.14
Wheel Path Chip Seal Rut Filling	$2.76
Wheel Path Chip Seal Patching	$4.44
Full Lane Chip Sealing	$7.08
Crack Sealing + Chip Sealing	$8.10
Blade Patch	$10.00
Dig Outs	$12.49
Dig Outs + Crack Sealing	$13.63
Dig Outs + Chip Sealing	$19.57

The data and methods used to calculate the cost for each of the preventive maintenance treatment types are as follows:

- Crack Sealing – Maintenance data showed that the average length of crack sealing in a one-mile length of pavement was 1.3 miles. Using the average cost for crack sealing of $.88 per lineal foot and the average length of 1.3 feet, the cost was (1.3 X $0.88 = $1.14).
- WP Chip Seal Rut Filling – The average width of the wheel paths of the five projects in the WP chip sealing category were measured on the photos at 4.67 feet (measurements were taken of the width of the pavement as well as the width of the sealed wheel paths to determine the scaling factor). Cost was (4.67 X $0.59 = $2.76).

- WP Chip Seal Patching – Using the same method as above the average combined width of the wheel paths was 7.52 for the two test sites. Cost was (7.52 X $0.59 = $4.44).
- Chip Sealing – The cost for 12 square feet of chip sealing at $0.59 per square foot was (12 X $0.59 = $7.08).
- Crack Sealing + Chip Sealing – Combination of 1.3 feet for crack sealing and 12 square feet of chip sealing was ($1.14 + $7.08 = $8.22).
- Blade Patch – The cost for one linear foot of blade patch was $10.00.
- Dig Outs –The amount of HMA for a dig out that is 3 feet wide by one foot in length and 3 inches in depth was (3.0’ X 0.25’ X 1.0’ = 0.75 cu.ft.) Using a density of 145 pcf, it would require 109 lbs of mix to fill the dig out which was 0.055 tons at $227/ton = $12.49
- Dig Outs + Crack Sealing – Cost was a combination of cost for dig outs and crack sealing ($12.49 + $1.14 = $13.63).
- Dig Outs + Chip Sealing – Cost was a combination of the costs for dig outs and chip sealing ($12.49 + $7.08 = $19.57).

The costs of the treatments were converting to a cost per square yard and square foot as shown in Table 4. There is only one cost listed for chip sealing since the cost per square yard or square foot is the same for wheel path chip sealing and full lane chip. The blade patch cost was converted from linear feet to square yards by dividing $10.00 by 1.3 since there are 1.33 square yards in a linear foot of patch 12 feet wide. Dig out cost was for the cost of the HMA for a square yard of patching 3 inches in depth. The costs for the combinations were simple additions of the cost of each treatment, since each cost is for a square yard or square foot of each treatment.

Table 4. Unit cost of each treatment.

Treatment	Cost	
	(SY)	(SF)
Crack Sealing	$3.12	$0.35
Chip Sealing	$5.31	$0.59
Crack Sealing + Chip Sealing ($3.12 + $5.31)	$8.43	$0.94
Blade Patch	$7.52	$0.85
Dig Outs	$37.03	$4.11
Dig Outs + Crack Sealing ($37.03 + $3.12)	$40.15	$4.46
Dig Outs + Chip Sealing ($37.03 + $5.31)	$42.34	$4.70

Cost Discussion

The guiding principle in choosing a maintenance strategy to fix a particular pavement distress is to choose the option that will provide the lowest annual cost. The least expensive treatment may not be the most cost effective. Crack sealing a pavement with cracking over the entire lane may be the least expensive option, but a chip seal may be the most effective in sealing the entire surface of the lane. The design of the study does not lend itself to prescribing specific treatments for particular pavement distresses; however, general guidelines for choosing the most cost effective treatment are discussed in the following paragraphs.

Crack Sealing

Crack sealing could be the best choice for a pavement with longitudinal and transverse cracking or block cracking that exceeds 1/4 inch in width. It would not be the best choice for alligator cracking because it is impossible to fill all of the cracks and a massive use of sealant could result in a slippery pavement (Figure 132). Crack sealing was used effectively on some sites with alligator cracking because filling the larger cracks prevented spalling of the pavement and the formation of potholes.

Figure 132. ER41, excessive crack sealant used on alligator cracking on SR 20, ER41. (November 2016)

Wheel Path Chip Sealing

Wheel path chip sealing is a good option when alligator cracking is confined to the wheel paths or when there is rutting in the wheel paths (Figure 133). The Eastern Region used wheel path chip sealing to fill ruts one summer followed by a full lane chip seal the next summer on one test site.

Figure 133. ER10, wheel path chip seal rut filling on US 2. (September 2016)

Full Lane Chip Sealing

Full lane chip sealing is one of the most effective treatments because it can cover a multitude of pavement distress (Figure 134). This would include alligator cracking, longitudinal cracking and transverse cracking (provided the cracks are less than ¼ inch in width), and patching. The experience in this study with three of the four test sites exhibited flushing would seem to indicate that this is a choice to be avoided, especially if the wheel paths are rutted; however, the very good experience when full lane chip seals placed under Region wide chip seal contracts would indicate just the opposite. As indicated previously, it may be that the materials used or the application techniques that may need to be given scrutiny in order to achieve the desired results. Chip sealing is often described as an art due to the many factors that can contribute to either success or failure. A few of these factors include the condition of the application equipment, both chip spreader and distributor, the properties of the oil and aggregates, the application of the correct amounts of aggregate and oil, the uniformity of the application, the development of good adhesion between the chip seal and the existing pavement and the weather during application (Testa & Hossain, 2014). Because of the lack of control over these many variables, chip sealing has not been as successful as would be expected. As one of the lower cost options, it would seem to provide a good choice when the distress in the pavement is not too severe and distributed over the entire lane.

Figure 134. OR3b full lane chip seal on SR 101. (September 2016)

Crack Sealing + Chip Sealing

The crack sealing plus chip sealing is the next lowest cost option (Figure 135). It is best used where some of the cracks exceed 1/4 inch in width and some are very fine. Sealing these larger cracks prior to the application of the chip seal will likely prevent the cracks from reflecting through the chip seal. Its use was limited to two test sites, probably due to the higher costs involved. On the Olympic Region test site (OR1a), either crack sealing or chip sealing alone would probably have provided a solution that would have lasted four plus years. The adjacent sections, OR1 and OR1b, which received only crack sealing or chip sealing, respectively, have performed very well. On the North Central site NC1, a special crack sealant was used to seal very wide thermal cracks in the chip seal prior to the application of another chip seal. In this case, the crack sealing was a necessity due to the wide transverse cracks in the existing pavement. To minimize issues with chip seal flushing, it is best to wait at least one season after the crack sealant is placed before placing the chip seal.

Figure 135. OR1a crack sealing plus chip sealing on SR 101. (September 2016)

Blade Patch

Blade patching is the next least costly treatment (Figure 136). It has limited application for roadways that are out of shape or have large cracks due to movement of the pavement caused by unstable subgrades or other issues. The experience has been generally satisfactory, and since other treatments are not an option, it will continue to be used for the previously described pavement issues.

Figure 136. ER20 blade patch on SR 395. (September 2016)

Dig Outs

Dig outs are one of the more expensive treatments due to the high cost of equipment, labor and materials required to prepare the holes, fill the holes, and compact the HMA (Figure 137). It is used when cracking in the wheel paths are wide and interconnected and are beginning to develop potholes. It is very effective because it removes the entire area of the distressed pavement and replaces it with new HMA. The performance of the dig out patches has been excellent on all of the test sites.

Figure 137. OR2 dig outs on SR 8. (September 2016)

Dig Outs + Crack Sealing

Using a combination of dig outs and crack sealing is a very expensive fix, but may be necessary to fix a pavement with alligator cracking in the wheel paths and longitudinal and transverse cracking throughout (Figure 138). The dig outs plus crack sealing test sites were ones in which the pavement was in such poor condition that the dig outs could not encompass all of the distressed pavement, and as a result, crack sealing was necessary to fill the large cracks between the dig outs.

Figure 138. OR4 dig outs plus crack sealing on SR 3. (September 2016)

Dig Outs + Chip Sealing

Dig outs plus chip sealing is the most expensive option (Figure 139). The flushing conditions on several of the sites could have been avoided by eliminating the chip seal. Placing a chip seal over newly placed dig out patches is not a good practice due to the strong possibility that the chip seal will flush or could result in chip loss. A solution is to place the chip seal in the next construction season after the patch has aged.

Figure 139. OR2a dig outs plus chip seal SR 8. (September 2016)

PSC Category Repair Costs

The report by Hicks ET AL, 2000 states, “the concept of preventive maintenance is to place an economical treatment early in the life of the pavement to preserve the pavement condition and possibly extend the pavement life.” Hicks also states, “the longer maintenance is delayed the more it will cost to repair the pavement.” Table 5-7 lists the average treatment cost for the test sites in each of the three PSC categories using the cost data from Table 3. The lowest average cost is for the Strategic category test sites at $8.83 per site followed by the Emerging category at $9.71 and the Reactive category at $11.97. The data indicates that early treatment is more cost effective than delayed treatment. This conclusion would be much stronger if the actual cost of the treatment for each test site were known.

Table 5. Average treatment cost for Strategic Category test sites.			
Strategic Category			
Treatment	**Treatment Cost** (1 Foot of Pavement on a 12 Foot Wide Lane)	**No. of Test Sites**	**Total Cost**
Crack Sealing	**$1.14**	**9**	**$10.26**
WP Chip Seal Rut Filling	**$2.76**	**5**	**$13.80**
WP Chip Seal Patching	**$4.44**	**1**	**$4.44**
Full Lane Chip Sealing	**$7.08**	**2**	**$14.16**
Crack Seal + Chip Seal	**$8.10**	**1**	**$8.10**
Blade Patch	**$10.00**	**9**	**$90.00**
Dig Outs	**$12.49**	**14**	**$174.86**
Dig Outs + Crack Seal	**$13.63**	**3**	**$40.89**
Dig Outs+ Chip Seal	**$19.57**	**3**	**$58.71**
	Total	**47**	**$415.22**
		Average	**$8.83**

Table 6. Average treatment cost for Emerging Category test sites.			
Emerging Category			
Treatment	**Treatment Cost** (1 Foot of Pavement on a 12 Foot Wide Lane)	**No. of Test Sites**	**Total Cost**
Crack Sealing	**$1.14**	**1**	**$1.14**
WP Chip Seal Patching	**$4.44**	**1**	**$4.44**
Dig Outs	**$12.49**	**5**	**$62.45**
	Total	**7**	**$68.03**
		Average	**$9.72**

Table 7. Average treatment cost for Reactive Category test sites.			
Reactive Category			
Treatment	Treatment Cost (1 Foot of Pavement on a 12 Foot Wide Lane)	No. of Test Sites	Total Cost
Crack Sealing	$1.14	1	$1.14
Full Lane Chip Sealing	$7.08	2	$14.16
Crack Seal + Chip Seal	$8.10	1	$8.10
Dig Outs + Crack Seal	$13.63	1	$13.63
Dig Outs+ Chip Seal	$19.57	3	$58.71
	Total	47	$95.74
		Average	$11.97

Preliminary Conclusions

The following conclusions are based on the observations made to date of the performance of the test sites and the preventive maintenance treatments. These may change depending on the performance data collected prior to the termination of the study.

- The findings in this study show that WSDOT's Instructional Letter and Integrated Pavement Preservation Plan is successfully extending pavement life. For these test sites pavement life has been extended two to four years as noted below.
- Properly applied crack sealing, full lane chip sealing and dig outs have extended pavement life a minimum of four years.
- Properly applied wheel path chip sealing for either rut filling or patching have extended pavement life a minimum of three years (oldest test site is 38 months).
- Properly applied blade patching has extended pavement life a minimum of two years (oldest test site is 27 months).
- Applying dig outs and chip seals in the same construction season has been shown to be a poor practice.
- The PSC of test sites with pavements in the Strategic and Emerging categories remain at relatively the same level after treatment.

- The PSC of test sites with pavements in the Reactive category (PSC 0-39) generally increased after treatment.
- Early treatment is more cost effective than delayed treatment.
- The Preventive maintenance work done in this study maximizes the time before a Capital Preservation Project must be completed (that is a reconstruction or resurfacing project) providing that the right treatment is done at the right time.

Preliminary Recommendations

The primary recommendation is that preventive maintenance techniques are best applied when distress is first observed. In general, the least expensive techniques of crack sealing and wheel path chip sealing are very effective treatments when the distress is confined to the wheel paths. Full lane chip sealing could be used more frequently than currently utilized because it can mitigate a number of pavement distress conditions, but must be constructed correctly. Dig outs are recommended when the distress is severe but generally confined in a small area. The use of dig outs plus chip sealing is not recommended due to the problems with flushing or chip loss and higher cost. Blade patching is a necessary practice to address specific types of distress such as settlement or a rough ride.

Future Research

This is a preliminary report issued four years after the first test sites were installed. A final report will be issued when these initial sites have reached the age of five years. Currently, all of the preventive maintenance techniques except wheel path chip seal patching, wheel path chip seal rut filling, and blade patching have four years of documented performance upon which to report. The additional evaluations may alter or improve the current conclusions and recommendations.

Authors Note

At the initiation of this study, it was thought that the performance of the various preventive maintenance treatments would be differentiated by the failure of some sites as contrasted with the good performance of other sites. This was not the case as virtually all of the treatments are performing the same in preserving the pavements for extended periods of time. This speaks strongly about the competence of our Regions, not only using the very best installation techniques, but also picking the correct treatment for the distress at a test site. This also support the study design which allowed the Regions to control the choice of what treatment to apply for a given pavement condition.

References

Hicks, R. Gary, Stephen Seeds, and David G. Peshkin, "Selecting a Preventive Maintenance Treatment for Flexible Pavements", Foundation for Pavement Preservation, Washington, DC, June 2000.

Testa, Dean M., Mustague Hossain, "Kansas Department of Transportation 2014 Chip Seal Manual", Kansas Department of Transportation, Report No. K-TRAN:KSU-09-8, March 2014.

Appendix A

Test Site Data

Table 8. Test site descriptions.

Test Site	Year	SR	DIR	Beg. SRMP	End SRMP	Length (miles)	Last Paved	Surface	Base	Age When Treated
Crack Sealing (12 sites)										
OR1	2012	101	I	321.90	322.10	0.20	2000	HMA	HMA	12
OR6	2013	8	D	17.55	17.75	0.20	1998	HMA	CTB	15
OR8	2013	101	I	344.90	345.30	0.40	2006	HMA	HMA	7
OR9	2013	105	B	47.88	47.98	0.10	1997	HMA	HMA	16
NC2	2014	2	B	98.87	100.81	1.94	2003	HMA	HMA	11
SC1	2015	97	I	69.20	74.20	5.00	2002	HMA	UTB	13
ER41	2016	395	B	202.79	207.82	5.03	2009	HMA	UTB	7
OR20	2016	12	I	17.80	20.96	3.16	2003	HMA	CTB	13
OR21	2016	12	B	21.30	22.20	0.90	2003	HMA	UTB	13
OR31	2016	115	B	0.00	2.28	2.28	2000	HMA	HMA	16
OR32	2016	160	B	0.70	1.03	0.33	1999	HMA	UTB	17
OR34	2016	302	B	1.00	1.25	0.25	2000	HMA	BST	16
Chip Sealing (4 sites)										
OR1b	2012	101	I	322.40	322.50	0.10	2000	HMA	HMA	12
OR3b	2012	101	I	152.22	152.45	0.23	1992	HMA	HMA	20
OR16	2013	12	B	37.35	37.55	0.20	1999	HMA	PCC	14
OR22	2015	101	B	167.00	167.50	0.50	1999	HMA	UTB	16
Wheel Path Chip Sealing/Cracking (2 sites)										
OR12	2013	20	B	7.90	10.20	2.30	2001	HMA	PCC	12
OR23	2015	104	B	9.00	10.10	1.10	2006	HMA	UTB	9
Wheel Path Chip Sealing/Rutting (5 sites)										
ER7	2013	20	B	390.43	402.00	11.57	2006	BST	BST	5
ER10	2014	2	B	253.55	256.75	3.20	1999	HMA	HMA	15
ER15	2015	395	B	219.00	221.00	2.00	2003	HMA	UTB	12
Wheel Path Chip Sealing/Rutting (continued)										
ER18	2015	31	B	0.00	1.00	1.00	2008	BST	UTB	7
ER40	2016	270	B	3.88	8.89	6.01	2007	HMA	UTB	9
Crack Seal Plus Chip Seal (2 sites)										
OR1a	2012	101	I	322.10	322.40	0.30	2000	HMA	HMA	12
NC1	2014	155	B	9.00	9.50	0.50	2006	BST	BST	8
Dig Outs (21 sites)										
OR2	2012	8	D	10.50	10.60	0.10	1995	HMA	CTB	17
ER2/4	2012	2	I	281.21	291.55	0.34	2005	HMA	PCC	7
ER3	2012	291	D	13.36	13.80	0.14	2004	HMA	HMA	8
ER5	2013	2	B	263.45	264.40	0.95	1998	HMA	PCC	15

Table 8. (Continued).										
Test Site	Year	SR	DIR	Beg. SRMP	End SRMP	Length (miles)	Last Paved	Surface	Base	Age
Dig Outs (continued)										
OR5	2013	7	D	53.71	53.86	0.15	2004	HMA	PCC	9
OR8a	2013	101	I	344.90	345.30	0.40	2006	HMA	HMA	7
OR10	2013	510	B	7.08	7.23	0.15	2001	HMA	PCC	12
OR11	2013	20	B	3.90	4.00	0.10	2006	HMA	HMA	7
OR15	2013	12	B	35.20	35.40	0.20	1999	HMA	HMA	14
ER9	2014	395	B	193.67	196.78	3.11	2009	HMA	HMA	5
ER11	2014	270	B	0.78	2.25	1.47	2002	HMA	HMA	12
SW5	2014	6	B	6.30	6.80	0.50	2005	BST	BST	9
ER17	2015	395	D	65.30	65.50	0.20	2007	HMA	CTB	8
ER24	2015	127	B	10.50	10.80	0.30	2004	HMA	UTB	11
ER29	2015	27	B	34.80	36.10	1.30	2012	BST	UTB	3
OR24	2015	119	B	3.50	4.00	0.50	2006	BST	UTB	9
OR28	2015	207	B	39.90	43.50	3.60	2005	HMA	PCC	10
SC5	2015	12	B	356.97	358.20	1.23	2000	HMA	UTB	15
SW6	2015	6	D	32.10	32.30	0.20	2010	BST	PCC	5
ER42	2016	20	B	379.16	390.41	11.25	2011	BST	UTB	5
ER43	2016	395	B	230.90	241.73	10.83	2005	HMA	HMA	11
Dig Outs Plus Crack Sealing (4 sites)										
ER1	2012	2	I	299.30	299.60	0.30	2002	HMA	HMA	10
OR4	2013	3	I	53.36	53.47	0.11	1993	HMA	HMA	20
OR27	2015	307	B	5.00	5.25	0.25	1992	HMA	UTB	23
SC4	2-15	395	B	22.78	25.42	2.62	2007	HMA	UTB	8
Dig Outs Plus Chip Seal (6 sites)										
OR2a	2012	8	D	10.60	11.00	0.40	1995	HMA	CTB	17
OR3	2012	101	I	151.74	151.90	0.16	1992	HMA	HMA	20
SW1	2012	14	B	119.54	129.00	9.46	2000	BST	BST	12
SW1a	2012	14	B	129.00	129.25	0.25	2000	BST	BST	12
OR14	2013	7	B	28.50	28.65	0.15	1999	HMA	PCC	14
NC3	2014	207	B	0.44	0.57	0.13	2008	BST	BST	6
Blade Patch (9 sites)										
ER8	2014	195	B	62.15	69.94	7.79	2006	HMA	HMA	8
ER9a	2014	395	B	195.10	195.20	0.10	2009	HMA	HMA	5
ER20	2015	272	B	17.70	18.10	0.40	2008	BST	ATB	7
ER26	2015	127	B	22.00	23.00	1.00	2011	BST	UTB	4
ER31	2015	21	B	30.50	30.70	0.20	2009	BST	BST	6

Table 8. (Continued).Table 8. (Continued)

Test Site	Year	SR	DIR	Beg. SRMP	End SRMP	Length (miles)	Last Paved	Surface	Base	Age
Blade Patch (continued)										
ER32	2015	20	B	310.00	318.60	8.60	2011	BST	BST	4
ER33	2015	270	B	5.50	6.50	1.00	2007	HMA	UTB	8
ER34	2015	271	B	2.00	2.10	0.10	2012	BST	BST	3
ER37	2015	395	B	227.90	228.50	0.60	2002	HMA	UTB	13
Control Sections (no treatment, 4 sites)										
OR3a	2012	101	I	151.90	152.00	0.10	1992	HMA	HMA	20
ER1a	2012	2	I	299.60	299.72	0.12	2002	HMA	HMA	10
ER2a	2012	2	I	291.55	291.85	0.30	2005	HMA	PCC	7
ER3a	2012	291	B	13.50	13.80	0.30	2004	HMA	HMA	8

Appendix B

WSPMS Historical PSC Ratings

Table 9. Yearly PSC data for each test site.					
Test Site	PSC				
	2012	2013	2014	2015	2016
2012 Test Sites					
OR1	18	11	28	17	35
OR1a	1	52	54	51	95
OR1b	33	55	55	54	95
OR2	45	No Data	33	31	29
OR2a	No Data	No Data	50	50	47
OR3	No Data	49	53	51	48
OR3a	No Data	27	51	45	24
OR3b	10	55	53	43	53
ER1	30	45	No Data	49	99
ER1a	27	42	No Data	52	100
ER2/4	59	55	47	53	99
ER2a	16	53	45	42	100
ER3	48	66	48	54	54
ER3a	56	64	66	54	54
SW1	No Data	No Data	No Data	71	No Data
SW1a	No Data	No Data	No Data	64	No Data
2013 Test Sites					
OR4	43	55	52	45	52
OR5	75	52	53	53	56
OR6	73	87	66	67	64
OR8	Ramp No Data				
OR8a	Ramp No Data				
OR9	98	93	95	94	94
OR10	78	92	75	71	70
OR11	79	64	56	62	60
OR12	88	75	76	74	75
OR14	68	54	54	54	96
OR15	52	56	55	54	No Data
OR16	68	55	51	52	49
ER5	11	23	19	34	2
ER7	No Data	No Data	No Data	No Data	No Data

Table 9. (Continued)					
Test Site	PSC				
	2012	2013	2014	2015	2016
2014 Test Sites					
NC1	No Data	No Data	No Data	No Data	No Data
NC2	88	83	74	79	74
NC3	No Data	No Data	No Data	No Data	No Data
ER8	82	81	74	79	78
ER9	85	81	54	56	53
ER9a	91	94	55	53	No Data
ER10	84	91	86	89	53
ER11	75	56	62	58	62
SW5	No Data	No Data	No Data	54	53
2015 Test Sites					
OR22	87	85	93	96	99
OR23	94	95	96	83	75
OR24	No Data	No Data	79	64	No Data
OR27	60	63	66	58	61
OR28	94	94	85	80	76
ER15	95	97	95	54	54
ER17	50	84	68	47	52
ER18	No Data	No Data	91	82	No Data
ER20	No Data	No Data	87	78	No Data
ER24	99	96	99	96	99
ER26	No Data	No Data	No Data	No Data	No Data
ER29	No Data	No Data	No Data	97	92
ER31				No Data	No Data
ER32				No Data	No Data
ER33	100	99	100	100	55
ER34				No Data	No Data
ER37	69	91	58	50	70
SC1	68	62	57	45	51
SC4	89	92	68	32	30
SC5	80	65	65	65	64
SW6	No Data	No Data	No Data	82	59

Table 9. (Continued)

Test Site	PSC				
	2012	2013	2014	2015	2016
2016 Test Sites					
OR20	89	83	91	87	86
OR21	97	93	No Data	91	74
OR31	87	85	93	96	95
OR32	52	62	64	78	58
OR34	89	95	87	93	80
ER40	99	98	99	97	54
ER41	98	99	98	97	96
ER42	No Data	No Data	No Data	No Data	No Data
ER43	82	83	86	86	88