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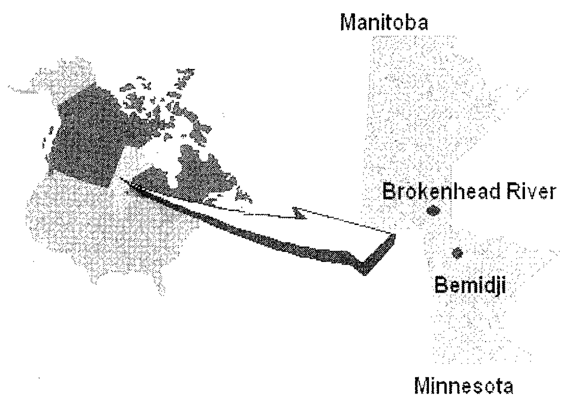

Asphalt Overlay Cost-Effectiveness

Manitoba TGS and Minnesota SPS-5 Projects 10-Year Ranking of Treatments

Technical Report Documentation Page

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This report is part of the Long-Term Pavement Performance (LTPP) Project, which is ongoing until the year 2010. Further reviews will be done as needed to report the findings. A final report is planned in 2010 when each project will be 20 years old.

16. Abstract (Limit: 200 words)

This report reviews Manitoba's and Minnesota's Specific Pavement Studies (SPS-5) projects. The studies focus on investigating the performance of hot mix asphalt (HMA) overlays on HMA pavements and involve nine core test sections. The SPS-5 design variables in test sections include a control section (do nothing), amount of preparation of the existing surface (mill, no-mill), overlay thickness (50-mm, 125-mm), and the type of overlay material (virgin, recycle).

Researchers plan to study the Manitoba and Minnesota SPS-5 projects, part of the Long-Term Pavement Performance (LTPP) Project, until 2010, when each project reaches the approximate age of 20 years.

This project update includes a field review by the authors, a review of the existing monitoring data, and an estimate of the expected performance and cost expectations for upcoming years until 2010.

Currently after 10 years all sections, excluding the control section, still are performing well. As a result at this point, researchers recommended the least costly treatment, 50mm recycled asphalt overlay with no surface preparation, for pavement rehabilitation.

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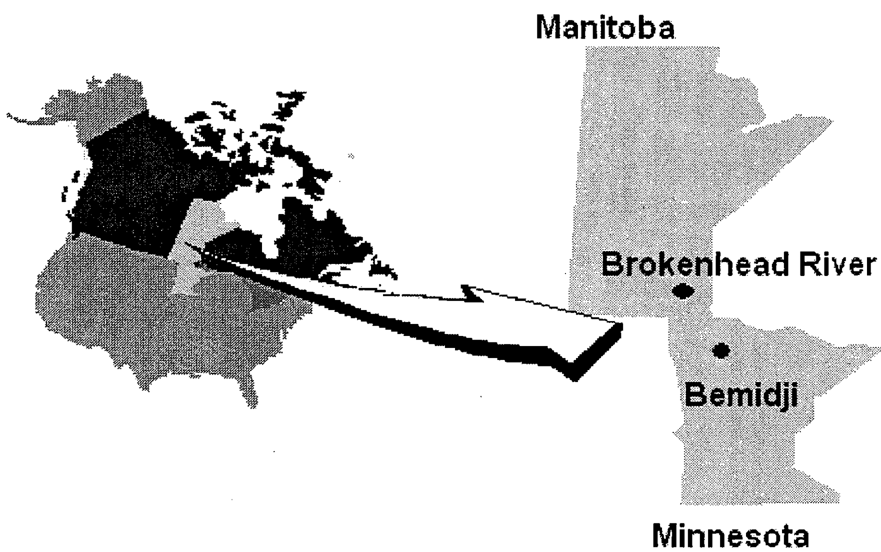
Asphalt Overlay Cost-Effectiveness

Manitoba and Minnesota SPS-5 Projects
10 - Year Ranking of Treatments

1989 - 1999



A cooperative research effort between

Manitoba Department of Highways and Government Services

Minnesota Department of Transportation

Asphalt Overlay Cost-Effectiveness

Manitoba and Minnesota SPS-5 Projects
10-Year Ranking of Treatments
(1989-1999)

Progress Report

Prepared by:

Craig Gilbertson (Mn/DOT – District 2 Bemidji Office)
Gene Skok (University of Minnesota)
Dennis Watson (Manitoba Department of Highways and Government Services)
Tom Wilson (ERES Consultants)
Benjamin Worel (Mn/DOT - Office of Minnesota Materials and Road Research)

Minnesota Department of Transportation
Office of Minnesota Materials and Road Research
Mail Stop 645
1400 Gervais Avenue
Maplewood, Minnesota 55109

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Mail Stop 330
395 John Ireland Boulevard
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The authors would also like to express their appreciation for the assistance of Gene Skok to this effort. Gene is a good friend to us all and is a researcher who has added to the careers of many engineers. Thanks – Gene.

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EXECTIVE SUMMARY

The Long-Term Pavement Performance (LTPP) Specific Pavement Study #5 (SPS-5) seeks to quantify the effect of the following parameters on the performance of hot mix asphalt (HMA) overlays on HMA pavements:

1. Environment
2. Traffic
3. Condition of existing surface
4. Amount of preparation of existing surface
5. Thickness of overlay (50-mm, 125-mm)
6. Type of Mix in Overlay (Virgin, Recycle)

This paper reviews the construction and performance to 1999 of SPS-5 projects built in Manitoba (1989) and Minnesota (1990). Both of the projects consist of eight core test sections defined using variables 4-6 above.

Traffic is monitored using a weigh-in-motion system; through 1998 the traffic is estimated at 2.3 million ESALs on the Manitoba project and 0.7 million ESALs on the Minnesota project.

Condition data consist of crack surveys, rut depth, surface rating, and rideability. Present Serviceability Rating (PSR) and Surface Rating (SR) are calculated from the data and Pavement Quality Index (PQI, measured by the Minnesota procedure) is used to represent the overall condition of the sites. The 1999 PQI for all treatments range from 3.3 to 3.8, much above the 2.5 trigger value for rehabilitation.

The cost of each rehabilitation method has also been summarized. All sections are performing well and, therefore, *the least costly treatment (50mm recycled asphalt overlay with no surface preparation) is recommended for a nine to ten year service life.*

It will be necessary to continue monitoring the sections to establish the performance curves and quantify the cost-effectiveness of each procedure over the actual service life of 20 years. Both highway agencies sponsoring these projects are committed to completing these studies through continued cooperation with the Long-Term Pavement Performance study.

NOTE: Metric conversions are rounded off as 25mm / inch, for example the 5 inch overlay is referred to throughout this report as 125-mm not the correct 127mm.

CHAPTER 1
INTRODUCTION

SHRP/LTPP Program Background

The US Strategic Highway Research Program (SHRP) Long-Term Pavement Performance (LTPP) program, started in 1987, includes individual test sections set up under the General Pavement Studies (GPS) and Specific Pavement Studies (SPS) experiments [1]. The GPS program includes the following experiments:

GPS-1	Hot Mix Asphalt (HMA) over Aggregate Base
GPS-2	Hot Mix Asphalt over Stabilized Aggregate Base
GPS-3	Plain Portland Cement Concrete (PCC) Surface
GPS-4	Reinforced Portland Cement Concrete Surface
GPS-5	Continuously Reinforced Concrete Pavement
GPS-6	Hot Mix Asphalt Overlay of HMA Pavement
GPS-7	Hot Mix Asphalt Overlay of Portland Cement Concrete Pavement
GPS-8	Unbonded Portland Cement Concrete Overlay of a PCC Pavement

Each of these experiments is defined using a design matrix with environment, traffic, thickness and other factors as variables. The GPS experiment is made up of about 1,000 test sections in the US and Canada each in defined experimental cells.

The SPS program includes projects with a number of test sections (three to twenty-two) at one location to study the effect of given design variables at a given location. Each GPS and SPS experiment is designed to include projects in four environmental zones studying the interaction between the environment and defined variables. The four environmental zones are:

1. Wet, Freeze
2. Wet, No Freeze
3. Dry, Freeze
4. Dry, No Freeze

The SPS experiments are:

SPS-1 Structural Design of Hot Mix Asphalt (HMA) Pavements
SPS-2 Structural Design of Portland Cement Concrete (PCC) Pavements
SPS-3 Effect of Routine Maintenance Procedures on the Performance of HMAPavements
SPS-4 Effect of Routine Maintenance Procedures on the Performance of PCC Pavements
SPS-5 Rehabilitation Techniques for Hot Mix Asphalt Pavements
SPS-6 Rehabilitation Techniques using HMA overlays of PCC Surfaced Pavements

SPS-7 Rehabilitation Techniques Using Bonded PCC Concrete Overlays of PCC Pavements
SPS-8 Design of Asphalt and PCC Pavements in the Absence of Heavy Loads
SPS-9 A SuperPave Asphalt Binder Study

All GPS and SPS sections have been set up based on existing soil and pavement materials uniformity. The properties and thickness of all the layers have been documented in the field and laboratory using extensive sampling and testing programs defined for each experiment. In-place properties of the pavement layers are evaluated periodically with the falling weight deflectometer (FWD).

Performance is defined using longitudinal (ride) and transverse profiles along with distress surveys. Longitudinal profiles are measured and converted to IRI (International Roughness Index) to show the profile as one composite number. The transverse profile condition is represented by rut depth. Distress surveys include transverse and longitudinal crack counts with level of extent and severity along with determination of the area of pattern cracking.

Continuous measurements of traffic volume, vehicle type distribution and weight distribution are used to calculate total traffic loading in terms of Equivalent Standard Axle Load (ESAL).

Weather stations are used at each SPS-1, SPS-2 and SPS-8 project location to measure actual temperature and precipitation at each project location. Local existing weather station data are used for all GPS sections and non SPS-1, SPS-2 and SPS-8 test projects to develop site-specific estimated climatic values.

Specific Pavement Study (SPS-5) National Effort

The SPS-5 experiment is a study of asphalt hot-mix overlay designs on asphalt pavements. The basic experiment has eight (8) test sections plus one (1) control section [1].

The SPS-5 study variables include the following:

- Climate: Precipitation (wet or dry), Temperature (freeze or no freeze)
- Original pavement condition: Fair or Poor
- Subgrade: Fine- or Coarse-grained Soils
- Traffic: >85,000 ESALs per year

The SPS-5 experiment uses the following variables for its 8 core test sections:

- Use of virgin and recycled hot mix asphalt overlay materials.
- Overlay thickness of 50-mm and 125-mm.
- Type of surface preparation (minimum and extensive); minimum preparation includes crack filling and overlay, extensive preparation includes milling and crack repair before overlay.

Table 1 is a list of the study variables for each section along with the codes used to identify them under the present study. Throughout Canada and the United States 18 SPS-5 projects have been built. These projects were built from Florida to Alberta and from Maine to California. Figure 1 shows the location of the two projects discussed in this report (Brokenhead River, Manitoba and Bemidji, Minnesota).

Manitoba SPS-5 Brokenhead River Project

The Brokenhead River test site was built in the fall of 1989 as the first site constructed for the SPS-5 experiment under the LTPP program. The site construction was contracted to Nelson River Construction Ltd. of Winnipeg as part of a larger rehabilitation project on the same portion of the Trans-Canada highway approximately 55 km east of Winnipeg.

The existing pavement structure built in 1971 consisted of 100-mm of hot mix asphalt and 330-mm of granular base placed on a sandy silt (A-4) subgrade. The site layout is shown as Figure 2 with a cross section of the site shown as Figure 3. The site was laid out as a mirror image of the virgin and recycled mixes, surface preparations, and overlay thickness. The Control Section had no rehabilitation applied.

Minnesota SPS-5 Bemidji Project

The Bemidji, Minnesota test site was laid out in the spring of 1990 and built that summer by Tri City Paving, Inc. of Little Falls, Minnesota. The test site was part of a 20-km rehabilitation project consisting of a 40-mm asphalt overlay on T.H. 2 approximately 23 km west of Bemidji. Bemidji is located approximately midway between Winnipeg, Manitoba and Minneapolis-St. Paul, Minnesota, each approximately 400 km away.

The existing pavement structure was built in 1970 as 175-mm of hot mix asphalt on 450-mm of granular base over a clay (A-7-6) subgrade. Figure 4 shows the layout of the test sections along the westbound lane of US2 west of Bemidji [2]. Figure 5 shows the cross section of the test site layout near Bemidji.

In addition to the standard LTPP test sites Mn/DOT built 3 supplemental test sites to investigate additional experimental variables of interest to them. They involve:

- Section # 270559; Mn/DOT standard mix with a 37-mm overlay. The preparation of the original mat consisted of milling out and blade patching cold mix into the transverse cracks.
- Section # 270561; SHRP mix with a 37-mm overlay.
- Section # 270560; intensive transverse crack repair (300-mm wide and 100-mm deep) with overlay.

CHAPTER 2
PROJECT CONSTRUCTION DETAILS

Pre-rehabilitation Condition of Test Sites

Table 2 is a list of the pavement conditions for the Manitoba and Minnesota sections before the test sections were constructed. The Manitoba project had more patching and alligator cracking whereas the Minnesota project had more transverse cracks, ravelling and bleeding. The bleeding was not severe as the aggregate was visible on the surface. Both of those pavements were defined as in fair condition for the experimental design.

Asphalt Overlay Mix Materials and Design

Two mix designs are used under the LTPP guidelines; one for a virgin asphalt mix and the other for a recycled asphalt mix. The details on these two mixes for both Manitoba and Minnesota are shown in Table 3.

The asphalt cement used in the Manitoba designs was 150/200 penetration grade. The Minnesota asphalt cements were an 85/100 and a 120/150 penetration grades for the virgin and recycled mixes, respectively.

A minimum of 70 percent of the coarse material had to have at least one fractured face as required by LTPP. The Mn/DOT crush requirement was 55 percent of the coarse aggregate must have two fractured faces. The Manitoba requirement was a minimum of 50 percent of the coarse aggregate must have at least one fractured face.

Table 4 is a summary of the mix design criteria for the Brokenhead River and Bemidji SPS-5 sites. Extractions of the asphalt cement from cores taken after construction showed an average total asphalt of 5.9 % for the Brokenhead River and 5.8 % for the Bemidji project.

Construction Details

The Brokenhead River Test Site was built over the period of September 7 - 13, 1989. Fifty millimetres of the existing surface was milled off on the four specified test sections with the milled asphalt used in the recycled asphalt product. The bituminous mixture was dumped from the truck trailer into the hopper of the paver. The paver had to be stopped at the end of every truckload to disconnect from the empty truck and to couple to the next truck. The breakdown roller was a steel vibratory making one vibratory and one static pass. The intermediate roller was a 9-wheel rubber roller that made two passes. The finishing roller was a second steel vibratory making one or two passes. Laydown temperatures were taken directly behind the paver and ranged from 128 to 140 ^{0}C. The lanes were typically opened to traffic two hours after final compaction was completed.

There was significant variation in the layer thickness placed compared with the design values. These variations are summarised in Table 5. The thickness of all the overlay layers applied were excessive in nearly all of the cells. The amounts of the excess layer thickness ranged from 15 to 43 mm. This report will refer to the design layer thickness, however the variance of these layer thickness will have to be considered in the final analysis.

Construction of the Bemidji test site began in August and was completed in mid-September, 1990. Milling of the four specified test sections was to a depth of 50-mm. The milled asphalt was used in the recycled asphalt product mixture. Transverse cracks were filled using a fine bituminous mix that was bladed into the cracks and then compacted using pneumatic rollers.

The bituminous mixture was windrowed on the roadway with a windrow elevator delivering the material into a paver. Use of the elevator allowed the paver to operate continuously, not having to stop for each truckload. By operating in this manner a smooth finished pavement surface resulted. A vibratory steel wheel roller initially compacted the bituminous mixture with two 13-wheel rubber-tired pneumatic rollers used to finish the surface.

Table 5 contains the limited amount of pavement layer thickness available for the Bemidji site, little variation is shown from actual design.

Pre and Post-Construction Profile

Table 6 is a list of the Profile Measurements of each of the test sections before and after construction excluding the control section for each project. The post-construction average International Roughness Index (IRI) for the Brokenhead River project sections is 1.00 and the Bemidji project is 0.94. These are equivalent to Present Serviceability Ratings of 4.0 and 4.1 respectively according to the relationship used by Mn/DOT [3].

CHAPTER 3

TEST SECTION MONITORING AND OBSERVATIONS

Test Section Evaluation

Contractors for the LTPP program are monitoring each project's sections is the following ways:

1. Material sampling and testing of the existing and materials used for construction.
2. Falling Weight Deflectometer (FWD) measurements.
3. Ride measurements (IRI).
4. Distress surveys
5. Traffic - continuous total vehicles, periodic weight or continuous weight distribution and type of axles (collected by agencies, processed by contractors).

The progression of distress with traffic and time will be used to evaluate [1]:

1. Current design procedures and relationships used to develop these procedures.
2. The effect of routine maintenance on the overall performance of pavements.
3. The most cost effective rehabilitation procedure for asphalt or concrete pavements at various levels of deterioration.
4. The relative effect and interaction of traffic and environment on various types of pavement structures.
5. The use of the falling weight deflectometer (FWD) to backcalculate the stiffness of pavement layers and their variation over time.
6. The performance of Performance Grade (PG) asphalt relative to current asphalt specification based on long term pavement performance.

The LTPP program was originally planned for 20 years and is now 10 years old. Consistent monitoring methods and documentation of performance of these sections over the remainder of this period will be used to develop performance models and document trends for predicting performance.

In the interim, it will be possible to make some comparative analyses, especially of the SPS project test sections, to evaluate various designs, rehabilitation procedures, and timing of repairs and maintenance.

Part of the evaluation process for the purpose of this report included the rating of both sites by staff from both the Manitoba Department of Highways and Government Services (MHGS) and the Minnesota Department of Transportation (Mn/DOT). A rating system used within the

Minnesota Mn/DOT was applied to the sites in order to rank the condition of the cells. Remaining life estimates were also made by the SPS-5 team members. This report details the type of information available and how the data can be used to evaluate the cost-effectiveness of the rehabilitation strategies used for these asphalt pavements.

The evaluations are made on each cell within a site as well as to the similar cell in the other site so that the performance of each cell (i.e. treatment strategy) can be quantified. The objective is to as much as possible, isolate each of the treatment variables used in order to evaluate its cost-effectiveness.

Traffic Volumes

Table 7 is a list of annual and accumulated ESALs for the two projects calculated from the traffic measured with the weigh-in-motion systems. Table 6 shows that the actual traffic on the Brokenhead River site was gradually increasing through 1993, but then decreased in 1994. This 1994 ESAL measurement may be mistaken as the value for 1995 and later returns to the levels expected.

The actual traffic on the Bemidji project was about 30% less than the design traffic. It will still be possible to evaluate the performance under actual measured traffic conditions for the research. Through 1998 the Brokenhead River project has been subjected to approximately 2.3 million ESALs whereas the Bemidji project has had 0.7 million ESALs.

Roughness

Table 8 is a summary of the roughness or rideability of the test sections measured using the International Roughness Index. The IRI is calculated from a summary of the longitudinal profile that is measured annually for the test sections by LTPP using a non-contact profilometer. The IRI is then used to determine a predicted Present Serviceability Rating (PSR) used by Mn/DOT. A graph explaining the IRI and its interpretation in operating speeds and ranges of surfaces is shown as Figure 6. Generally IRI values for a freshly paved surface range from 0.7 to 1.1 mm/m, while IRI values of more than 3.8 mm/m indicate damaged pavements whose highest normal use speed would be in the 100 km/h range.

Figure 7 shows the roughness progression on the Brokenhead River test site. Note that the pre-rehabilitation IRI values were not taken on the Brokenhead River test site and are not shown in this figure. The 125-mm overlays were applied in one more lift than their 50-mm counterparts resulting in significantly lower roughness values (0.2 to 0.8 mm/m IRI) immediately after the paving was completed. Inspection of Figure 7 shows that there is negligible increase in roughness for the cells for the first 6 years of service. Roughness values increase in both 1997 and 1998 at more significant rates. The 1998 values of IRI are all below the 1.9 mm/m IRI value. The 125-mm overlays have lower 1998 roughness values than the 50-mm overlays, and the milled sections with lower roughness than the minimal surface preparation cells. These lower IRI values in 1998 can therefore be attributed to the extra paving lift and its resulting smoother values, the additional structural support of the thicker overlay, and the intensive surface preparation (milling and paving additional layer with fresh asphalt). The roughness on the Brokenhead River site is so low that identifying the sole source is difficult, however the few transverse cracks are not depressed or cupped.

Figure 8 shows roughness progression on the Bemidji site from pre-rehabilitation1990 through 1998. The roughness in IRI on most of the Bemidji cells ranged between 2.5 to 3.2 mm/m prior to rehabilitation occurring. The roughness decreased to 0.8 to 1.1 mm/m for the cells after rehabilitation. The extra paving lift of the 125-mm overlays did not result in lower post-rehabilitation roughness values than those of the 50-mm overlays. The roughness values remained stable for the first 4 years of service but increased substantially in 1997 and 1998. By 1998 the roughness on the control section was near 3.5-mm/m and increasing annually at a large rate. Similar to the cells at Brokenhead River the 125-mm overlays have the lowest 1998 roughness values. The lowest roughness figures belong to the 125-mm overlays on the milled or intensive surface preparation. There does not appear to be any significant difference between the cells with virgin material compared to the recycled material cells.

It should be noted that the roughness on the Bemidji site is caused by cupped transverse cracks. The survey conducted by the rating crew noted that the surface in between the transverse cracks is relatively smooth.

Figure 9 allows for direct comparison of the 1998 roughness values on the cells on both sites. All of the Brokenhead River cells have much lower roughness values than their counterparts on the Bemidji site. Note that the low value for roughness on the Brokenhead River Control Section (Cell #1) is attributed to patching that was applied in 1994.

Rut Depth

Transverse profiles have been measured annually on the test sections by the LTPP Raters using dipstick equipment. The rut depths shown in Figure 10 have been calculated with LTPP data for 1998 and measured with a 1.83-m (6-ft) straight edge in 1996.

Table 9 is a list of rut depths measured in 1998, and Figure 10 graphs the results. Rutting values range from 3 to 6 mm and from 1 to 3 on the Brokenhead River and Bemidji cells, respectively. The rutting is lowest on the 125-mm virgin-material overlay with no surface preparation (i.e. no milling). A noticeable trend is that rutting is higher on the milled sections compared to those sections with no milling. No other conclusive trend is noted between the asphalt material type or overlay thickness. The rutting on the Brokenhead River control section has exceeded the tolerable safe limit for rutting set by the agency and was in fact patched in 1994 and again in 1999.

The last trend noted from the data is that in all cases rutting is lower on the Bemidji site when compared to the Brokenhead River site. Note that rutting data for the Bemidji cells numbered 3 and 8 were not available at this time. The rut depths on all of the cells are not considered to be severe enough as of 1998 to require any maintenance intervention.

Transverse and Longitudinal Cracking

Table 10 is a summary of the percent original transverse cracks that reflected through the Minnesota test sections by 1998. An average of 61 percent of the cracks have reflected through the 125-mm overlays and 92 percent of the transverse cracks have reflected through the 50-mm overlays. Virgin mix cells had 67 percent of the cracks reflected through whereas 85 percent of the cracks on the sections with 30 percent RAP have reflected through. As of 1998 the cracks are just opening to the extent that filling is warranted. The mode of failure for this site is primarily environmental with the surface condition better on the recycled material because of the softer asphalt cement.

Total transverse and longitudinal cracking is summarised for the sites and shown in Figure 11. The lowest amount of cracking is on the Brokenhead River 125-mm thick recycled material overlay with no milling. However, the next lowest amount of cracking is on the Bemidji 125-mm thick recycled material with milling. Cracking is generally higher on the virgin material in all but one Brokenhead River cell. Intensive preparation of the surface (milling) has not significantly reduced the amount of cracking on the surface. Lower levels of cracking are found on the 125-mm thick overlays with one exception on the Brokenhead River site.

Fatigue Cracking

Surface fatigue area in square metres is plotted as Figure 12. The most noticeable fact is there is no fatigue cracking in evidence on any of the Bemidji cells. The Bemidji site has a much thicker structure and lower traffic that are the probable causes of this difference.

General fatigue cracking trends on the Brokenhead River test site are the 125-mm virgin material overlays with milled surface preparations have less fatigue area than their respective counterparts. The recycled material cells exhibit generally higher fatigue area measurements than the virgin material cells. The additional thickness provided by the 125-mm overlays seems to be limiting fatigue cracking when compared to the 50-mm overlays. The cells with milled surface preparation do not exhibit lower fatigue areas than the unmilled surface cells.

Surface Distress Index Ratings

Field surveys were made by the authors in 1996 and 1999 to determine the surface rating (SR) for each test section as shown in Table 11. The results indicate that all sections other than the Control Sections were in good to very good condition.

For the Bemidji project, the 1996 PSR range is 3.5 to 3.8 dropping to 3.3 to 3.6 in 1998, and is essentially constant throughout the project. The Manitoba 125-mm overlay sections are somewhat smoother than the 50-mm sections; the average PSR for the 125-mm sections is 3.8 and for the 50-mm sections is 3.5, therefore not a great difference. A PSR value of 2.5 is considered appropriate for rehabilitation. None of the sections were near the critical level of 2.5 at the time of the rating in 1996 or 1998.

The overall pavement quality index (PQI) is a measure of the combination rating between the surface rating (SR, scale 0 worst to 4 perfect) and Present Serviceability Rating (PSR, scale 0 worst to 5 perfect). It is calculated by multiplying the SR by PSR and taking the square root of the product. Table 12 is a list of the PQI of the sections in the Manitoba and Minnesota projects in 1996 and 1999. Based on the PQI values the condition of the sections is essentially the same after eight and nine years respectively.

The panel of raters that surveyed the sites in 1999 made estimates of the remaining life of the surfaces on each cell. Figure 13 and Table 13 detail the estimate from some of the Raters. The Rater's opinions varied on the estimates and no agreement could be found on the remaining life estimates. Therefore, the use of this rating is questionable at best.

With this limitation on the remaining life estimates in mind, the data still show that the Raters expect the remaining life be significantly less on the Brokenhead River site. The fatigue cracking is the primary surface distress on the site and the severity level is beginning to exhibit block and even alligator cracking in some locations. These distresses were felt to indicate that the site is going to require extensive maintenance intervention such as a mill and overlay in as little as 3 to 5 years from 1999.

The Bemidji site exhibits a high level of roughness at the transverse joints requiring maintenance intervention to smooth the surface. However this maintenance intervention would not require a complete new surface such as that at Brokenhead River. The Raters felt that once the transverse crack roughness was corrected the Bemidji site cells would not require major surface repairs for quite some time. This is the reason for the lower remaining surface life estimates for the Brokenhead River site.

Cost Analysis

The cost analysis for this paper will use the data collected during the 1999 SPS-5 field review to determine remaining life including failure modes. This along with estimates of common cost data based on Minnesota data will be used to determine cost estimates for the 20-year period ending in the year 2010 for each section. The following is a description of data and the method used to develop the cost analysis.

Condition Ratings

PSR (Ride – Table 8), SR (Distress – Table 11), and PQI (Ride and Distress – Table 12) are discussed in the evaluation of the test sections earlier in this paper. This information was used along with the distress types to determine what was the first type of maintenance event that was required. A typical example for the Bemidji sections that contain transverse cracks will require a different fix than a Brokenhead River section that contained fatigue cracking.

1999 SPS-5 Panel Remaining Life Estimates

Table 13 shows the SPS-5 panel's remaining life estimates that were used as a basis for the determination of when and what type(s) of pavement preservation was needed to maintain the section to the year 2010. During the visits to the sites the panel was asked to establish the number of years remaining and the type of rehabilitation or maintenance each section needed. This information is used in the first part of Tables 15 and 16 for the "Remaining Life / Distress Types" calculation.

1999 Maintenance and Cost Estimates

Table 14 shows a list of typical costs relating to common maintenance and rehabilitation based on historical Minnesota data. It was decided to use a common set of costs to simplify the cost comparison between Minnesota's and Manitoba's unique systems. Data were also used from Minnesota and Manitoba on the length of time each fix would last in the field. This was used in the second part in Tables 15 and 16 as "Estimated Maintenance Events / Costs". This uses the condition ratings, SPS-5 panel life estimates, and the costs to maintain the sections to the year 2010. The control sections were determined to have deteriorated too far to be included in this comparison. Each section cost consists of fiscal year 2000 dollars and includes a 4% discount rate.

Using the remaining life / distress types along with the estimated maintenance events / costs a total cost for each section is calculated and is summarized in the third part of Tables 15 and 16 as "Cost Summary" for each project. The total 20-year costs are summarized in Figure 14. This shows the most cost-effective SPS-5 treatment consists of a no mill - 50-mm recycled overlay for both Bemidji and Brokenhead River at this time. It also shows that the extra cost to mill a pavement may not be cost-effective for pavements in the poor to fair original condition as these two sites were. The cost comparisons will be confirmed as further reviews are done in the upcoming years.

It is planned to continue evaluating these projects for the next 10 years as part of the LTPP program. It is anticipated that the better surface preparation and thicker overlays will result in lower life-cycle costs over the design life of the projects.

CHAPTER 4

SUMMARY AND CONCLUSIONS

Summary and Conclusions

The LTPP Program includes SPS-5 projects that are studies of asphalt mix overlays over asphalt pavements. The SPS-5 variables are:

1. Environment zones: wet-freeze, wet-no freeze, dry-freeze, and dry-no freeze
2. Pavement condition: fair, poor
3. Existing surface preparation: minimum, intensive (surface milling)
4. Overlay Material - recycled asphalt mix, virgin asphalt mix
5. Overlay thickness - 50-mm and 125-mm

Throughout Canada and the United States, 18 SPS-5 projects have been constructed with the same basic eight test sections.

This report considers the design, construction and evaluation of two of the early SPS-5 projects, Brokenhead River, Manitoba, built in 1989, and Bemidji, Minnesota, built in 1990. These sites are located approximately 160 km apart. Through 1998 the Manitoba project had been subjected to about 2.3 million ESALs and the Minnesota project had been subjected to 0.7 million ESALs.

The condition of the various test sections in 1996 and 1998 has been used to evaluate their performance. The condition evaluation has included:

- Traffic Volumes
- Roughness
- Rut Depth
- Surface Cracking
- Surface Fatigue Area
- Index Ratings
- Cost Analysis Quality Index

The Brokenhead River test cells demonstrated the benefit of the additional paving lift (125-mm overlays) in reducing the post-rehabilitation IRI roughness by 0.2 to 0.8 mm/m. Note that the paving method in Manitoba differs from Minnesota with the paver stopping to connect to each truck and each truck unloading directly into the hopper of the paver. This method resulted in rougher surfaces when just one overlay lift is paved. Application of the second lift corrects most of this roughness and the IRI values of those cells compare well with those in Minnesota.

Analysis of the Bemidji test cells roughness data indicates that there was no difference in the post-rehabilitation roughness between the 50 and the 125-mm overlay cells. Post-rehabilitation roughness of the Bemidji compared to the Brokenhead River 50-mm overlay cells shows 0 to 0.4 mm/m lower IRI values. When the post-rehabilitation roughness values start at the same value, the 125-mm overlay cells had 0.2 to 0.4 mm/m less roughness over the first 8 years of service. This benefit of the increased layer thickness is expected to increase over the remainder of this study.

The Bemidji cells had higher roughness values in 1998 than the similarly constructed Brokenhead River cells. This higher roughness is primarily caused by the propagation of transverse cracks that have reflected through the overlays. The transverse cracks are so severe that the edges have subsided causing cupped or depressed cracks. The pre-rehabilitation condition of the Bemidji transverse cracks was much more severe than those present at Brokenhead River. Although the cracks were filled with asphalt mix and compacted before the rehabilitation occurred, severe cracks still reflected through the asphalt overlay creating a need for maintenance attention after just 9 years of service.

Analysis of the rutting data shows some benefit to the additional thickness provided by the 125-mm overlay. The virgin material seemed to have less rutting while the milling seems to have caused larger rut values. However, the values of rutting are very low for these cells after nearly 10 years service. Thus rutting is not a significant factor in pavement performance on either of these sites.

The Brokenhead River test site shows large areas of fatigue cracking while Bemidji shows none. The reason is thought to be caused by the higher traffic (and much higher allowable 62,500 kg GVW of the Canadian B-Trains operating on this site) and the lighter pavement structure. Even with the up to 43-mm more overlay thickness than what was designed for, the Brokenhead River fatigue cracking still is much higher than that at the Bemidji site.

The fatigue cracking is combining with new transverse cracking to form moderate severity "block" or "map" cracking. The progression rate of this block cracking distress has increased largely over the last three years. This block cracking is the primary distress mechanism that will be monitored over the next ten years to ascertain whether it causes failure of the pavement surface. Given that the original Brokenhead River surface had a large amount of fatigue and block cracking, all combinations of the treatments applied to it seem to have been ineffective in preventing the block cracking from re-establishing in the overlay layer after just ten years of service. An LTPP Initial SPS-5 Evaluation report [6] notes that more fatigue cracking occurred on the dry-freeze sites.

The Bemidji test site has severe levels of depressed transverse cracks. The original surface had severe transverse cracks that were filled with a fine asphalt mix and compacted. After less than 9 years of service these transverse cracks once again require maintenance treatment to correct the roughness they cause. As all of the cells on the Bemidji site now demonstrate this high severity transverse cracking problem, the pre-rehabilitation treatment of the original transverse cracks was ineffective after less than 9 years in preventing the roughness caused by the re-occurrence of the high severity transverse cracks. Although the LTPP report [6] notes that less transverse cracking occurred on sites with intensive surface preparation, the same observation has not been noted at either of these sites.

Based on the pavement section conditions through 1999 all of the rehabilitation procedures are performing well. Therefore, the least cost procedure (50-mm overlay with minimum of surface preparation) would be recommended for a 9 to 10-year service life.

With continued observation of the pavement conditions over the next 10 years it will be possible to track the performance of the various rehabilitation procedures to determine the most cost effective procedure.

In addition to the pavement conditions reported in this paper, Falling Weight Deflectometer deflections have been run on the test sections. Analysis of the FWD data will make it possible to relate the structural integrity of the sections to their performance. The deflection analysis was not within the scope of this report.

When the information for these projects and the other SPS-5 projects are analysed, performance prediction trends can be developed together with an improved design procedure for HMA overlays on HMA pavements.

REFERENCES

1. Strategic Highway Research Program, "Specific Pavement Studies Experimental Design and Research Plan for Experiment SPS-5, Rehabilitation of Asphalt Concrete Pavements," April, 1989.

2. Urbach, Ronald R. and Worel, Benjamin J., "SPS-5 Construction Report," Trunk Highway 2 Westbound, 14 miles West of Bemidji, Minnesota, June, 1996.

3. Minnesota Department of Transportation, Pavement Management Section, "Pavement Management Surface Rating Manual," April, 1991.

4. Strategic Highway Research Program, "Distress Identification Manual For the Long-Term Pavement Performance Project," SHRP-P-338, 1993.

5. Gilbertson, Graig, PAVEMENT, "Menu of Fixes", Life & Cost, $/Mile, Minnesota DOT, 1996.

6. FHWA LTPP Data Analysis Technical Support Contractor, "Initial Evaluation of the SPS-5 Experiment – Draft Final Report", FHWA, 6300 Georgetown Pike, McLean, Virginia, 22101, April, 2000

Table 1 - SPS-5 Test Section Identification

LTPP ID #	Surface Preparation	Asphalt Mix Type	Overlay Thickness (mm)
1 (C)	None	None	None
2(U50R)	None	Recycled	50
3(U125R)	None	Recycled	125
4(U125V)	None	Virgin	125
5(U50V)	None	Virgin	50
6(M50V)	Milled	Virgin	50
7(M125V)	Milled	Virgin	125
8(M125R)	Milled	Recycled	125
9(M50R)	Milled	Recycled	50

Table 2 - Distress Conditions before SPS-5 Construction

LTPP ID [1] #	Patching (m^2)		Transver. Cracks (total m)		Alligator Cracking (total m^2)		Ravelling (m^2)		Bleeding (m^2)		Rut Depth[3] (mm)	
	MB	MN	MB	MN	MB	MN	MB	MN	MB	MN	MB	MN
1 (C)	0	0	11	11	0	0	47	465	0	93	NA	>13
2(U50R)	0.9	0	4	8	0	0	47	186	0	116	NA	13
3(U125R)	0	0	11	10	42	1	47	186	0	70	NA	>13
4(U125V)	0.3	0.1	5	12	7	6	0	279	0	93	NA	>13
5(U50V)	17	0	0	10	0	1	33	279	0	93	NA	13
6(M50V)	31	0	0	12	0	2	19	232	0	46	NA	13
7(M125V)	0.6	0	4	11	9	3	56	279	0	139	NA	13
8(M125R)	23	0	4	10	0	0	85	163	0	116	NA	13
9(M50R)	39	0	4	9	11	0	38	232	0	46	NA	13

Note: (1) LTPP site identification numbers are:27050_ for Bemidji, 83050_ for Brokenhead River

Table 3 - Comparison of Asphalt Overlay Aggregate Gradations

Sieve Opening (ASTM mm)	Virgin Material		Recycled Material	
	Brokenhead River	Bemidji	Brokenhead River	Bemidji
19	100	100	100	100
16	99	96	100	100
12.5	93	83	94	98
9.5	83	75	81	95
4.75	63	64	62	81
2	48	51	46	61
0.425	24	19	24	27
0.075	5	5	6	7

Table 4 - Asphalt Mix Design Criteria for the SPS-5 Projects

Mix Design Criteria	Virgin Mix		Recycled Mix	
	Brokenhead River	Bemidji	Brokenhead River	Bemidji
Fines	69	80	28	25
Coarse	31	20	22	-
Recycled Bituminous	-	-	30	30
Clean Sand	-	-	20	45
Penetration Grade	150/200	85/100	150/200	120/150
Percent	5.2	5.6	4.2(added) 5.9 (total)	4.6(added) (5.8 total)
Blows	75	75	75	75
Stability (lb)	1600	1680	1833	1869
Air Voids (%)	3 – 5	3 – 5	3 - 6	3 - 5
VMA (%)	14.1	15 min.	14.1	15 min.

Table 5 – Cell Thickness Design and As-Built

LTPP ID #	Design Thickness (mm)	As-Built Thickness (mm)	
		Brokenhead River	Bemidji
1	0	NA	NA
2	50	69	61
3	125	124	Unknown
4	125	142	Unknown
5	50	Unknown	48
6	50	81	Unknown
7	125	165	142
8	125	165	Unknown
9	50	94	Unknown

Table 6 - Pre and Post Construction Profile Measurements, IRI, m/km

LTPP ID #	Brokenhead River		Bemidji	
	Pre-Rehab	Post-Rehab	Pre-Rehab	Post-Rehab
1 (C)	1.49	1.49	2.25	2.04
2(U50R)	NA	0.82	2.52	1.00
3(U125R)	NA	0.81	2.74	0.76
4(U125V)	NA	0.82	3.19	1.12
5(U50V)	NA	1.08	2.65	1.08
6(M50V)	NA	1.5	2.06	1.08
7(M125V)	NA	0.71	2.62	0.85
8(M125R)	NA	0.82	2.52	1.00
9(M50R)			2.85	0.78

Table 7 - Annual and Accumulated ESAL Data

Year	Brokenhead River[1]		Bemidji[2]	
	Annual	Accumulated	Annual	Accumulated
1989	75,000	75,000	-	-
1990	260,000	335,000	17,500	17,500
1991	263,000	598,000	75,000	92,500
1992	254,000	852,000	71,000	163,500
1993	229,000	1,081,000	82,500	246,000
1994	185,000	1,266,000	83,800	329,800
1995	250,000	1,516,000	95,300	425,100
1996	250,000	1,766,000	83,400	508,500
1997	270,000	2,036,000	95,200	603,700
1998	270,000	2,306,000	88,000	691,700

Note: (1) 1992 through 1994 ESAL values are from LTPP calculations from WIM data, all other ESAL data estimated from Manitoba Pavement Design Manual formula

(2) 1990 through 1996 Minnesota ESAL calculated by Mn/DOT, 1997 – 1998 values estimated.

Table 8 - SPS-5 Roughness Measurements and Present Serviceability Rating (PSR)

LTPP ID #	IRI 1998 (m/km)		PSR			
			1996		1998	
	Brokenhead River	Bemidji	Brokenhead River	Bemidji	Brokenhead River	Bemidji
1 (C)	1.9	3.5	NA	2.6	3.3	2.7
2(U50R)	1.6	1.8	3.3	3.6	3.5	3.3
3(U125R)	1.1	1.5	3.6	3.6	3.9	3.4
4(U125V)	1.1	1.7	3.7	3.6	3.9	3.3
5(U50V)	1.8	1.9	3.5	3.5	3.4	3.3
6(M50V)	1.8	1.7	3.3	3.7	3.4	3.4
7(M125V)	1.0	1.2	3.9	3.7	3.9	3.6
8(M125R)	0.9	1.3	3.8	3.7	4.0	3.6
9(M50R)	1.3	1.6	3.7	3.8	3.7	3.6

Table 9 - 1998 Calculated Rut Depths

LTPP ID #	Average rut depth (mm) 1998	
	Brokenhead River	Bemidji
1 (C)	13	7
2(U50R)	3	2
3(U125R)	4	NA
4(U125V)	3	1
5(U50V)	3	1
6(M50V)	4	2
7(M125V)	5	2
8(M125R)	6	NA
9(M50R)	3	3

Table 10 - Bemidji SPS-5 Percent of Transverse Cracks Reflected 1996

LTPP ID #	% Reflected
1 (C)	NA
2(U50R)	100
3(U125R)	59
4(U125V)	46
5(U50V)	84
6(M50V)	86
7(M125V)	36
8(M125R)	73
9(M50R)	91

Table 11 - SPS-5 Surface Rating (SR) of Test Sections**

LTPP ID #	Brokenhead River		Bemidji	
	1996	1999	1996	1999
1 (C)	NA	NA	NA	3.0
2(U50R)	3.9	3.3	3.9	3.8
3(U125R)	3.8	3.7	3.8	3.9
4(U125V)	3.9	3.6	3.6	3.5
5(U50V)	3.7	3.9	3.6	3.3
6(M50V)	3.8	3.5	3.7	3.4
7(M125V)	3.9	3.9	3.6	3.5
8(M125R)	3.7	3.9	3.9	3.9
9(M50R)	3.7	3.6	3.7	3.6

** Minnesota method for calculating Surface Rating index calculation

Table 12 - SPS-5 Pavement Quality Index Levels in 1996 for Minnesota and Manitoba

	PQI			
	1996		1999	
LTPP ID #	Brokenhead River	Bemidji	Brokenhead River	Bemidji
1 (C)	NA	NA	NA	2.8
2(U50R)	3.6	3.7	3.4	3.5
3(U125R)	3.7	3.7	3.8	3.6
4(U125V)	3.8	3.6	3.8	3.3
5(U50V)	3.6	3.5	3.6	3.3
6(M50V)	3.6	3.7	3.5	3.3
7(M125V)	3.9	3.6	3.9	3.6
8(M125R)	3.7	3.8	4.0	3.7
9(M50R)	3.7	3.7	3.7	3.6

Table 13 - Estimate of Remaining Life in 1999

LTPP ID #	Life Remaining (yrs)	
	Brokenhead River	Bemidji
1 (C)	0	0
2(U50R)	3	5
3(U125R)	5	6
4(U125V)	7	3
5(U50V)	1.5	3
6(M50V)	3	3
7(M125V)	6.5	6
8(M125R)	3.5	7
9(M50R)	2.5	6

Table 14 – Typical Costs for Maintenance Types for Manitoba and Minnesota

Maintenance Type	Research Estimate	Year 2000 US Dollars	per	Life (Years)
Milling - 1"	.35/yd-yd	235	12'x500'	Original
Milling - 1.5"	.50/yd-yd	333	12'x500'	Original
Milling - 2"	.65/yd-yd	435	12'x500'	Original
Recycled Overlay - 2"	$19/Ton	1400	12'x500'	Original
Recycled Overlay - 5"	$19/Ton	3490	12'x500'	Original
Virgin Overlay - 2"	$21/Ton	1540	12'x500'	Original
Virgin Overlay - 5"	$21/Ton	3850	12'x500'	Original
Patches (Manitoba)		500		3
Route & Seal	.50/ft	0.5	ft	5
Seal only	.25/ft	0.25	ft	3
Mill and HMA Fill Cracks	$3.50/ft (4"x12")	3.5	ft	10
Micro Seal - Crack Leveling	.20/ft	0.2	ft	3
Chip Seal - single	$.70/yd-yd	467	12'x500'	3
Chip Seal - double	$1.00/yd-yd	667	12'x500'	5
Slurry Seal	$1.25/yd-yd	835	12'x500'	3
Micro Seal - 1 pass	$1.50/yd-yd	1000	12'x500'	5
Micro Seal - 2 pass	$2.60/yd-yd	1733	12'x500'	7

* All cost include labor, materials, and traffic control
** 12'x500' cost estimates for a large project (miles)

Table 15 - Bemidji SPS-5 Dollar Comparisons

Bemidji - Remaining Life/Distress Types

Section	Mill & Replace	Mix Type	SPS-5 '90 Cost	1999 Life Remains	Distress Major	Distress Minor
1	--	None	0	1	Transverse	?
2	No	2" Recycle	1400	7.5	Transverse	
3	No	5" Recycle	3490	12	ok	ok
4	No	5" Virgin	3850	13.5	ok	ok
5	No	2" Virgin	1540	4	Transverse	?
6	Yes	2" Virgin	3515	7.5	Transverse	
7	Yes	5" Virgin	5825	12.5	ok	ok
8	Yes	5" Recycle	5325	11	ok	ok
9	Yes	2" Recycle	3235	10	ok	ok

Bemidji - Estimated Maintenance Events/Costs

Section	1st Maintenance Event Type	Year	Life	Cost	2nd Maintenance Event Type	Year	Life	Cost
1	--	--	--	--	--	--	--	--
2	Micro Crack	2007	3	36	--	--	--	0
3	None	2011	--	0	--	--	--	0
4	None	2012	--	0	--	--	--	0
5	Mill/fill	2003	10	630	--	--	--	0
6	Micro Crack	2007	3	36	--	--	--	0
7	None	2011	--	0	--	--	--	0
8	None	2010	--	0	--	--	--	0
9	None	2009	3	36	--	--	--	0

Bemidji – Cost Summary

Section	Original Adj Cost	1st main Adj Cost	2nd main Adj Cost	Total 1999 Adj Cost	Life Remaining	Cost Year	Total 20 Year Cost
1	0	--	--	--	--	--	--
2	1,993	26	0	2,019	0	101	2,019
3	4,967	0	0	4,967	1	237	4,731
4	5,480	0	0	5,480	2	249	4,982
5	2,192	539	0	2,730	3	119	2,374
6	5,003	26	0	5,029	0	251	5,029
7	8,291	0	0	8,291	1	395	7,896
8	7,579	0	0	7,579	0	379	7,579
9	4,604	24	0	4,629	2	210	4,208

Table 16 Brokenhead River SPS-5 Dollar Comparisons

Brokenhead River - Remaining Life/Distress Types

Section	Mill & Replace	Mix Type	SPS-5 '90 Cost	1999 Life Remains	Distress Major	Minor
1	--	None	0	-3	Fatigue	
2	No	2" Recycle	1400	3	Fatigue	
3	No	5" Recycle	3490	5	Fatigue	
4	No	5" Virgin	3850	7	None	
5	No	2" Virgin	1540	1.5	Fatigue	
6	Yes	2" Virgin	3515	3	Fatigue	
7	Yes	5" Virgin	5825	6.5	5 mm Ruts	
8	Yes	5" Recycle	5325	3.5	6mm Ruts	
9	Yes	2" Recycle	3235	2.5	Fatigue	

Brokenhead River - Estimated Maintenance Events/Costs

Section	1st Maintenance Event				2nd Maintenance Event			
	Type	Year	Life	Cost	Type	Year	Life	Cost
1	Patch	1994	6	500	--	--	--	--
2	2" Virgin	2002	11	1540	--	--	--	0
3	2" Virgin	2004	11	1540	--	--	--	0
4	Route/Seal	2006	5	60	--	--	--	0
5	2" Virgin	2001	11	1540	--	--	--	0
6	2" Virgin	2002	11	1540	--	--	--	0
7	Micro (1)	2006	5	1000	--	--	--	0
8	Micro (2)	2003	7	1733	--	--	--	0
9	2" Virgin	2002	11	1540	--	--	--	0

Brokenhead River – Cost Summary

Section	Original Adj Cost	1st main Adj Cost	2nd main Adj Cost	Total 1999 Cost	Life Remaining	Cost Year	Total 20 Year Cost
1	0	--	--	--	--	--	--
2	1,993	1,369	0	3,362	3	146	2,923
3	4,967	1,266	0	6,233	5	249	4,987
4	5,480	46	0	5,525	1	263	5,262
5	2,192	1,424	0	3,616	2	164	3,287
6	5,003	1,369	0	6,372	3	277	5,541
7	8,291	760	0	9,051	1	431	8,620
8	7,579	1,481	0	9,061	0	453	9,061
9	4,604	1,369	0	5,973	3	260	5,194

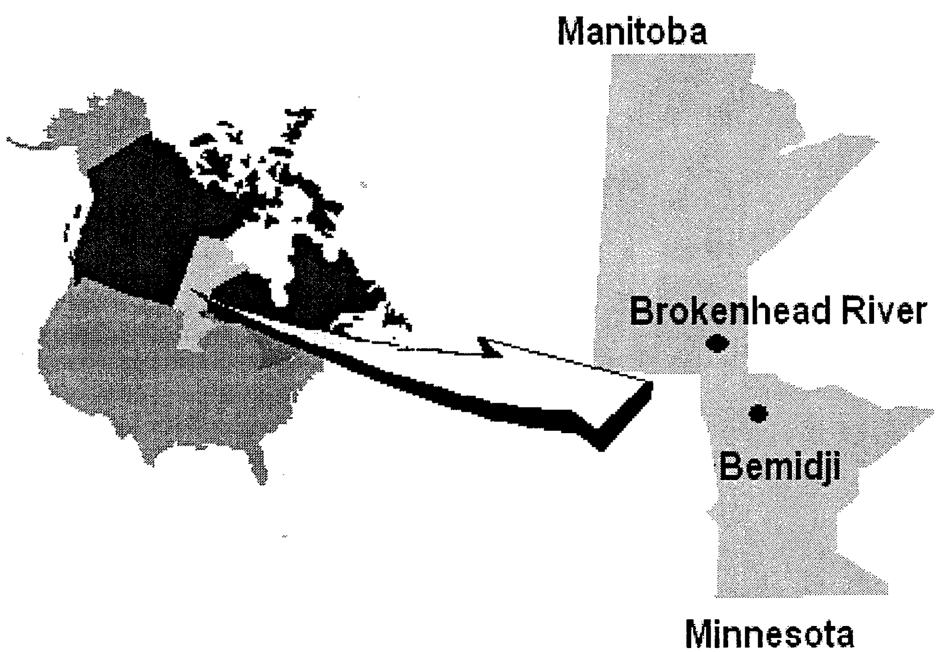


Figure 1 – Location of the Manitoba and Minnesota SPS-5 Sections

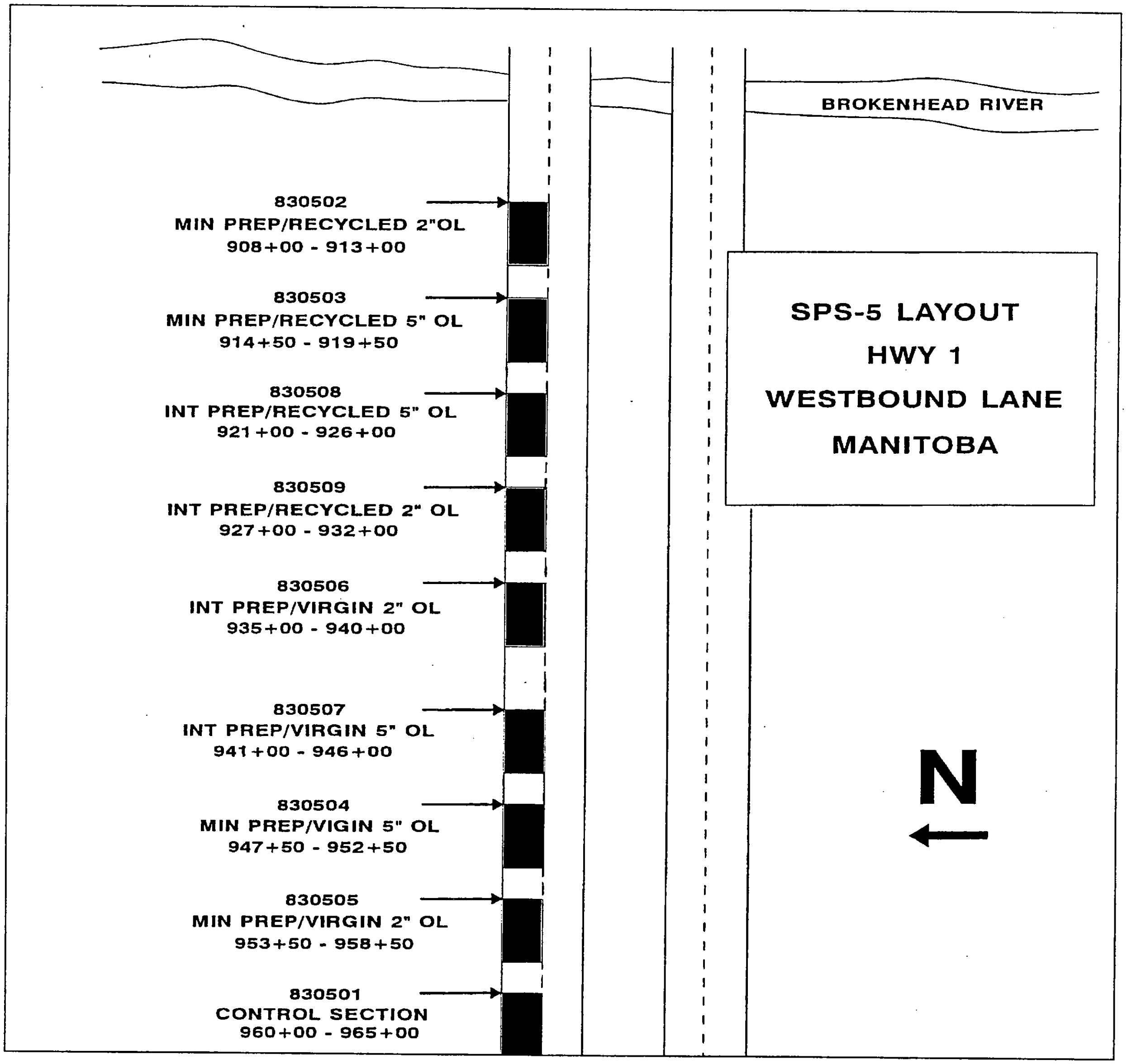


Figure 2 – Manitoba's SPS-5 Section Layout

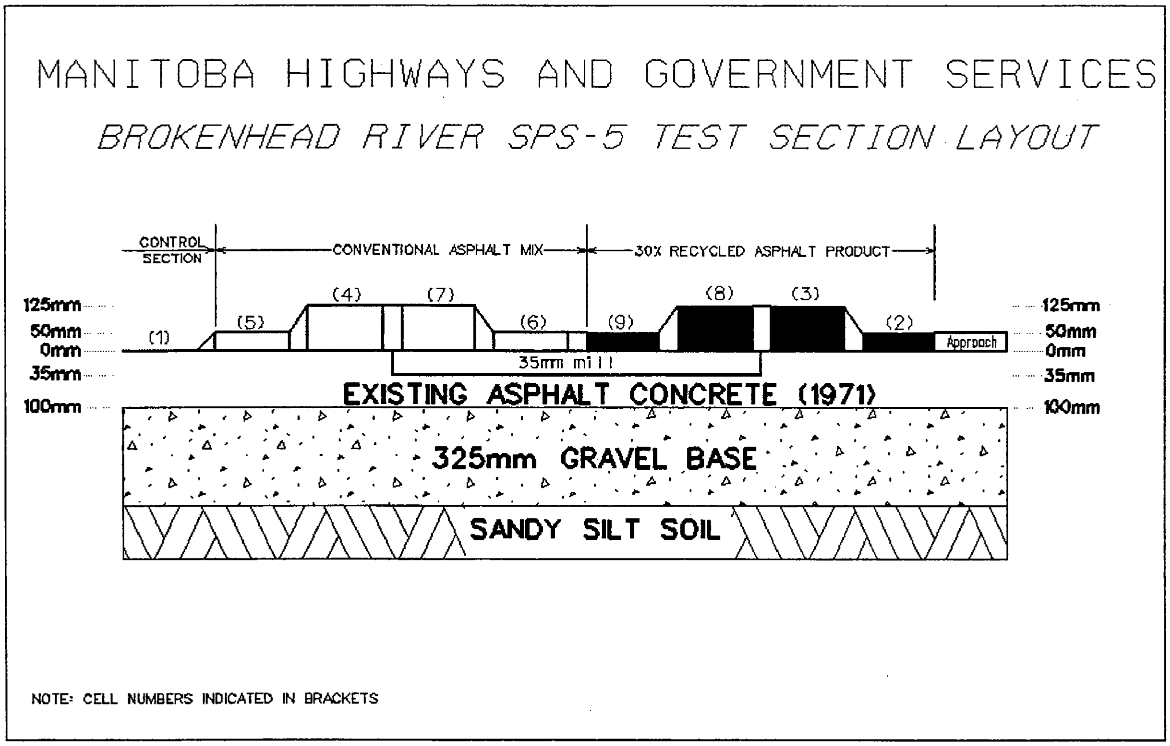


Figure 3 – Manitoba's SPS-5 Designed Section Layout

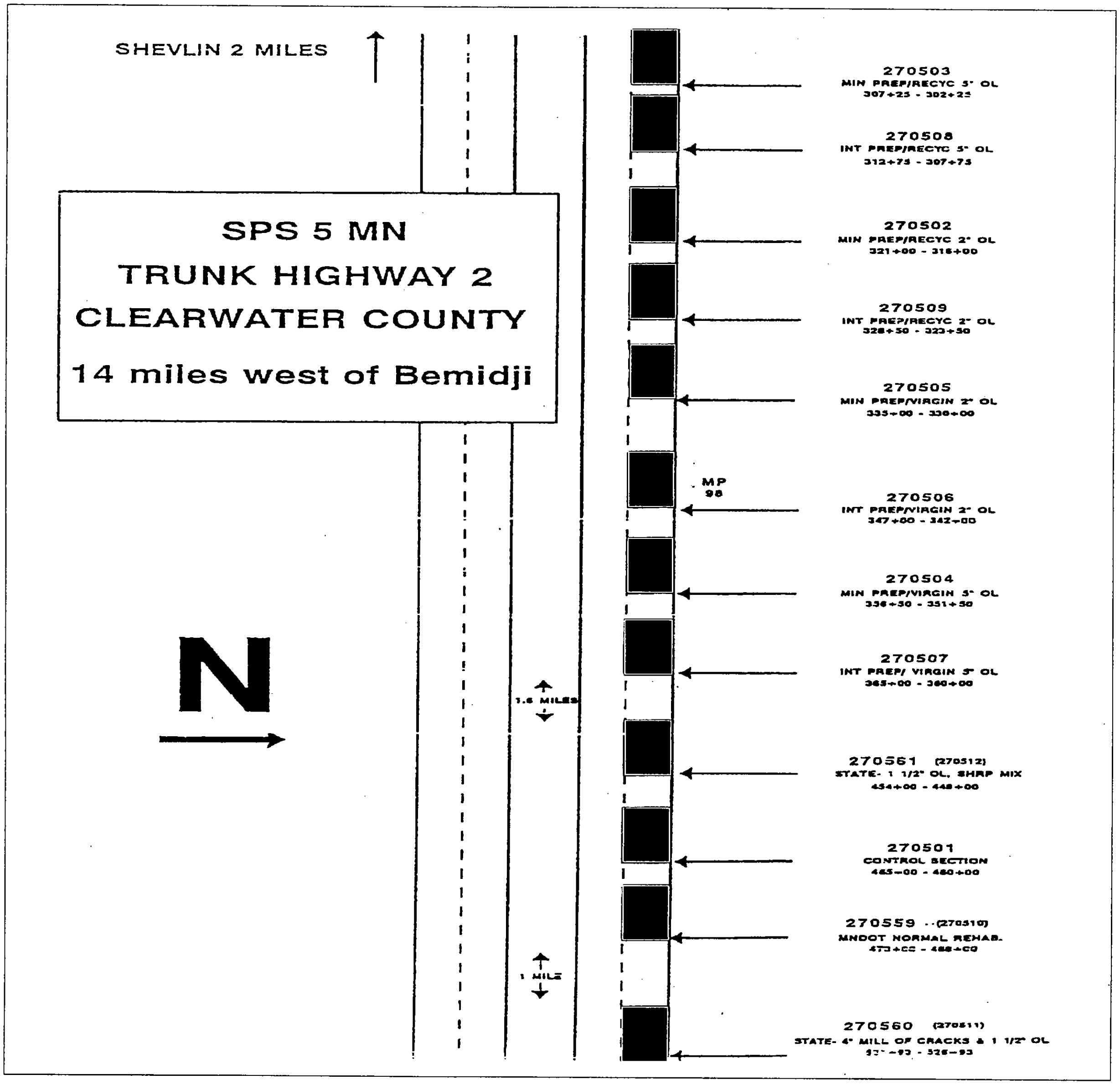


Figure 4 – Minnesota's SPS-5 Section Layout

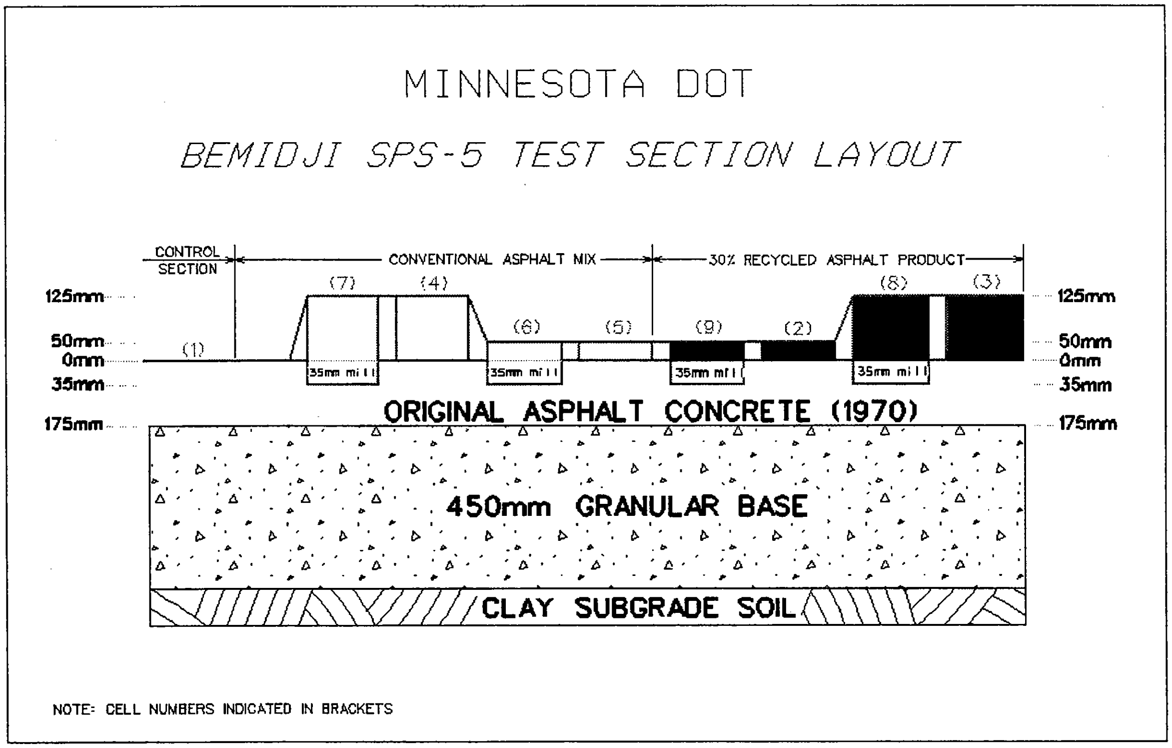
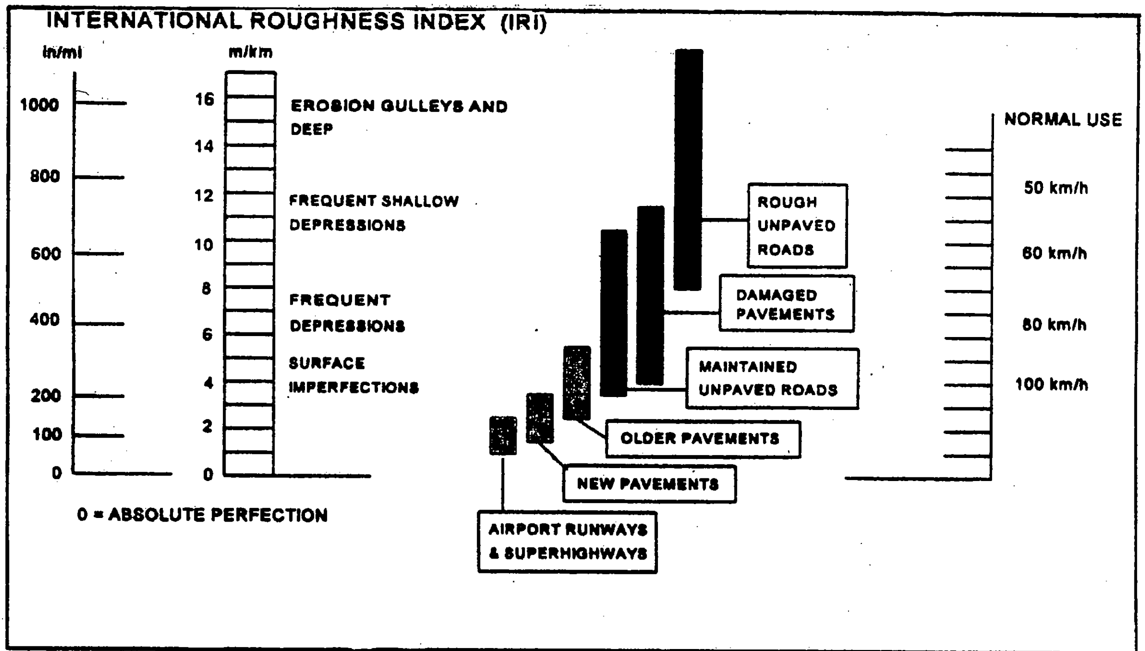


Figure 5 - Minnesota's SPS-5 Designed Section Layout



Physical Interpretation of the IRI

Figure 6 - International Roughness Index

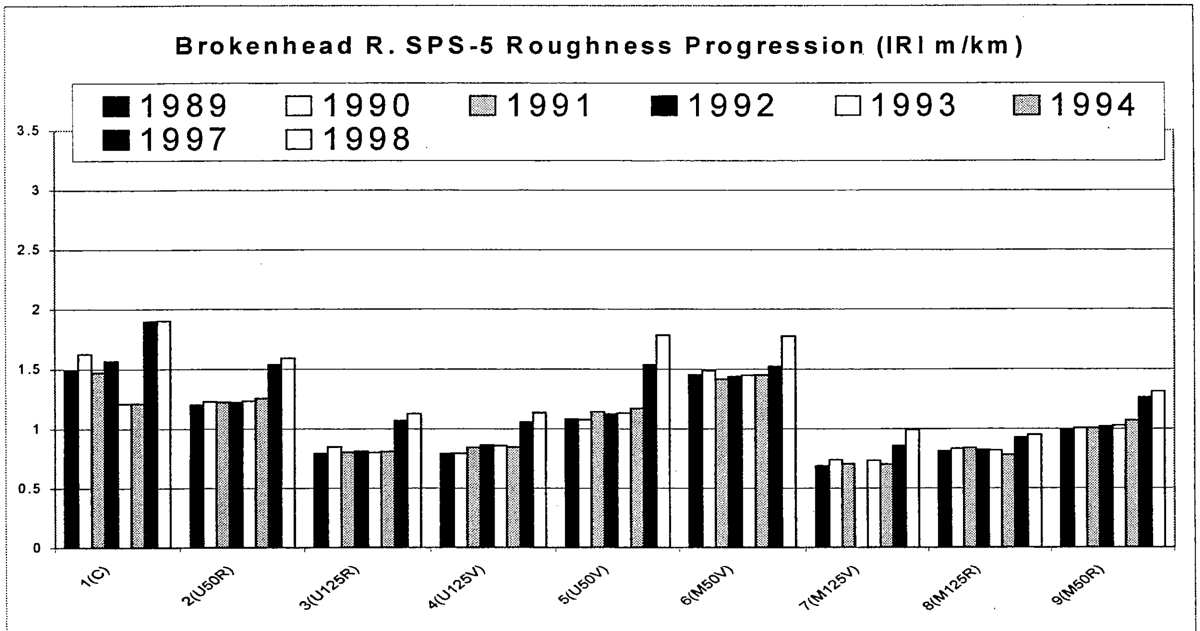


Figure 7 – Brokenhead River Roughness Progression

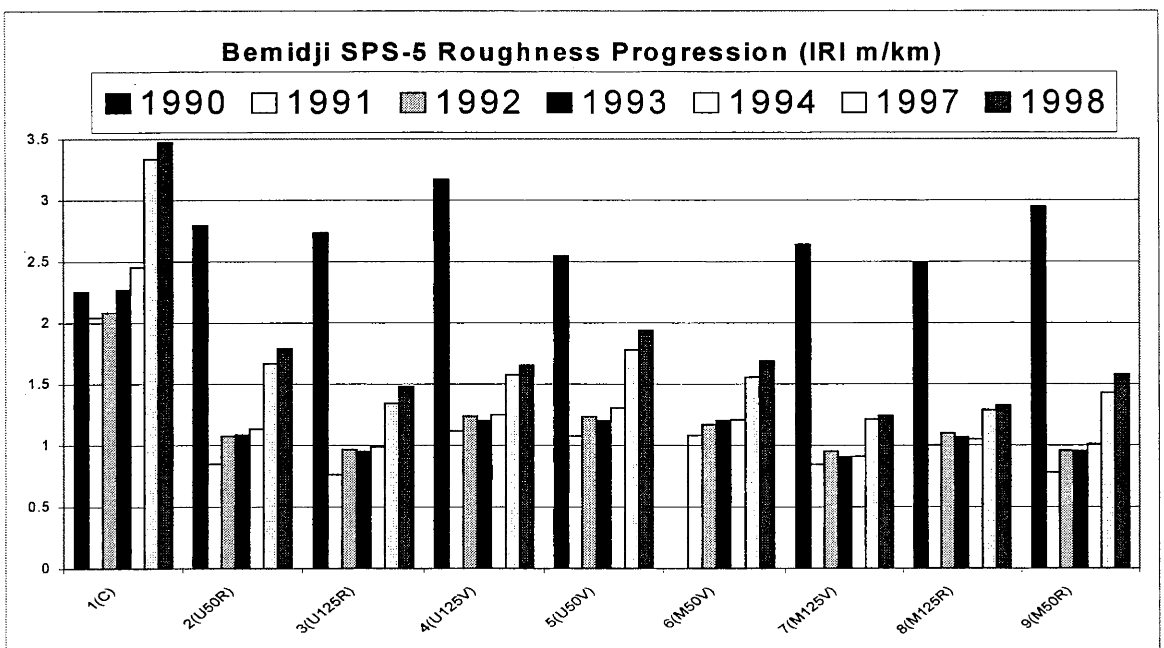


Figure 8 – Bemidji Roughness Progression

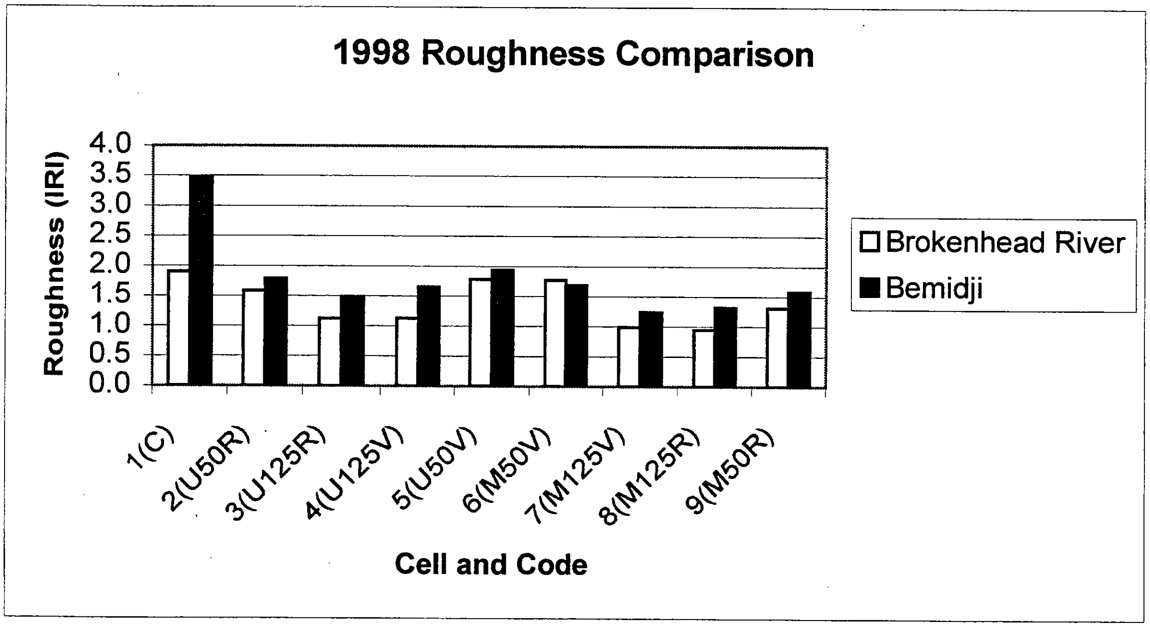


Figure 9 – 1998 Roughness Comparison

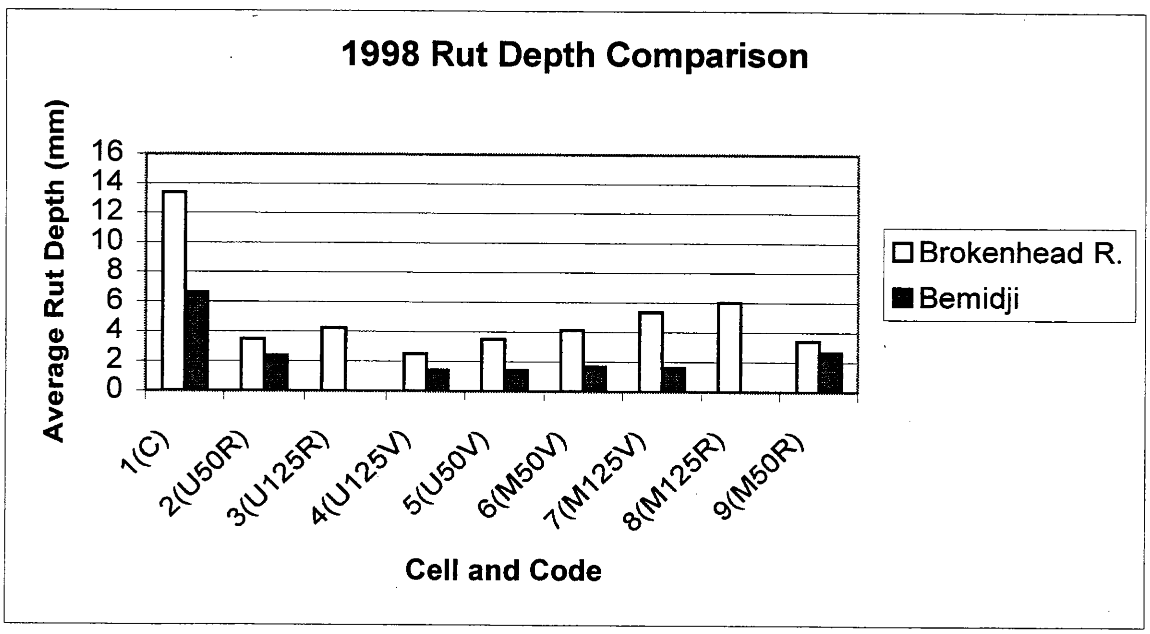


Figure 10 – 1998 Rut Depth Comparison

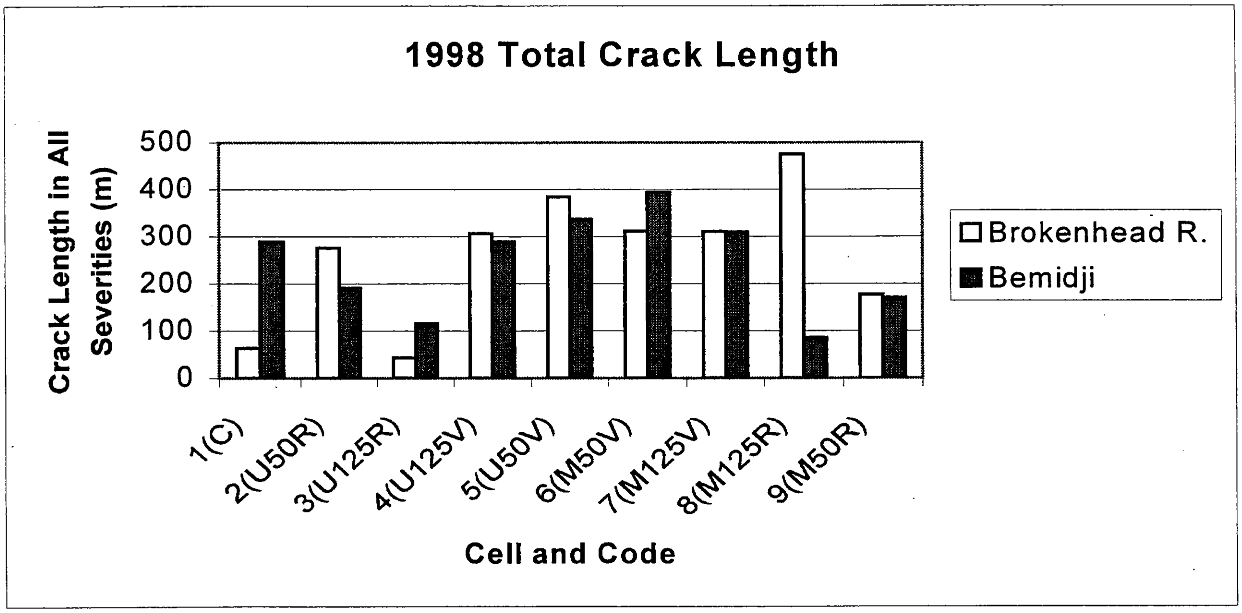


Figure 11 – 1998 Total Crack Length Comparison

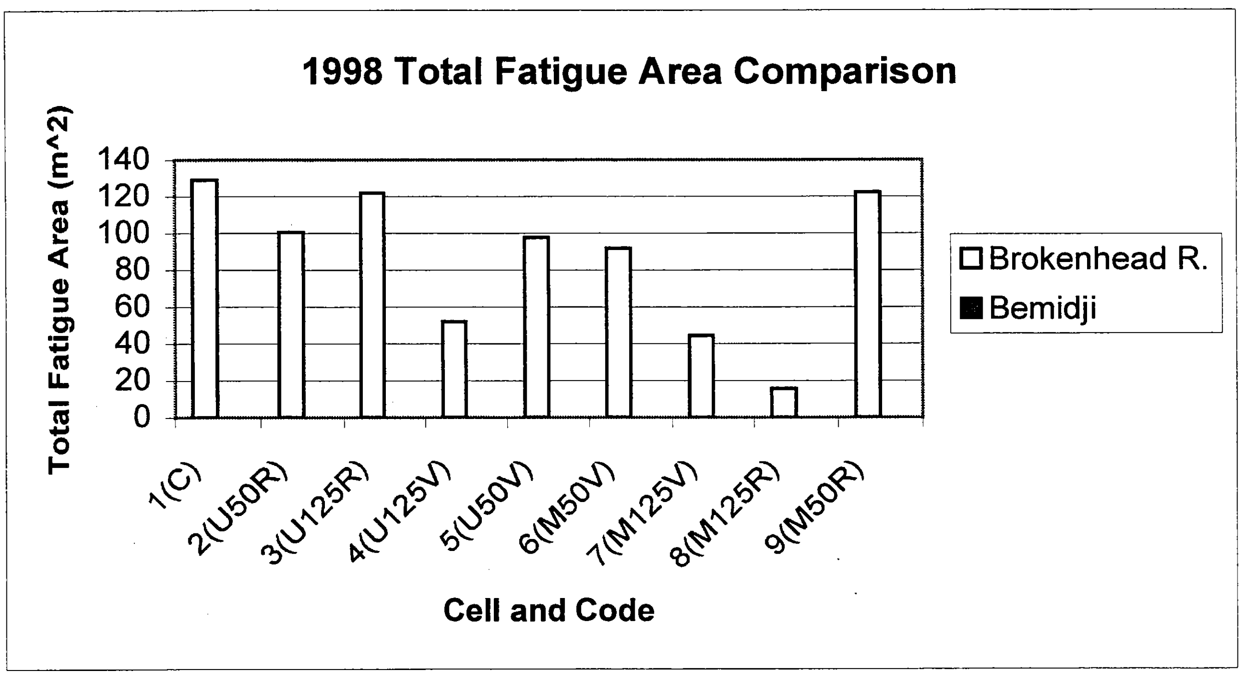


Figure 12 – 1998 Total Fatigue Area Comparison

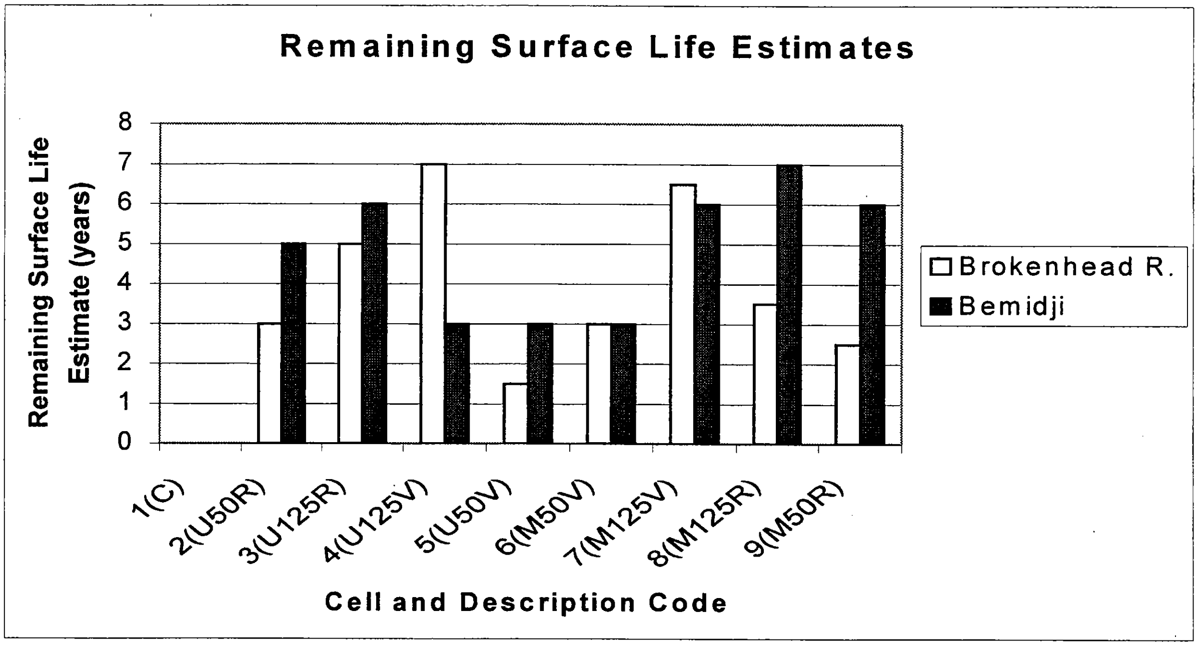


Figure 13 – Remaining Surface Life Estimates

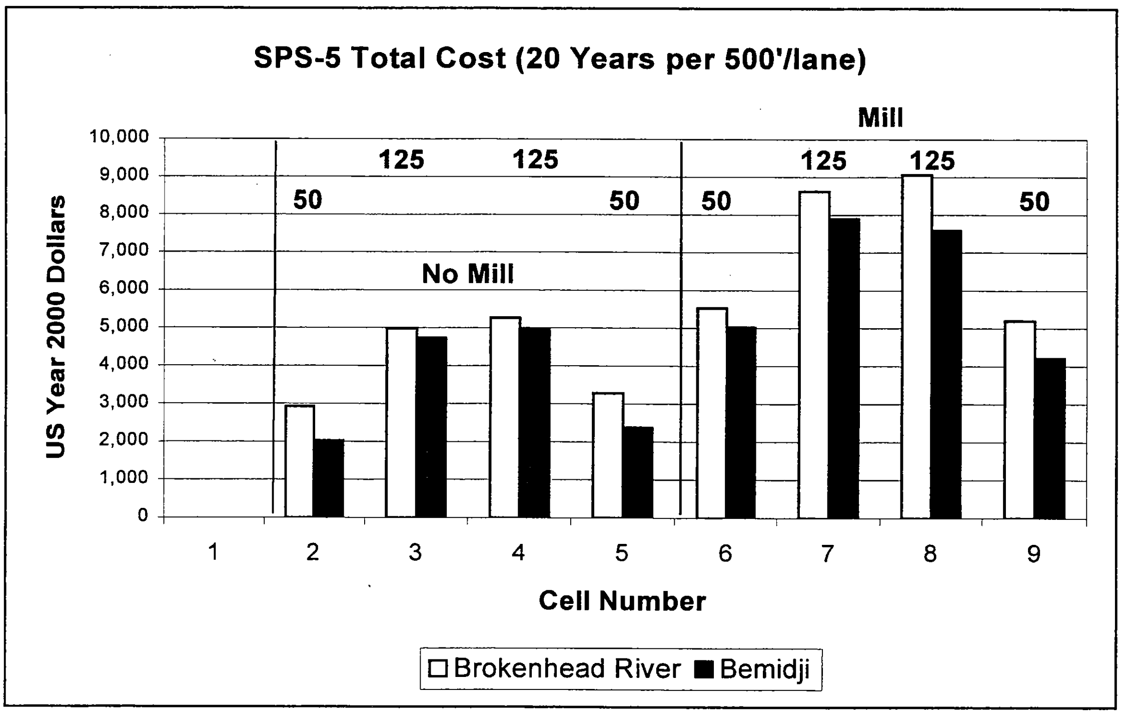


Figure 14 – Total Costs per SPS-5 Treatment

Office of Research Services
395 John Ireland Blvd., Mail Stop 330
Saint Paul, Minnesota 55155

(651) 282-2274