# Effect of Pavement Overlay Characteristics on Pavement's Long-Term Performance

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**SUMMARY**

The most common type of pavement rehabilitation is the asphalt concrete (AC) overlay. An understanding of the factors affecting the long-term performance of overlays should enable pavement engineers to build overlays with longer service lives. Original pavement conditions, overlay thickness, mix properties, traffic characteristics, and weather conditions can all affect the long-term performance of AC overlays. There are some models that were developed to evaluate the performance of the overlay. One of these models, by Hajek et al, was developed to predict the service life of the overlay that are constructed in Ontario. Hajek et al recommended updating this model using new data that would be available later. In 1989, the Canadian Long-Term Pavement Performance (C-LTPP) project was established with a main objective of identifying the best procedure for pavement rehabilitation. Overlays with different characteristics were constructed over the existing pavement and their surface conditions were monitored.

The objectives of this study are; to investigate the effect of AC overlay thickness and mix type [virgin vs. recycled] on long-term performance by using the data available in C-LTPP, and to evaluate the results produced from applying Hajek et al model on Ontario test sections available in C-LTPP. The data in the C-LTPP database were used to develop mathematical models correlating the expected service life of the overlay to its thickness and mix types. These models suggested that thickness and mix type might have limited effect on the expected service life under specific conditions. Therefore, pavement engineers must exercise a high degree of caution to select the most cost-effective overlay rehabilitation technique. More data over longer periods of time are needed to establish more accurate models predicting the service life of a new overlay. Also, the expected service life of Ontario overlays were calculated by Hajek model and the developed models. It was found that there are some differences between the results of Hajek et al model and the results of the models developed in this study. The causes of these variations were discussed in this report and it is recommended to re-evaluate the accuracy of these models later after monitoring the actual service life of the overlays in the field.

## 1. INTRODUCTION

Asphalt concrete (AC) overlay is one of the most common techniques of pavement rehabilitation. Rapid deterioration of this type of rehabilitation is one of the biggest problems that face highway engineers. The actual service life for most overlays is usually considerably less than the expected design life. Consequently, an additional budget will be required to bring these roads back to an acceptable level of serviceability. On the other hand, a good understanding of the factors affecting the long-term performance of overlays should enable pavement engineers to design and construct overlays with longer service lives so that the total cost of maintenance work would decrease.

There are many factors that can affect the long-term performance and rate of deterioration of AC overlays. Among these factors are the original pavement conditions, overlay thickness, mix properties, traffic characteristics, and weather conditions. In 1987, Hajek et al [1] investigated some of these factors by analysing data collected from Ontario roads to develop a mathematical model that can predict the design life of the overlay. The variables considered in this model were the overlay thickness, equivalent single axle load (ESAL), patching works in the original pavement prior to the overlay, and the service life of the original pavement. However, due to the limitations imposed by the data available while creating this model, the authors recommended updating this model using new data that would be available later.

In 1987, the Canadian Strategic Highway Research Program (C-SHRP) was initiated. The main objectives of this project are to study the long-term pavement performance of Canadian roads and transfer the technology developed through the US-SHRP. In 1989, the Canadian Long-Term Pavement Performance (C-LTPP) project was established as part of C-SHRP. This project was designed to allow a comparison of the performance of different types of overlay rehabilitation with respect to the overlay characteristics. The overall goal of this project has been stated as to increase pavement life through the development of cost-effective pavement rehabilitation procedures, based upon a systematic observation of in-service pavement performance [2].

## 2. PROJECT OBJECTIVES

The main objectives of this study are; to investigate the effect of the overlay thickness and the overlay mix type [virgin AC versus recycled AC] on the performance of the overlay, to evaluate the accuracy of Hajek et al model in predicting the service life of the overlays. Thus, the results of this study can help in selecting the most appropriate material and thickness to be used in the rehabilitation process using AC overlay. The sections that are available in the C-LTPP database were classified into seven different groups according to their environmental conditions, subgrade type, and traffic level. The data from C-LTPP database were analysed to determine the level of serviceability for each section under study. Based on the outcome of this analysis, a set of mathematical models was developed to relate the level of serviceability for each group of sections to the type and thickness of the overlay, the age of original pavement before constructing overlay, and the strength of original pavement cross section. These developed models were used in order to predict the expected surface life for the sections under study. Then

Hajek et al model was used to predict the expected service life for Ontario sections under study. Finally, a comparison between the results of Hajek model and the results of the developed models for Ontario sections was carried out.

The report is divided into four parts; the first part gives a brief description of the C-LTPP project. The second part presents the technique used in this study to predict the level of serviceability of the overlay. The third part describes the data collection and analysis, while the fourth part presents the summary and conclusions.

## 3. CANADIAN LONG-TERM PAVEMENT PERFORMANCE PROJECT

As mentioned before, the C-LTPP project was established in 1989 as part of C-SHRP. The main objective of this project is to develop cost-effective overlay rehabilitation techniques (to increase the service life of the asphalt concrete pavement) based on monitoring the actual performance of the pavement in the field [2]. Through the C-LTPP project, twenty-four test sites on the major provincial highway system across Canada were established by constructing AC overlays with different thicknesses and mix types over the existing pavement. The performance of these overlays has been monitored from the time of construction to date. These test sites were divided into sixty-five sections, where each test site has between two to four adjacent sections. The reason for using adjacent sections is to neutralise the effect of other factors (subgrade, climate, traffic, etc) on the comparison of the performance of the different types of overlay [2]. Table 1 illustrates the rehabilitation strategies for C-LTPP project and Table 2 illustrates C-LTPP test site locations.

**Table 1. C-LTPP Rehabilitation Strategies**

| Experiment Type Code | Experiment Description | Number of Sites |
|---|---|---|
| 1 | - Performance comparison of overlay thickness (HMAC*)- Two adjacent test sections. | 14 |
| 2 | - Performance comparison of overlay thickness (RAP**)- Two adjacent test sections. | 0 |
| 3 | - Performance comparison of overlay material type, HMAC vs. RAP - Two adjacent test sections. | 0 |
| 4 | - Performance comparison of overlay thickness (HMAC)- Three adjacent test sections. | 2 |
| 5 | - Performance comparison of overlay additive or mix property variation - Two adjacent test sections. | 1 |
| 6 | - Combination of experiments 1, 2, and 3 | 2 |
| 7 | - Combination of experiments 1 and 3 | 1 |
| 8 | - Combination of experiments 1, 3, and 5 | 2 |
| 9 | - Combination of experiments 1 and 5 | 2 |
| | Total | 24 |

** Hot Mix Asphalt Concrete*
*** Recycled Asphalt Pavement*

**Table 2. C-LTPP Test Sites Locations**

| Province | C-SHRP ID | No. of sections | Experiment Type Code |
|---|---|---|---|
| Alberta | 810404 | 4 | 6 |
| British Columbia | 820205 | 2 | 1 |
| | 820502 | 2 | 5 |
| | 820605 | 2 | 1 |
| Manitoba | 830403 | 3 | 4 |
| | 830801 | 4 | 6 |
| New Brunswick | 840101 | 3 | 7 |
| | 840204 | 2 | 1 |
| | 840604 | 4 | 8 |
| Newfoundland | 850201 | 2 | 1 |
| | 850206 | 2 | 1 |
| | 850601 | 2 | 1 |
| Nova Scotia | 860501 | 3 | 9 |
| | 860603 | 3 | 4 |
| Ontario | 870102 | 2 | 1 |
| | 870504 | 2 | 1 |
| | 870505 | 4 | 8 |
| | 870701 | 2 | 1 |
| Prince Edward Island | 880203 | 4 | 1 |
| Quebec | 890503 | 4 | 9 |
| | 890702 | 2 | 1 |
| Saskatchewan | 900402 | 2 | 1 |
| | 900802 | 3 | 1 |
| | 900803 | 2 | 1 |
| Total | 24 test sites | 65 sections | |

The main factors that can affect the performance of the overlay that were included in the C-LTPP can be summarised as follows:

- Overlay material: two material types are used - virgin mix and recycled mix.
- Overlay thickness: overlay thickness is classified into three groups - 30-60 mm, 60-100 mm, and 100-185 mm.
- Climatic condition: climatic conditions at the test sites are classified into three classes - wet low-freeze, wet high-freeze, and dry high-freeze.
- Subgrade: two types of subgrade material are included - fine and coarse subgrade.
- Traffic: two traffic levels are included - low and high.

Table 3 illustrates the main characteristics of each section.

**Table 3. C-LTPP Sections Classified by climatic zone, subgrade type, traffic level, overlay material, and overlay thickness**

| Traffic | Overlay Material | Overlay Thickness | Moisture, Freezing Index and Subgrade | | | | |
|---|---|---|---|---|---|---|---|
| | | | Wet | | | | Dry |
| | | | Low Freeze | | High Freeze | | High Freeze |
| | | | Fine Subgrade | Coarse Subgrade | Fine Subgrade | Coarse Subgrade | Fine Subgrade |
| Low | Recycled AC | 30-60 mm | | | | | 8104044 |
| | | 60-100 mm | | | | | 8104043 |
| | | 100-185 mm | 8205021<br>8205022<br>8705054 | | | | |
| | Virgin AC | 30-60 mm | 8206051<br>8701022 | 8202051<br>8606033<br>8802031<br>8802033 | 8707011 | | |
| | | 60-100 mm | 8206052<br>8701021<br>8705051<br>8705052 | 8202052<br>8402042<br>8502012<br>8502062<br>8506012<br>8606031<br>8606032<br>8802034 | | | |
| | | 100-185 mm | | 8402041<br>8502011<br>8502061<br>8506011<br>8802032 | 8707012 | | 8104041<br>8304031<br>9004021 |
| High | Recycled AC | 30-60 mm | | | | | 8104042<br>8304032<br>8304033<br>9004022 |
| | | 60-100 mm | | 8401013 | | | |
| | | 100-185 mm | | 8401012<br>8406041 | | | |
| | Virgin AC | 30-60 mm | 8605011<br>8605013 | 8406043<br>8406044<br>8705041 | 8907021 | 8905031<br>8905032 | 9008021 |
| | | 60-100 mm | 8605012 | 8406042<br>8705042 | 8907022 | 8905034 | 9008022 |
| | | 100-185 mm | | 8401011 | | 8905033 | 8308013<br>8308014<br>9008023<br>9008031<br>9008032 |

## 4. PAVEMENT EVALUATION

There are four criteria that can be used for the pavement evaluation process [3]:

- Pavement roughness (rideability).
- Pavement distress (surface condition).
- Pavement deflection (structural failure).
- Skid resistance (safety).

Using these criteria, the concept of Present Serviceability Index (PSI) was presented to correlate the quality of the pavement to the road roughness, cracking, patching, and rutting [4]. The minimum value for PSI is zero, which corresponds to a very poor pavement, and its maximum value is 5, which corresponds to a very good pavement. Practically, the maximum value for PSI that can be actually achieved in the field is approximately 4.5, which is reached directly after the initial construction. On the other hand, the minimum limit for PSI should not be allowed to drop below 2.5 for major roads and 2.0 for minor roads. Beyond these limits, rehabilitation or reconstruction works should be applied to bring these roads back to an acceptable level of serviceability. The typical relationship between PSI and pavement age (or accumulated traffic) can be presented graphically as shown in Figure 1 [3].

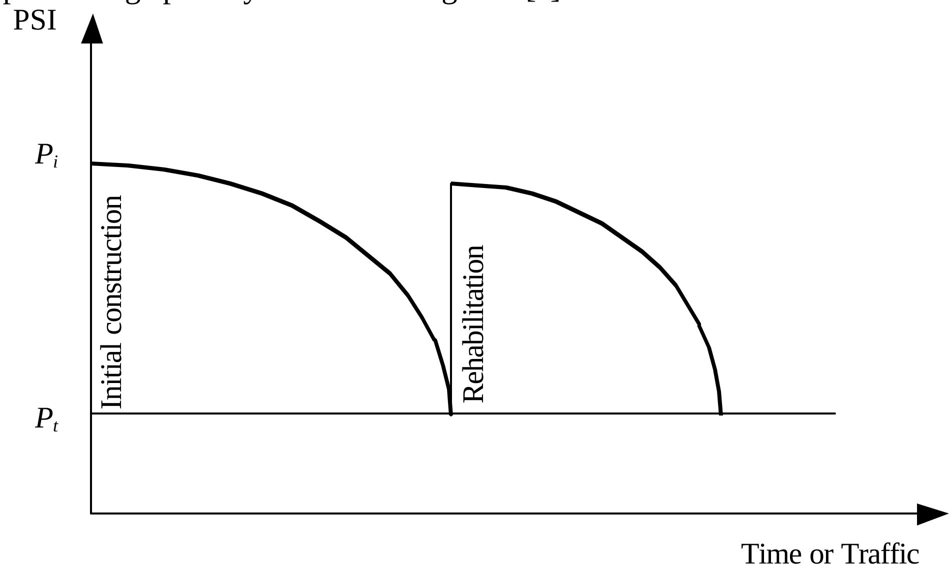


**Figure 1. Pavement Life Cycle.**

As shown in the figure, the maximum value of PSI (referred to as initial serviceability index, $p_i$) is achieved directly after the initial construction. This value then decreases gradually with time and the rate of reduction of PSI also increases with time. When PSI reaches its minimum acceptable level (referred to as terminal serviceability index, $p_t$, and its value is usually 2.5 for major roads and 2.0 for minor roads), major maintenance work (rehabilitation) should be applied to increase PSI again to an acceptable level. After the rehabilitation, PSI decreases again with time. If, after a number of rehabilitation cycles, the rate of deterioration of PSI is so high that the benefits of the rehabilitation process are too small relative to its cost, a reconstruction should take place as an economical solution.

The original equation for determining the PSI was developed based on the data of the AASHTO Road test, and can be expressed in metric units as follows [4,5]:

$$PSI = 5.03 - 1.9 \log (1 + SV) - 0.01 (C + P)^{0.5} - 0.002139 \, RD^{2} \qquad (1)$$

where:

- $PSI$ = Present Serviceability Index,
- $SV$ = slope variance,
- $C$ = cracks in m per 1000 $m^2$ area,
- $P$ = bituminous patching in $m^2$ per 1000 $m^2$ area, and
- $RD$ = rut depth in mm (both wheel tracks) measured with a 1.2-m straightedge.

However, previous studies that were carried out using the data from the AASHTO Road test showed that the pavement roughness could contribute about 95 percent in describing the serviceability level of the pavement [5]. Therefore, another formula was developed by Al-Omari [6] to predict the PSI as a function of the International Roughness Index (IRI) as follows:

$$PSI = 5e^{(0.26 IRI)} \qquad (2)$$

## 5. DATA COLLECTION AND ANALYSIS

### 5.1 Data Collection

Out of the total 24 test sites with 65 sections in the C-LTPP project, the data that are available for establishing the relationship between PSI of an overlay and its characteristics (thickness and mix type) are for 17 test sites with 42 sections. As shown in Table 4, the test sites and sections cover all Canadian regions and nearly all the provinces. The sections also cover all the parameters addressed in the C-LTPP project that can affect the overlay performance. These parameters include overlay characteristics, which are thickness and mix type (virgin mix vs. recycled mix), as well as field conditions, which are traffic level, environmental conditions, and subgrade type. However, the data collected on these sites and sections had to be checked against irregularities that may have been introduced during collection or documentation.

To examine the available sites and sections against possible data irregularities, the trend of PSI versus time was examined on all available sections. A linear regression equation between PSI (based on the collected data of IRI) and time for each section was established. The sole objective of this linear regression was to separate the sections that exhibit the trend of increasing PSI with time due to possible data irregularities. This step should not be confused with the modelling of PSI, where the relationship is more accurately modelled as a curve as shown in Figure 1. The developed linear relationship between PSI and time was found to have a positive slope on seven sections, indicating that the pavement serviceability increases with time (see for example Section 3 in Figure 2). As such a trend is counter-intuitive and violates the concept of PSI, it must have resulted from data irregularities on the associated sections. As a result, the sections that displayed this trend were excluded from this study. Subsequently, a total number of 16 sites with 35 sections were used for analysis in this study. Figures B-1 to B-42 in appendix B illustrate the trend of PSI versus time for all the sections under study.

**Table 4. Selected Test Sites**

| Province | C-SHRP ID | No. of sections |
|---|---|---|
| Alberta | 810404 | 4 |
| British Columbia | 820205 | 2 |
| | 820605 | 2 |
| Manitoba | 830801 | 4 |
| New Brunswick | 840101 | 3 |
| | 840204 | 2 |
| Newfoundland | 850201 | 2 |
| | 850206 | 2 |
| | 850601 | 2 |
| Ontario | 870102 | 2 |
| | 870504 | 2 |
| | 870701 | 2 |
| Prince Edward Island | 880203 | 4 |
| Quebec | 890702 | 2 |
| Saskatchewan | 900402 | 2 |
| | 900802 | 3 |
| | 900803 | 2 |
| Total | 17 test sites | 42 sections |

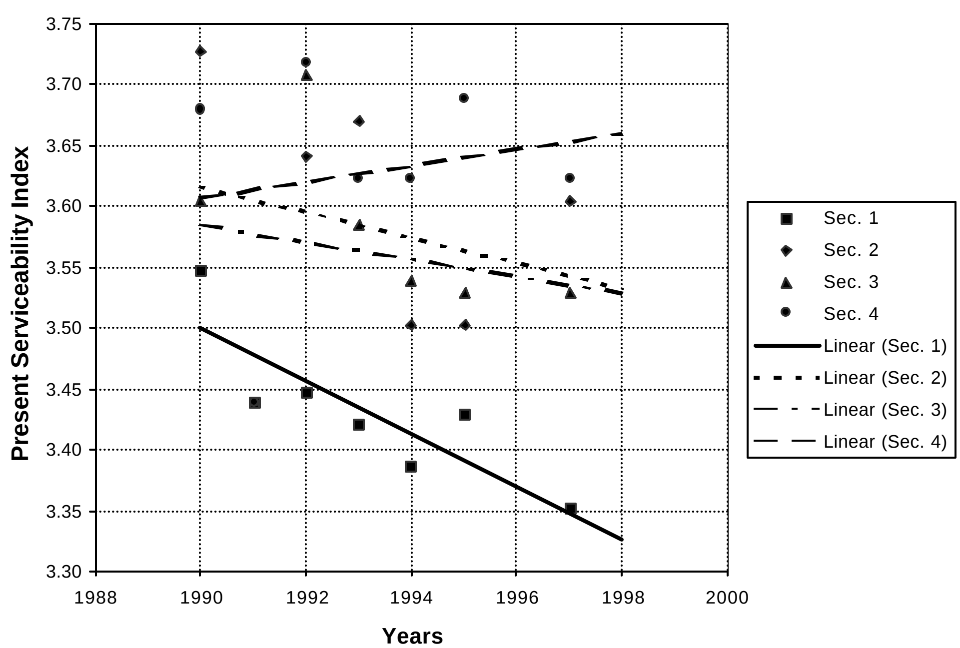


**Figure 2. Example of examining the trend of PSI with time for Site 810404**

It should be noted that although this preliminary analysis, as well as the analysis presented in the following sections, was based on Equation 2 that uses the IRI data, both models in Equations 1 and 2 were tried. As mentioned earlier, the data required to calculate the PSI using Equation 1 are slope variance, cracks in meter per 1000 $m^2$ area, bituminous patching in $m^2$ per 1000 $m^2$ area and rut depth in mm (both wheel tracks) measured with a 1.2-m straightedge. All these data can be calculated based on the information available in the C-LTPP database. On the other hand, only the value of the IRI is required to calculate the PSI using Equation 2. The data of the IRI are available directly in C-LTTP database for both the outer wheel path (OWP) and the inner wheel path (IWP).

However, it was noted that some of the PSI values estimated using Equation 1 were unrealistic. For example, the values of PSI immediately after rehabilitation for some sections were found to be less than 2.5, which is not logical. These unrealistic values may have resulted from inaccurate measurements for the types of pavement distress that were used as input data in Equation 1 or from unsuitability of Equation 1 under the conditions of test sites and sections. On the other hand, the PSI values that were estimated using Equation 2 were found to be more realistic. Consequently, the PSI values obtained using Equation 2 were used in the further stages of this study. Tables A-1 to 42 in appendix A summarises the IRI values for each section under study as well as the calculated values of PSI using equation 2.

## 5.2 Factors Affecting Overlay Performance

As mentioned before, all sections in the C-LTPP project, including those selected in this study, are classified according to five main factors. These factors are climatic conditions, subgrade type, traffic level, overlay material, and overlay thickness. In addition to the previous factors, two more factors can be extracted from the C-LTPP database, which are the strength of the original pavement structure and the age of the pavement layer before constructing the overlay.

The strength of the original pavement structure before overlay can be calculated using the Asphalt Institute conversion factors (AICF). These factors, shown in Table 5 are used to determine the equivalent asphalt concrete thickness corresponding to each layer in the pavement structure (base, subbase, cracked AC layer before rehabilitation) [5]. The summation of all these thicknesses can be used as an indication of the strength of the original pavement structure. Table 6 summarises the characteristics of each section used in this study based on all the factors discussed above.

**Table 5. Asphalt Institute Conversion Factors.**

| Material Type | Equivalency Factors |
|---|---|
| ***Asphalt Materials*** | |
| 1-cm AC (uncracked, little deformation in the wheelpaths) | 0.9-1.0 cm AC |
| 1-cm AC (fine cracking, slight deformation, stable) | 0.7-0.9 cm AC |
| 1-cm AC (appreciable cracking and crack patterns) | 0.5-0.7 cm AC |
| ***Unbound Granular*** | |
| 1-cm Granular base or subbase (CBR > 20, PI ≤ 6) | 0.1 cm AC |
| I-cm Granular base or subbase (CBR > 20, PI > 6) | 0.2 cm AC |

*AC = asphalt concrete; CBR = California Bearing Ratio; PI = Plasticity Index*

**Table 6. Characteristics of Selected Test Sections.**

| Province | C-SHRP ID | Sec. No. | Traffic Level | *TH* (mm) | *M* | Environmental Conditions | Subgrade | *EQTH* (mm) | *SLIFE* (year) |
|---|---|---|---|---|---|---|---|---|---|
| Alberta | 810404 | 1 | low | 61.0 | virgin | dry-high freeze | fine | 134.4 | 13 |
| | | 2 | | 103.0 | virgin | | | 136.2 | |
| | | 3 | | 94.0 | recycled | | | 141.6 | |
| British Columbia | 820205 | 1 | low | 42.0 | virgin | wet-low freeze | coarse | 142.6 | 13 |
| | | 2 | | 83.0 | virgin | | | 139.6 | |
| Manitoba | 830801 | 1 | high | 185.0 | recycled | dry-high freeze | fine | 126.1 | 18 |
| | | 2 | | 103.3 | recycled | | | 132.5 | |
| | | 3 | | 126.0 | virgin | | | 126.5 | |
| | | 4 | | 170.0 | virgin | | | 130.5 | |
| New Brunswick | 840101 | 3 | high | 87.0 | recycled | wet-low freeze | coarse | 171.8 | 14 |
| | 840204 | 1 | low | 114.0 | virgin | wet-low freeze | coarse | 110.0 | 14 |
| | | 2 | | 88.0 | virgin | | | 113.0 | |
| Newfound-land | 850201 | 2 | low | 73.0 | virgin | wet-low freeze | coarse | 163.2 | 24 |
| | 850206 | 1 | low | 106.0 | virgin | wet-low freeze | coarse | 187.2 | 25 |
| | | 2 | | 63.0 | virgin | | | 187.8 | |
| | 850601 | 1 | low | 122.0 | virgin | wet-low freeze | coarse | 221.2 | 29 |
| | | 2 | | 74.0 | virgin | | | 224.2 | |
| Ontario | 870102 | 1 | low | 94.5 | virgin | wet-low freeze | fine | 195.1 | 22 |
| | | 2 | | 46.2 | virgin | | | 195.1 | |
| | 870504 | 1 | high | 31.0 | virgin | wet-low freeze | coarse | 293.9 | 14 |
| | | 2 | | 61.3 | virgin | | | 284.7 | |
| | 870701 | 1 | low | 42.5 | virgin | wet-high freeze | fine | 294.6 | 23 |
| | | 2 | | 106.0 | virgin | | | 294.6 | |
| Prince Edward Island | 880203 | 1 | low | 51.0 | virgin | wet-low freeze | coarse | 83.6 | 11 |
| | | 2 | | 109.0 | virgin | | | 78.2 | |
| | | 3 | | 51.0 | virgin | | | 109.4 | |
| | | 4 | | 99.0 | virgin | | | 113.0 | |
| Quebec | 890702 | 1 | high | 44.0 | virgin | wet-high freeze | fine | 293.2 | 13 |
| | | 2 | | 85.0 | virgin | | | 293.2 | |
| Saskatchew an | 900402 | 1 | low | 86.3 | virgin | dry-high freeze | fine | 77.0 | 26 |
| | 900802 | 1 | high | 54.5 | virgin | dry-high freeze | fine | 99.2 | 21 |
| | | 2 | | 66.7 | virgin | | | 95.6 | |
| | | 3 | | 104.3 | virgin | | | 93.2 | |
| | 900803 | 1 | high | 157.5 | virgin | dry-high freeze | fine | 67 | 5 |
| | | 2 | | 107.6 | virgin | | | 67 | |

*TH* = overlay thickness, *EQTH* = equivalent thickness of the original pavement, *SLIFE* = service life of the original pavement before constructing overlay, and *M* = overlay material.

## 5.3. Model Development

The linear regression analysis technique was used to develop mathematical models to relate the pavement's PSI to its age. As a single model that would be applicable to all the sections included in the study could not be established, the sections were first classified according to the traffic level, environmental conditions, and subgrade type. Then, a unique model was developed for each class of sections, where the dependent variable in each model was the PSI. The independent variables included in all models were the overlay service life, overlay thickness, equivalent thickness of the original pavement, service life of the original pavement before constructing the overlay, and finally the overlay material whenever applicable. The total number of data points used in the regression was 282. The various models are described in Table 7, which summarises the constants and the coefficient of determination ($R^2$) for each model. Several trials were carried out to establish the best form for the developed models. The general form for all models is as follows:

$$PSI = C_0 + C_1\ t^3 + C_2\ TH + C_3\ EQTH + C_4\ SLIFE + C_5\ M \qquad (3)$$

where *PSI* = Present Serviceability Index,
*t* = expected service life for the overlay to reach a certain PSI (years),
*TH* = overlay thickness (mm),
*EQTH* = equivalent thickness of the original pavement (mm),
*SLIFE* = service life of the original pavement before constructing overlay (years),
*M* = overlay material (0 for recycled mix, and 1 for virgin mix), and
*C's* = model's constants.

## 5.4. Models Evaluation and Analysis

Based on the results in Table 7, it can be shown that the $R^2$ values for Models 6 and 7 are low. This indicates that the accuracy of the predicted values of the PSI using Models 6 and 7 would also be low. These low values of $R^2$ may be explained by the fact that the period of monitoring the sections of these models is not enough to establish an accurate trend to predict the PSI. Consequently, these two models (6 and 7) will not be taken into consideration during the analysis, and it is recommended to update these two models when more data are available.

The developed models were used to investigate the effect of the overlay thickness and mix type on the expected service life of the overlay. In Equation 3, the value of the PSI was set equal to the terminal PSI, assumed 2.5 for all sections, and the equation was solved to determine the time required to reach this terminal PSI value. To neutralise the effect of *EQTH* (for Model 2) and *SLIFE* (for Models 2 and 4), these two variables were assumed to be constant and their values were set as 160 mm and 15 years, respectively. Based on these assumptions, Figure 3 illustrates the effect of increasing the overlay thickness on the expected service life of the overlays.

**Table 7. Constants of Developed Models.**

| Model description | $R^2$ | $C_0$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|---|---|
| 1. Low Traffic, Fine Subgrade, Wet-Low Freeze | 0.80 | 2.724 | -0.0012 | 0.0123 | ---§ | ---§ | N/A‡ |
| 2. Low Traffic, Coarse Subgrade, Wet-Low Freeze | 0.61 | 3.170 | -0.00036 | 0.000288 | 0.00865 | -0.043 | N/A‡ |
| 3. Low Traffic, Fine Subgrade, Wet-High Freeze | 0.96 | 3.231 | -0.00058 | 0.00781 | ---§ | ---§ | N/A‡ |
| 4. Low Traffic, Fine Subgrade, Dry-High Freeze | 0.67 | 3.038 | -0.00012 | 0.00357 | ---§ | 0.0152 | -0.011 |
| 5. High Traffic, Coarse Subgrade, Wet-Low Freeze | 0.79 | 3.119 | -0.0003 | 0.00424 | ---§ | ---§ | 0.491 |
| 6. High Traffic, Fine Subgrade, Wet-High Freeze | 0.27* | 3.871 | -0.0018 | -0.0041 | ---§ | ---§ | N/A‡ |
| 7. High Traffic, Fine Subgrade, Dry-High Freeze | 0.30* | 3.765 | -0.00024 | 0.0029 | -0.0082 | 0.0415 | -0.160 |

‡ *Not applicable (value of parameter is constant for all data points in the model).*
§ *Parameter was excluded from the model as it was statistically insignificant.*
* These models will be discarded because of low of $R^2$ value.

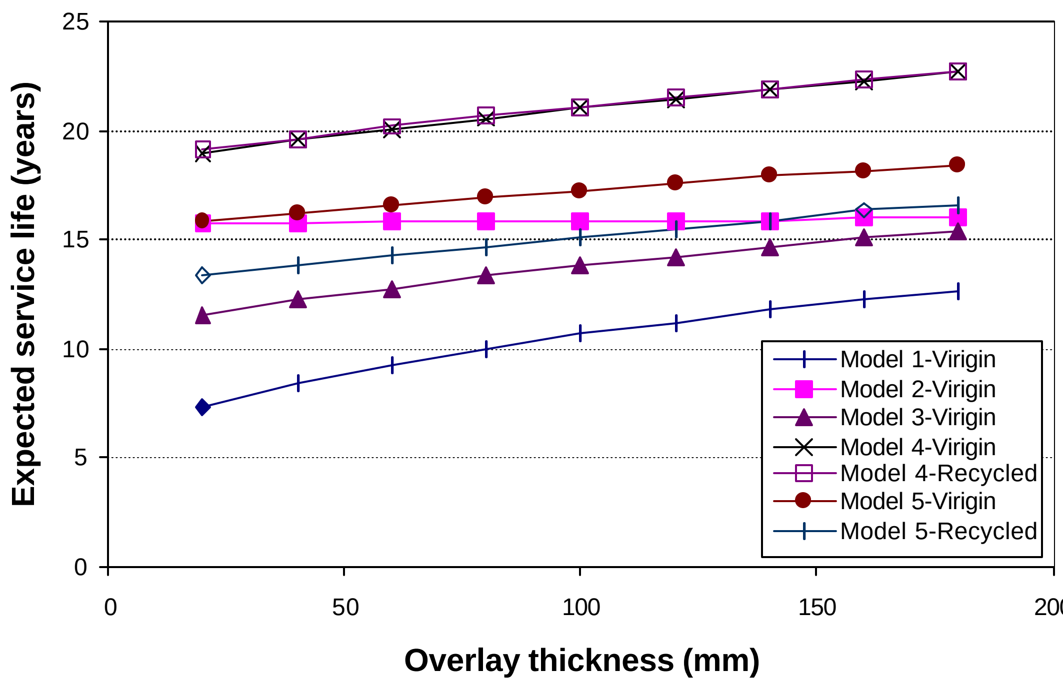


**Figure 3. Effect of Overlay Thickness and Material on Expected Service Life.**

From Figure 3 the following can be concluded:

- For all models, except Model 2, the effect of overlay thickness on the service life of the overlay was approximately the same regardless of the mix type, traffic level, subgrade type, and environmental conditions. Furthermore, the effect of increasing the overlay thickness on the expected service life (for these models) was minimal for all sections. For example, to increase the expected service life of an overlay by two years, the overlay thickness should be doubled.
- For Model 2 (low traffic, coarse subgrade, wet low-freeze), increasing the overlay thickness had almost no effect on its service life. Such a finding may be explained by the small effect the low traffic level and low-freeze conditions have on the rate of deterioration of a pavement constructed over a good quality subgrade.
- Comparing results of Models 2 (low traffic, coarse subgrade, wet-low freeze) and 5 (High traffic, coarse subgrade, wet-low freeze) for a virgin AC show that the predicted service life under high traffic conditions is higher than that under low traffic conditions. Such a trend is clearly counter-intuitive and may have resulted from the previous finding related to Model 2 and/or the selected values of *EQTH* and *SLIFE* that were included in Model 2 but not Model 5. In addition, excluding Models 6 and 7 does not allow a good comparison of the effect of low and high traffic levels when all other conditions are the same.
- A considerable difference exists between the service life predicted using Models 1 (low traffic, fine subgrade, wet-low freeze) and that predicted using Model 2 (low traffic, coarse subgrade, wet-low freeze). Such a difference can be attributed to the effect of subgrade quality on the pavement performance. However, as mentioned above, the values assumed for *EQTH* and *SLIFE* that were included in Model 2 but not Model 1 might have influenced the absolute value of the effect of subgrade type.
- Comparing Models 3 (low traffic, fine subgrade, wet-high freeze) and 4 (low traffic, fine subgrade, dry-high freeze) shows that the environmental condition of pavement moisture can significantly affect the pavement performance and the expected service life of the overlay.
- The effect of the overlay material can be evaluated by comparing the results of Models 4 (low traffic, fine subgrade, dry-high freeze) and 5 (high traffic, coarse subgrade, wet-low freeze) for virgin AC against recycled AC. For Model 4, the overlay material has almost no effect on the expected service life. Such a finding indicates that the favourable conditions of low traffic level and dry pavement conditions make a pavement made of recycled AC more cost effective than the higher quality pavement made of virgin AC. Alternatively, the high freeze condition might have been an overriding factor, over the overlay material, in determining the expected service life of the overlay. Thus, recycled AC overlays would be a better rehabilitation technique under these conditions considering both the environmental and economic points of view. On the other hand, the results of Model 5 shows that the expected service life using recycled AC was less than that of the virgin AC by about 2.5 year. Thus, the higher quality pavement of virgin AC provides better performance under unfavourable conditions of high traffic level and wet pavement.

Table 8 presented the estimated service life, for the sections under study, based on the developed models

**Table 8. Predicted Overlay's Service Life Based on Developed Models**

| Province | C-SHRP ID | Sec. No. | Predicted Service Life |
|---|---|---|---|
| Alberta | 810404 | 1 | 19.9 |
| | | 2 | 20.9 |
| | | 3 | 20.7 |
| British Columbia | 820205 | 1 | 15.6 |
| | | 2 | 15.5 |
| New Brunswick | 840101 | 3 | 14.9 |
| | 840204 | 1 | 14.3 |
| | | 2 | 14.4 |
| Newfound-land | 850201 | 2 | 14.4 |
| | 850206 | 1 | 15.1 |
| | | 2 | 15.1 |
| | 850601 | 1 | 15.6 |
| | | 2 | 15.7 |
| Ontario | 870102 | 1 | 10.5 |
| | | 2 | 8.7 |
| | 870504 | 1 | 16.1 |
| | | 2 | 16.6 |
| | 870701 | 1 | 12.4 |
| | | 2 | 13.9 |
| Prince Edward Island | 880203 | 1 | 13.7 |
| | | 2 | 13.6 |
| | | 3 | 14.8 |
| | | 4 | 15.0 |
| Saskatchewan | 900402 | 1 | 21.7 |

## 6. COMPARISON WITH HAJEK MODEL

As mentioned before, there are many factors that can affect the long-term performance of the AC overlays. In order to develop a mathematical model that can predict the overlays cycle life for Ontario roads, a statistical analysis for the performance of the overlays was carried out by Hajek et al [1]. The purpose of this analysis is to develop a model that can be used to evaluate the long term-performance of the overlays. This model (Hajek et al model) correlates the duration of the overlay life cycle (at a specific terminal serviceability) to some related factors that can affect the overlay performance. The factors that were included in this model are; overlay thickness, number of equivalent single axle loads, life cycle of the initial pavement structure, and finally patching during the initial life cycle of the original pavement (pavement before constructing the overlay). The final equation for this model was as follows:

$$AFT55 = 1.32 * BEF55^{0.33} * THOV^{0.47} * ESAL^{-0.097} * 1.14^{PATCH} \qquad (4)$$

where

AFT55 = Overlay life cycle corresponding to the terminal Pavement Condition Rating (PCR) level of 55, the different ranges of PCR are illustrated in Table 9, (years),

BEF55 = Life cycle of the initial pavement structure corresponding to the terminal Pavement Condition Rating (PCR) level of 55 (years),

THOV = Thickness of overlay (mm),

PATCH = Dummy variable is equal to 0 for no or limited amount of patching and is equal to 1 for all other cases

ESAL = Number of equivalent single axle loads per day

= AADT83 * TRUCK*TRUCKF*LDF/200

where

AADT83 = 1983 annual average daily traffic,

TRUCK = truck percentage,

TRUCKF = truck factor, and

LDF = lane factor.

This was a preliminary model and the authors recommended updating it when more data become available. The range of the variables that are included in this model are as follows:

- AADT ranged from 1000 to 8000 vehicles.
- Percentage of trucks ranged from 4 to 24.
- Freezing index ranged from 420 to 2040 degree-days Celsius.
- Total overlay thicknesses ranged from 40 to 175 mm with the average value equal to 70 mm.
- Average value of BEFF was 13.1 years.

In order to calculate the expected service life by Hajek model, for the G-Sharp section sited in Ontario, using the data available in C-LTPP database the following assumption were applied:

- The patching work along the service life of the initial pavement were significant (i.e. dummy variable = 1)
- ESAL was calculated as an average value for the data available through the C-LTTP database, which were collected from the year 1989 to 1993. Table 10 illustrates a detailed calculation of the ESAL for the C-SHRP section in Ontario.
- PCR 55 is equivalent to PSI 2.75
- Because there are no data available about the performance of the original pavement before the overlay construction (with exception of the evaluation that was made just before the overlay construction), it was assumed that there is a linear relationship between PSI (or PCR) and the age of the initial pavement. This assumption will be used to calculate BEF55, which is required as an input factor in Hajek model. Also, the initial PSI just after construction of the original pavement was assumed equal to 4.5. Table 11 illustrates the service life of the initial pavement, PSI values for Ontario sections just before overlay construction, and finally the calculated service life of the initial pavement corresponding to PSI equal to 2.75.

Based on the previous assumptions Table 12 summarises the data required to calculate the AFT55 using Hajek et al model, calculated service life using Hajek model (AFT55), as well as the calculated service life using the developed models of this study (see section 5-3).

**Table 9. Pavement Condition Rating**

| PCR Range | Pavement Condition |
|---|---|
| 0 – 20 | Pavement is in poor to very poor condition with extensive severe cracking, alligatoring and dishing.<br>Rideability is poor and the surface is very rough and uneven |
| 20-30 | Pavement is in poor condition with moderate alligatoring and extensive severe cracking and dishing.<br>Rideability is poor and the surface is very rough and uneven |
| 30 - 40 | Pavement is in poor to fair condition with frequent moderate alligatoring and extensive moderate cracking and dishing.<br>Rideability is poor to fair and the surface is moderately rough and uneven |
| 40 – 50 | Pavement is in poor to fair condition with frequent moderate cracking and dishing, an intermittent moderate alligatoring.<br>Rideability is poor to fair and surface is moderately rough and uneven |
| 50 - 65 | Pavement is in fair condition with intermittent moderate and frequent slight cracking, and with intermittent slight to moderate alligatoring and dishing.<br>Rideability is fair and surface is slightly rough and uneven |
| 65 – 75 | Pavement is in fairly good condition with slight cracking, slight or very slight dishing and a few areas of slight alligatoring.<br>Rideability is fairly good with intermittent rough and uneven |
| 75 - 90 | Pavement is in good condition with frequent very slight or slight cracking.<br>Rideability is good with a few slightly rough and uneven sections |
| 90 - 100 | Pavement is in excellent condition with few cracks.<br>Rideability is excellent with few areas of slight distortion. |

*Source: Manual for condition rating of flexible pavement [2]*

**Table 10. Calculation of ESAL For Ontario Sites Under Study.**

| C-SHRP ID | Year | AADT | DDF$^{\delta}$ | % Trucks | LDF$^{*}$ | % Trucks (C-SHRP lane) | TF$^{\vartheta}$ | ESAL$^{\perp}$ | Average ESAL |
|---|---|---|---|---|---|---|---|---|---|
| 870102 | 1989 | 1250 | 0.5 | 15 | 1 | 15 | 0.95 | 89.1 | |
| 870102 | 1990 | 1400 | 0.5 | 15 | 1 | 15 | 0.95 | 99.8 | |
| 870102 | 1991 | 1300 | 0.5 | 15 | 1 | 15 | 0.95 | 92.6 | 93.8 |
| 870102 | 1992 | 285 | 0.5 | 5 | 1 | 5 | 0.95 | 6.8[a] | |
| 870102 | 1993 | 809 | 0.5 | 13.5 | 1 | 13.5 | 0.95 | 51.9[a] | |
| 870504 | 1990 | 10650 | 0.5 | 13 | 0.8 | 13 | 0.95 | 526.1 | |
| 870504 | 1991 | 11600 | 0.5 | 13 | 0.8 | 13 | 0.95 | 573.0 | |
| 870504 | 1992 | 11600 | 0.5 | 13 | 0.8 | 40 | 0.95 | 573.0 | 574.3 |
| 870504 | 1993 | 11800 | 0.5 | 13 | 0.8 | 40 | 0.95 | 582.9 | |
| 870504 | 1994 | 12000 | 0.5 | 13 | 0.8 | 40 | 0.95 | 592.8 | |
| 870504 | 1995 | 12100 | 0.5 | 13 | 0.8 | 40 | 0.95 | 597.7 | |
| 870701 | 1990 | 6200 | 0.5 | 15 | 1 | 15 | 0.95 | 441.8 | |
| 870701 | 1991 | 6000 | 0.5 | 15 | 1 | 15 | 0.95 | 427.5 | 434.7 |
| 870701 | 1992 | 807 | 0.5 | 10 | 1 | 10 | 0.95 | 38.3[a] | |
| 870701 | 1993 | 4727 | 0.5 | 6.5 | 1 | 6.5 | 0.95 | 145.95[a] | |

[d] *Directional distribution factor*
[*] *Lane distribution factor*
[J] *Truck Factor*
[^] *ESAL = AADT CDDF CLDF C%Truck CTF, the shadded cells were discarded because there are unlogical values*
[a] *Values are not included in the average values*

**Table 11. Service Life For Initial Pavement Calculated From Hajek Model (BEF55)**

| C-SHRP ID | Section number | Service life (Years) | PSI | BEF55 (Years) |
|---|---|---|---|---|
| 870102 | 1 | 22 | 2.08 | 15.9 |
| 870102 | 2 | 22 | 2.18 | 16.6 |
| 870504 | 1 | 14 | 3.3 | 20.4 |
| 870504 | 2 | 14 | 3.26 | 19.8 |
| 870701 | 1 | 23 | 3.49 | 39.9 |
| 870701 | 2 | 23 | 3.39 | 36.3 |

**Table 12. Overlay Service Life Calculated by Hajek model Vs Calculated by Developed Models.**

| C-SHRP ID | Section number | BEF55 | Overlay thickness | ESAL | Patching factor | AFT55 | Overlay service life* |
|---|---|---|---|---|---|---|---|
| 870102 | 1 | 15.9 | 94.5 | 93.8 | 1 | 20.5 | 9.8 |
| 870102 | 2 | 16.6 | 46.2 | 93.8 | 1 | 14.8 | 7.7 |
| 870504 | 1 | 20.4 | 31 | 574.3 | 1 | 11.0 | 14.9 |
| 870504 | 2 | 19.8 | 61.3 | 574.3 | 1 | 15.1 | 15.5 |
| 870701 | 1 | 39.9 | 42.5 | 434.7 | 1 | 16.4 | 11.2 |
| 870701 | 2 | 36.3 | 106 | 434.7 | 1 | 24.4 | 13.1 |

** Calculated service life using the developed models of this study are based on terminal serviceability index equal to 2.75.*

Based on the results in Table 12, it is clear that, there is a big difference between the results of Hajek model and the developed models in sections 8701021, 8701022, and 870701. On the other hand, the difference in the other sections is relatively small especially in section 870504.

There are many factors that may have caused this variation in the results. For example the factors that are included in each model are different. Also the range of the factors that are included during the development of Hajek model does not include some values of the characteristics of Ontario sites. For example the range of the freezing index that is included in Hajek model is from 420 to 2040 degree-days Celsius but the freezing index for site 870102, as in C-LTPP database, is 376.1 degree days Celsius.

So it is recommended to re-evaluate these models, the Hajek model and the developed models, after monitoring the actual service life of the overlay in the field and updating these models based on the actual monitoring data, to select the most appropriate model to be used for Ontario road.

## 7. SUMMARY AND CONCLUSIONS

The main objectives of this study were to investigate the effect of the overlay thickness and mix type on the performance of the overlay as well as to evaluate Hajek et al model. The data available in the C-LTPP project were collected and analysed. Based on these data, a number of mathematical models were developed to study the effect of the overlay thickness and type on its expected service life. These models were classified according to the traffic level, subgrade type, and environmental conditions. Some of the developed models had low values of the coefficient of determination, and were not taken into consideration during the analysis. Rather, it is recommended to update these models when more data are available. On the other hand, the models that had high values of coefficient of determination were used to predict the expected service life of the overlay at different thicknesses and different mix types (virgin and recycled). Based on the results of the developed models, it was concluded that the effect of increasing the overlay thickness on the expected service life is negligible for the conditions of low traffic, coarse subgrade, and wet low-freeze environmental conditions. For all other combinations of conditions, the overlay service life increases with the increase of overlay thickness. However, within the range of the data used in the analysis, the economic value of the increase of expected service life due to the use of thicker overlays may be questionable. Such a finding affirms the conclusion by Bekheet et al that was based on quantitative economic analysis [8]. Also, the results indicate that using recycled AC under the favourable conditions of low traffic level and dry pavement conditions yields almost the same service life had virgin AC been used. On the other hand, using a high quality pavement of virgin AC provides better performance under unfavourable conditions of high traffic level and wet pavement where the expected service life for the recycled AC was found to be less than that of the virgin AC by about 2.5 year. Also, the expected service life for the overlay constructed in Ontario sites were calculated by using Hajek et al model and the models that were developed in this study. Some variations were found between the results of Hajek model and the developed models. These variations may refer to: that, the variables that were included in the models are different, and the range of the variables of Hajek et al model does not include all the values that are for C-SHRP sites. So, It is recommended to revaluate these models after the overlays reach the actual end of their life and update these models to match the actual behaviour of the performance of the overlay along their life.

## 8. REFERENCES


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# APPENDEX A

**Table A.1. IRI and PSI for Site 810404**

| Section # | 8104041 | | 8104042 | | 8104042 | | 8104043 | |
|---|---|---|---|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI | IRI | PSI | IRI | PSI |
| Prior to Overlay | 2.59 | 2.55 | 2.23 | 2.80 | 2.41 | 2.67 | 2.2 | 2.82 |
| 1990 | 1.32 | 3.55 | 1.13 | 3.73 | 1.26 | 3.60 | 1.18 | 3.68 |
| 1991 | 1.44 | 3.44 | 1.44 | 3.44 | 1.44 | 3.44 | 1.44 | 3.44 |
| 1992 | 1.43 | 3.45 | 1.22 | 3.64 | 1.15 | 3.71 | 1.14 | 3.72 |
| 1993 | 1.46 | 3.42 | 1.19 | 3.67 | 1.28 | 3.58 | 1.24 | 3.62 |
| 1994 | 1.50 | 3.39 | 1.37 | 3.50 | 1.33 | 3.54 | 1.24 | 3.62 |
| 1995 | 1.45 | 3.43 | 1.37 | 3.50 | 1.34 | 3.53 | 1.17 | 3.69 |
| 1996 | ----* | ----* | ----* | ----* | ----* | ----* | ----* | ----* |
| 1997 | 1.54 | 3.35 | 1.26 | 3.60 | 1.34 | 3.53 | 1.24 | 3.62 |
| 1998 | ----* | ----* | ----* | ----* | ----* | ----* | ----* | ----* |

** Data are not available*

**Table A.2. IRI and PSI for Site 820205**

| Section # | 8202051 | | 8202052 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 1.32 | 3.55 | 1.39 | 3.48 |
| 1990 | ----* | ----* | ----* | ----* |
| 1991 | 0.85 | 4.01 | 0.94 | 3.92 |
| 1992 | 0.92 | 3.94 | 1.12 | 3.74 |
| 1993 | 0.86 | 4.00 | 1.06 | 3.80 |
| 1994 | 1.10 | 3.76 | 1.07 | 3.79 |
| 1995 | 0.99 | 3.87 | 1.11 | 3.75 |
| 1996 | ----* | ----* | ----* | ----* |
| 1997 | ----* | ----* | ----* | ----* |
| 1998 | ----* | ----* | ----* | ----* |

** Data are not available**

**Table A.3. IRI and PSI for Site 820605**

| Section # | 8206051 | | 8206052 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 1.74 | 3.18 | 1.98 | 2.99 |
| 1990 | ----* | ----* | ----* | ----* |
| 1991 | 1.26 | 3.60 | 1.28 | 3.58 |
| 1992 | 1.33 | 3.54 | 1.97 | 3.00 |
| 1993 | 1.30 | 3.57 | 1.29 | 3.58 |
| 1994 | 1.35 | 3.52 | 1.49 | 3.39 |
| 1995 | 1.40 | 3.47 | 1.55 | 3.34 |
| 1996 | ----* | ----* | ----* | ----* |
| 1997 | ----* | ----* | ----* | ----* |
| 1998 | ----* | -----* | ----* | ----* |

***** *Data are not available*

**Table A.4. IRI and PSI for Site 830801**

| Section # | 8308011 | | 8308012 | | 8308013 | | 8308014 | |
|---|---|---|---|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI | IRI | PSI | IRI | PSI |
| Prior to Overlay | 1.72 | 3.20 | 1.83 | 3.11 | 1.24 | 3.62 | 1.78 | 3.15 |
| 1989 | 0.83 | 4.03 | 0.90 | 3.96 | 1.36 | 3.51 | 0.77 | 4.09 |
| 1990 | 1.04 | 3.82 | 1.20 | 3.66 | 1.50 | 3.39 | 1.06 | 3.80 |
| 1991 | 1.03 | 3.83 | 1.05 | 3.81 | 1.33 | 3.54 | 0.77 | 4.09 |
| 1992 | 1.04 | 3.82 | 1.35 | 3.52 | 1.94 | 3.02 | 1.31 | 3.56 |
| 1993 | 0.83 | 4.03 | 1.01 | 3.85 | 1.53 | 3.36 | 0.82 | 4.04 |
| 1994 | 0.82 | 4.04 | 0.99 | 3.87 | 1.33 | 3.54 | 0.96 | 3.90 |
| 1995 | 0.90 | 3.96 | 1.14 | 3.72 | 1.42 | 3.46 | 0.93 | 3.93 |
| 1996 | 1.24 | 3.62 | 1.13 | 3.73 | 1.46 | 3.42 | 0.93 | 3.93 |
| 1997 | ----* | ----* | ----* | ----* | ----* | ----* | ----* | ----* |
| 1998 | 0.98 | 3.88 | 1.18000 | 3.68 | 1.58 | 3.32 | 0.98 | 3.88 |

***** *Data are not available*

**Table A.5. IRI and PSI for Site 840101**

| Section # | 8401011 | | 8401012 | | 8401013 | |
|---|---|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI | IRI | PSI |
| Prior to Overlay | 3.91 | 1.81 | 1.77 | 3.16 | 1.42 | 3.46 |
| 1989 | 1.21 | 3.65 | 1.49 | 3.39 | 1.49 | 3.39 |
| 1990 | 1.48 | 3.40 | 0.99 | 3.87 | 1.29 | 3.58 |
| 1991 | 1.26 | 3.60 | 1.13 | 3.73 | 1.33 | 3.54 |
| 1992 | ----* | ----* | ----* | ----* | ----* | ----* |
| 1993 | 1.21 | 3.65 | 0.96 | 3.90 | 1.34 | 3.53 |
| 1994 | 1.26 | 3.60 | 1.00 | 3.86 | 1.43 | 3.45 |
| 1995 | 1.53 | 3.36 | 1.20 | 3.66 | 1.74 | 3.18 |
| 1996 | 1.24 | 3.62 | 0.96 | 3.90 | 1.41 | 3.47 |
| 1997 | 1.41 | 3.47 | 1.18 | 3.68 | 1.66 | 3.25 |
| 1998 | 1.16 | 3.70 | 1.03 | 3.83 | 1.49 | 3.39 |

** Data are not available*

**Table A. 6. IRI and PSI for Site 840204**

| Section # | 8402041 | | 8402042 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 3.66 | 1.93 | 3.03 | 2.27 |
| 1989 | ----* | ----* | 1.27 | 3.59 |
| 1990 | 1.28 | 3.58 | 1.45 | 3.43 |
| 1991 | 1.16 | 3.70 | 1.17 | 3.69 |
| 1992 | ----* | ----* | ----* | ----* |
| 1993 | 1.25 | 3.61 | 1.35 | 3.52 |
| 1994 | 1.27 | 3.59 | 1.26 | 3.60 |
| 1995 | 1.46 | 3.42 | 1.41 | 3.47 |
| 1996 | 1.42 | 3.46 | 1.34 | 3.53 |
| 1997 | 1.84 | 3.10 | 1.80 | 3.13 |
| 1998 | 1.49 | 3.39 | 1.70 | 3.21 |

** Data are not available*

**Table A.7. IRI and PSI for Site 850201**

| Section # | 8502011 | | 8502012 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 3.30 | 2.12 | 3.50 | 2.01 |
| 1989 | 1.62 | 3.28 | 1.43 | 3.45 |
| 1990 | 1.75 | 3.17 | 1.53 | 3.36 |
| 1991 | 1.61 | 3.29 | 1.49 | 3.39 |
| 1992 | 1.66 | 3.25 | 1.49 | 3.39 |
| 1993 | 2.00 | 2.97 | 1.59 | 3.31 |
| 1994 | 1.71 | 3.21 | 1.51 | 3.38 |
| 1995 | 1.69 | 3.22 | 1.63 | 3.27 |
| 1996 | 1.67 | 3.24 | 1.51 | 3.38 |
| 1997 | 1.68 | 3.23 | 1.54 | 3.35 |
| 1998 | 1.66 | 3.25 | 1.67 | 3.24 |

** Data are not available*

**Table A.8. IRI and PSI for Site 850206**

| Section # | 8502061 | | 8502062 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 2.39 | 2.69 | 2.87 | 2.37 |
| 1990 | 1.21 | 3.65 | 1.02 | 3.84 |
| 1991 | 1.23 | 3.63 | 1.01 | 3.85 |
| 1992 | 1.20 | 3.66 | 1.01 | 3.85 |
| 1993 | 1.33 | 3.54 | 1.10 | 3.76 |
| 1994 | 1.27 | 3.59 | 1.16 | 3.70 |
| 1995 | 1.41 | 3.47 | 1.34 | 3.53 |
| 1996 | 1.27 | 3.59 | 1.34 | 3.53 |
| 1997 | 1.28 | 3.58 | 1.35 | 3.52 |
| 1998 | 1.28 | 3.58 | 1.25 | 3.61 |

** Data are not available*

**Table A.9. IRI and PSI for Site 850601**

| Section # | 8506011 | | 8506012 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 1.71 | 3.21 | 1.47 | 3.41 |
| 1989 | 0.80 | 4.06 | 0.79 | 4.07 |
| 1990 | 1.03 | 3.83 | 0.84 | 4.02 |
| 1991 | 0.87 | 3.99 | 0.87 | 3.99 |
| 1992 | 0.91 | 3.95 | 0.83 | 4.03 |
| 1993 | 0.98 | 3.88 | 1.01 | 3.85 |
| 1994 | 0.99 | 3.87 | 0.96 | 3.90 |
| 1995 | 1.02 | 3.84 | 1.01 | 3.85 |
| 1996 | 1.11 | 3.75 | 0.94 | 3.92 |
| 1997 | 1.13 | 3.73 | 1.04 | 3.82 |
| 1998 | 1.03 | 3.83 | 1.04 | 3.82 |

** Data are not available*

**Table A.10. IRI and PSI for Site 870102**

| Section # | 8701021 | | 8701022 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 3.38 | 2.08 | 3.20 | 2.18 |
| 1989 | ----* | ----* | ----* | ----* |
| 1990 | ----* | ----* | ----* | ----* |
| 1991 | 0.94 | 3.92 | 1.11 | 3.75 |
| 1992 | ----* | ---- * | 1.63 | 3.27 |
| 1993 | 1.07 | 3.79 | 1.68 | 3.23 |
| 1994 | 1.20 | 3.66 | 1.95 | 3.01 |
| 1995 | 1.19 | 3.67 | 2.08 | 2.91 |
| 1996 | 1.47 | 3.41 | 2.53 | 2.59 |
| 1997 | 1.59 | 3.31 | 2.63 | 2.52 |
| 1998 | 1.80 | 3.13 | 2.35 | 2.71 |

** Data are not available*

**Table A.11. IRI and PSI for Site 870504**

| Section # | 8705041 | | 8705042 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 1.60 | 3.30 | 1.65 | 3.26 |
| 1990 | ----* | ----* | ----* | ----* |
| 1991 | 1.03 | 3.83 | 0.96 | 3.90 |
| 1992 | ----* | ----* | ----* | ----* |
| 1993 | 1.26 | 3.60 | 1.01 | 3.85 |
| 1994 | 1.05 | 3.81 | 0.94 | 3.92 |
| 1995 | 1.14 | 3.72 | 1.08 | 3.78 |
| 1996 | 1.20 | 3.66 | 1.05 | 3.81 |
| 1997 | 1.27 | 3.59 | 1.14 | 3.72 |
| 1998 | ----* | ----* | ----* | ----* |

** Data are not available*

**Table A.12. IRI and PSI for Site 870701**

| Section # | 8707011 | | 8707012 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 1.38 | 3.49 | 1.49 | 3.39 |
| 1990 | ----* | ----* | ----* | ----* |
| 1991 | 1.21 | 3.65 | 0.78 | 4.08 |
| 1992 | 1.29 | 3.58 | 0.85 | 4.01 |
| 1993 | 1.32 | 3.55 | 0.81 | 4.05 |
| 1994 | 1.32 | 3.55 | 0.86 | 4.00 |
| 1995 | 1.43 | 3.45 | 0.86 | 4.00 |
| 1996 | 1.44 | 3.44 | 0.98 | 3.88 |
| 1997 | 1.60 | 3.30 | 1.05 | 3.81 |
| 1998 | 1.67 | 3.24 | 0.96 | 3.90 |

** Data are not available*

**Table A.13. IRI and PSI for Site 880203**

| Section # | 8802031 | | 8802032 | | 8302033 | | 8302034 | |
|---|---|---|---|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI | IRI | PSI | IRI | PSI |
| Prior to Overlay | 2.24 | 2.79 | ----* | ----* | 1.57 | 3.32 | 1.98 | 2.99 |
| 1989 | ----* | ----* | ----* | ----* | ----* | ----* | ----* | ----* |
| 1990 | 1.16 | 3.70 | 1.18 | 3.68 | 1.10 | 3.76 | 1.20 | 3.66 |
| 1991 | 1.50 | 3.39 | 1.56 | 3.33 | 1.61 | 3.29 | 1.51 | 3.38 |
| 1992 | 1.35 | 3.52 | 1.32 | 3.55 | 1.17 | 3.69 | 1.23 | 3.63 |
| 1993 | 1.28 | 3.58 | 1.15 | 3.71 | 1.14 | 3.72 | 1.19 | 3.67 |
| 1994 | 1.54 | 3.35 | 1.49 | 3.39 | 1.51 | 3.38 | 1.45 | 3.43 |
| 1995 | 1.34 | 3.53 | 1.45 | 3.43 | 1.27 | 3.59 | 1.25 | 3.61 |
| 1996 | 1.34 | 3.53 | 1.55 | 3.34 | 1.42 | 3.46 | 1.25 | 3.61 |
| 1997 | 1.42 | 3.46 | 1.59 | 3.31 | 1.71 | 3.21 | 1.46 | 3.42 |
| 1998 | ----* | ----* | ----* | ----* | ----* | ----* | ----* | ----* |

***** *Data are not available*

**Table A.14. IRI and PSI for Site 890702**

| Section # | 8907021 | | 8907022 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | ----* | ----* | ----* | ----* |
| 1991 | ----* | ----* | ----* | ----* |
| 1992 | 1.20 | 3.66 | 1.17 | 3.69 |
| 1993 | 1.25 | 3.61 | 1.16 | 3.70 |
| 1994 | ----* | ----* | ----* | ----* |
| 1995 | 1.51 | 3.38 | 1.49 | 3.39 |
| 1996 | 1.78 | 3.15 | 1.56 | 3.33 |
| 1997 | 1.51 | 3.38 | 1.49 | 3.39 |
| 1998 | 1.22 | 3.64 | 2.96 | 2.32 |

***** *Data are not available*

**Table A.15. IRI and PSI for Site 900402**

| Section # | 9004021 | | 9004022 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 2.77 | 2.43 | 2.60 | 2.54 |
| 1989 | 1.11 | 3.75 | 1.11 | 3.75 |
| 1991 | 1.15 | 3.71 | 1.10 | 3.76 |
| 1992 | 1.15 | 3.71 | 1.11 | 3.75 |
| 1993 | 1.15 | 3.71 | 1.20 | 3.66 |
| 1994 | 1.18 | 3.68 | 1.06 | 3.80 |
| 1995 | 1.13 | 3.73 | 1.11 | 3.75 |
| 1996 | 1.11 | 3.75 | 1.12 | 3.74 |
| 1997 | 1.19 | 3.67 | ----* | ----* |
| 1998 | 1.15 | 3.71 | 1.07 | 3.79 |

** Data are not available*

**Table A.16. IRI and PSI for Site 900802**

| Section # | 9008021 | | 9008022 | | 9008023 | |
|---|---|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI | IRI | PSI |
| Prior to Overlay | 2.04 | 2.94 | 2.34 | 2.72 | 2.02 | 2.96 |
| 1989 | 0.80 | 4.06 | 0.97 | 3.89 | 0.91 | 3.95 |
| 1990 | 0.85 | 4.01 | 0.90 | 3.96 | 0.88 | 3.98 |
| 1991 | 0.88 | 3.98 | 1.03 | 3.83 | 0.84 | 4.02 |
| 1992 | 0.89 | 3.97 | 1.03 | 3.83 | 0.88 | 3.98 |
| 1993 | 0.84 | 4.02 | 0.91 | 3.95 | 0.84 | 4.02 |
| 1994 | 0.82 | 4.04 | 0.94 | 3.92 | 0.87 | 3.99 |
| 1995 | 1.47 | 3.41 | 1.71 | 3.21 | 1.54 | 3.35 |
| 1996 | 0.90 | 3.96 | 1.00 | 3.86 | 0.92 | 3.94 |
| 1997 | 0.92 | 3.94 | 1.030 | 3.83 | 0.93 | 3.93 |
| 1998 | ----* | ----* | ----* | ----* | ----* | ----* |

** Data are not available*

**Table A.17. IRI and PSI for Site 900803**

| Section # | 9008031 | | 9008032 | |
|---|---|---|---|---|
| Year | IRI | PSI | IRI | PSI |
| Prior to Overlay | 2.33 | 2.73 | 2.64 | 2.52 |
| 1989 | 1.00 | 3.86 | 1.15 | 3.71 |
| 1991 | 1.01 | 3.85 | 1.13 | 3.73 |
| 1992 | 1.05 | 3.81 | 1.25 | 3.61 |
| 1993 | 1.09 | 3.77 | 1.44 | 3.44 |
| 1994 | 1.07 | 3.79 | 1.47 | 3.41 |
| 1995 | 1.03 | 3.83 | 1.52 | 3.37 |
| 1996 | 1.05 | 3.81 | 1.55 | 3.34 |
| 1997 | 1.11 | 3.75 | 1.68 | 3.23 |
| 1998 | 1.23 | 3.63 | 1.81 | 3.12 |

* *Data are not available*

# APPENDEX B

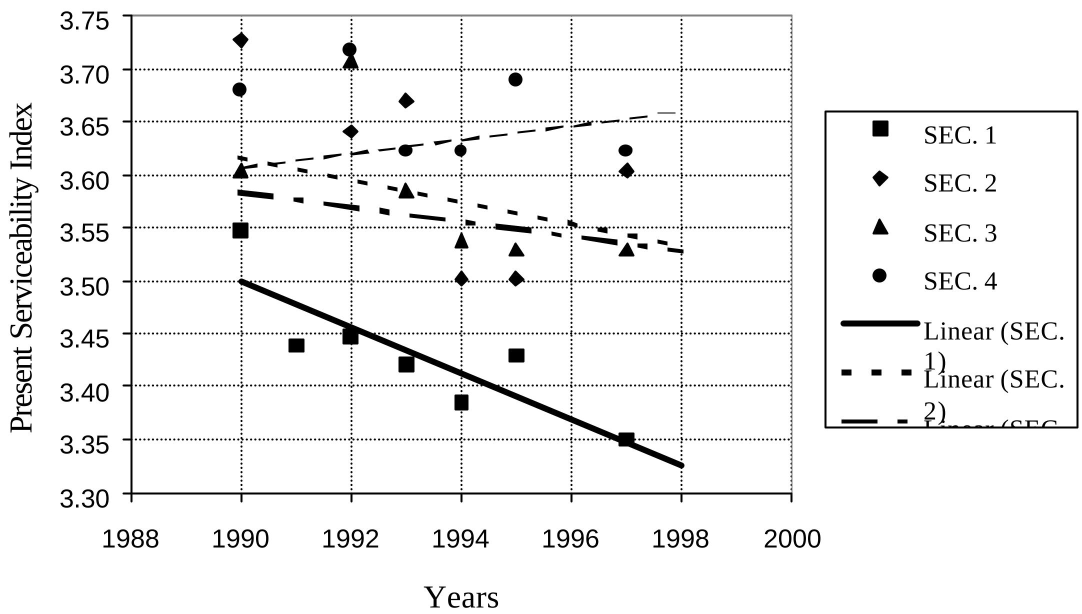



**Figure B.1. Trend of PSI with time for Site 810404**

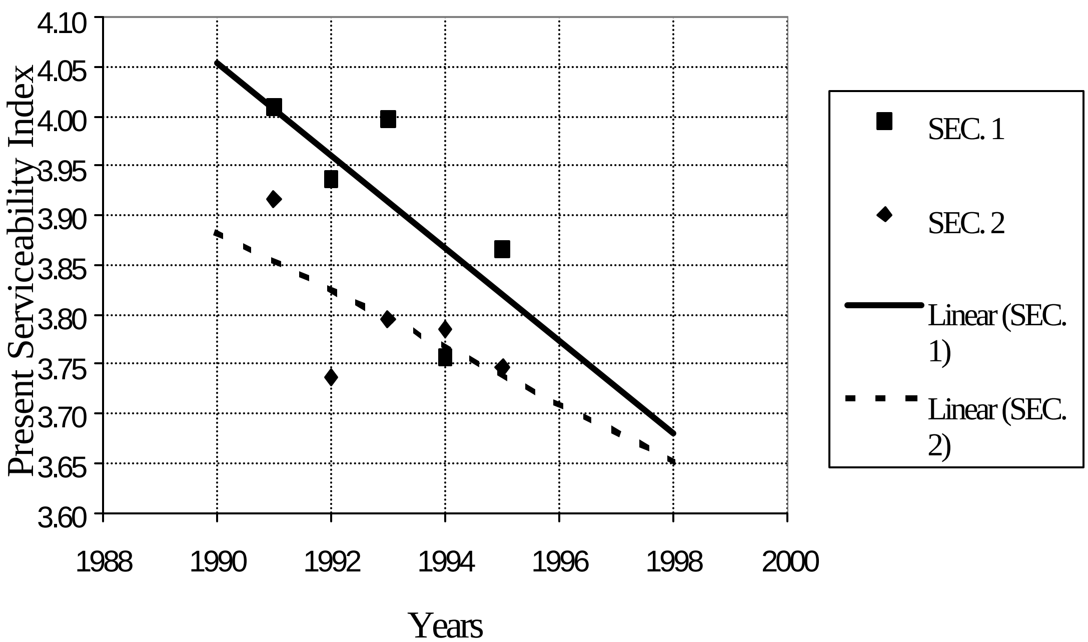



**Figure B.2. Trend of PSI with time for Site 820205**

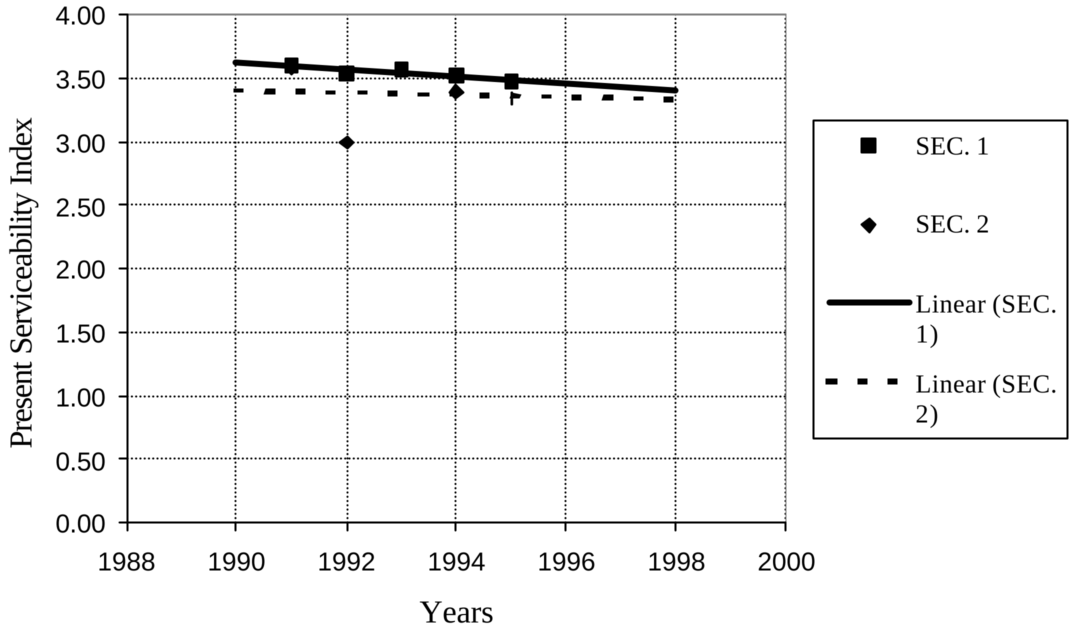



**Figure B.3. Trend of PSI with time for Site 820605**

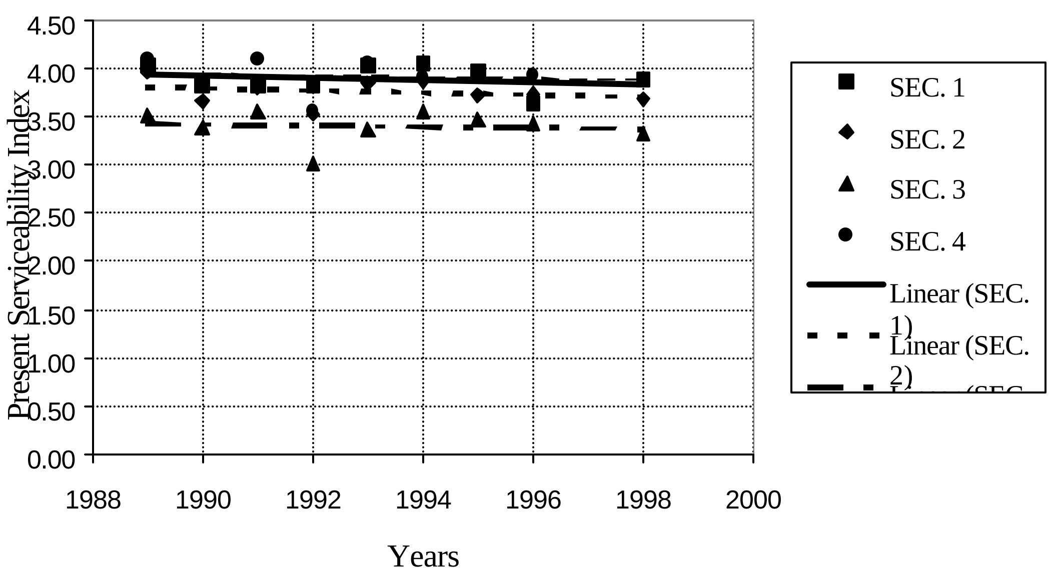



**Figure B.4. Trend of PSI with time for Site 830801**

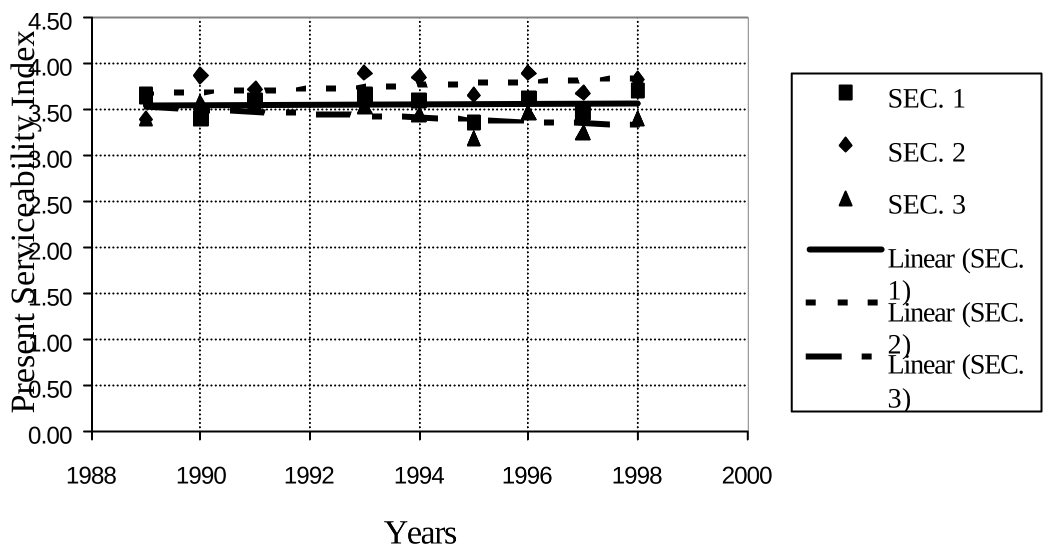



**Figure B.5. Trend of PSI with time for Site 840101**

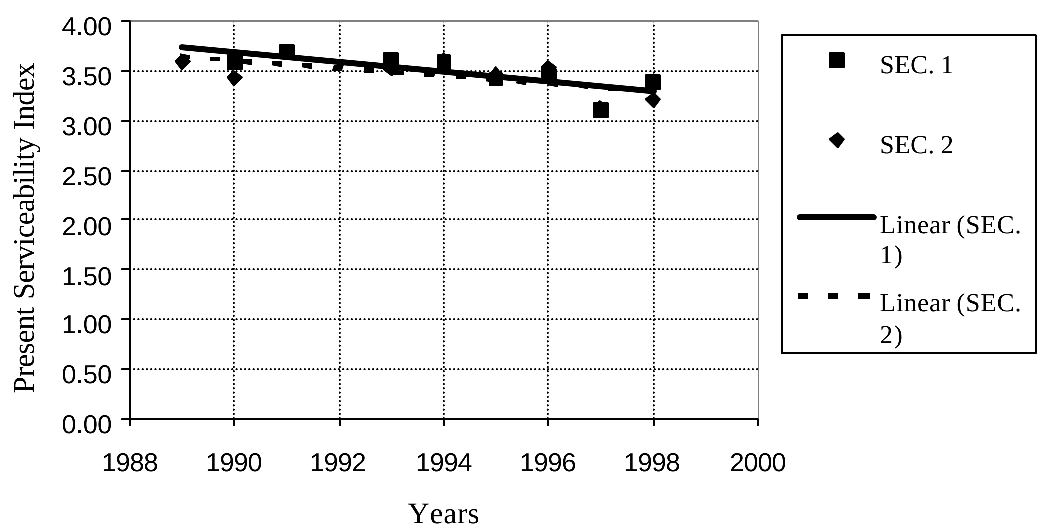



**Figure B.6. Trend of PSI with time for Site 840204**

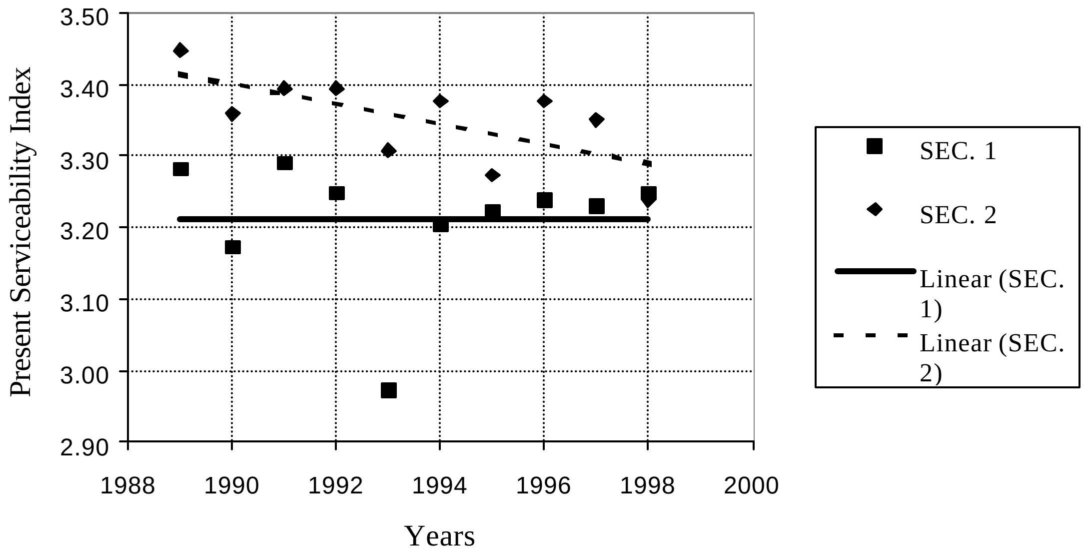



**Figure B.7. Trend of PSI with time for Site 850201**

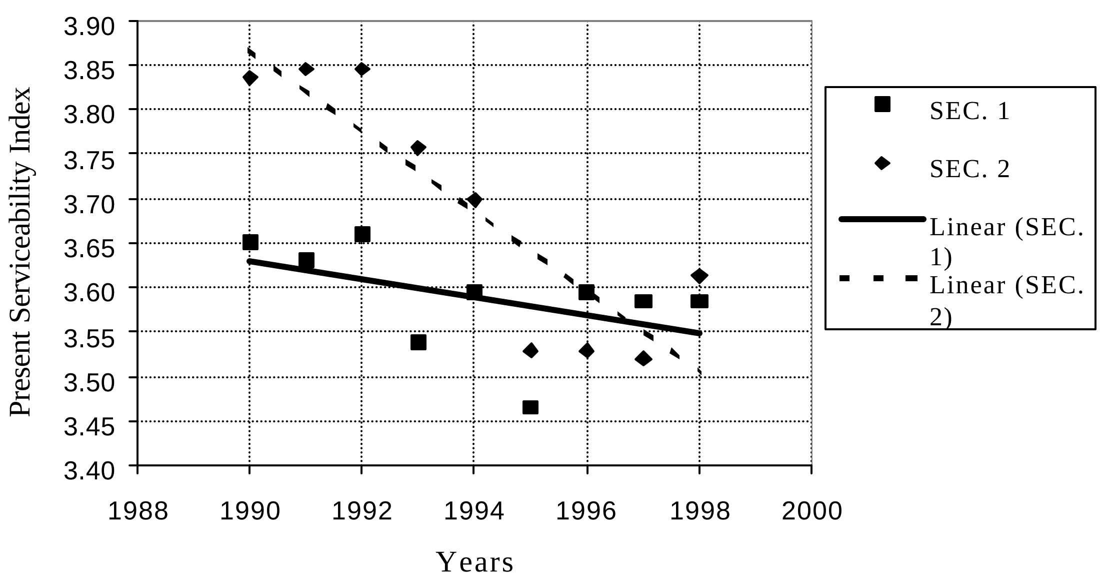



**Figure B.8. Trend of PSI with time for Site 850206**

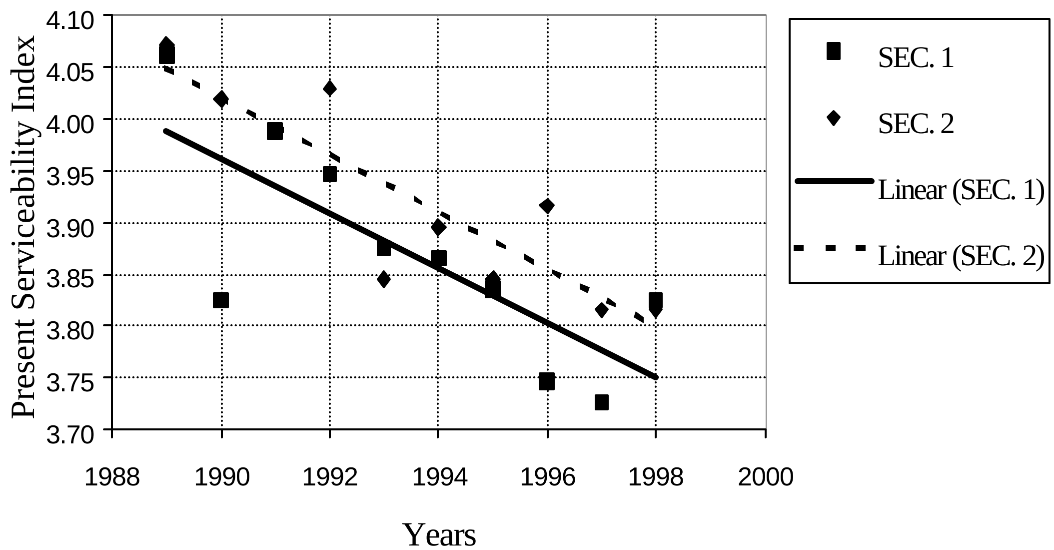



**Figure B.9. Trend of PSI with time for Site 850601**

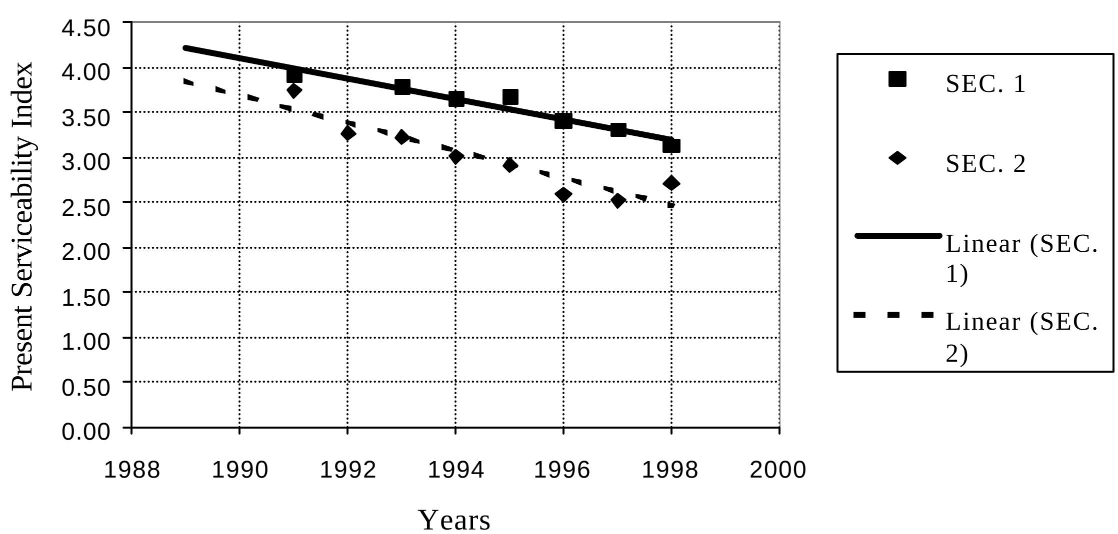



**Figure B.10. Trend of PSI with time for Site 870102**

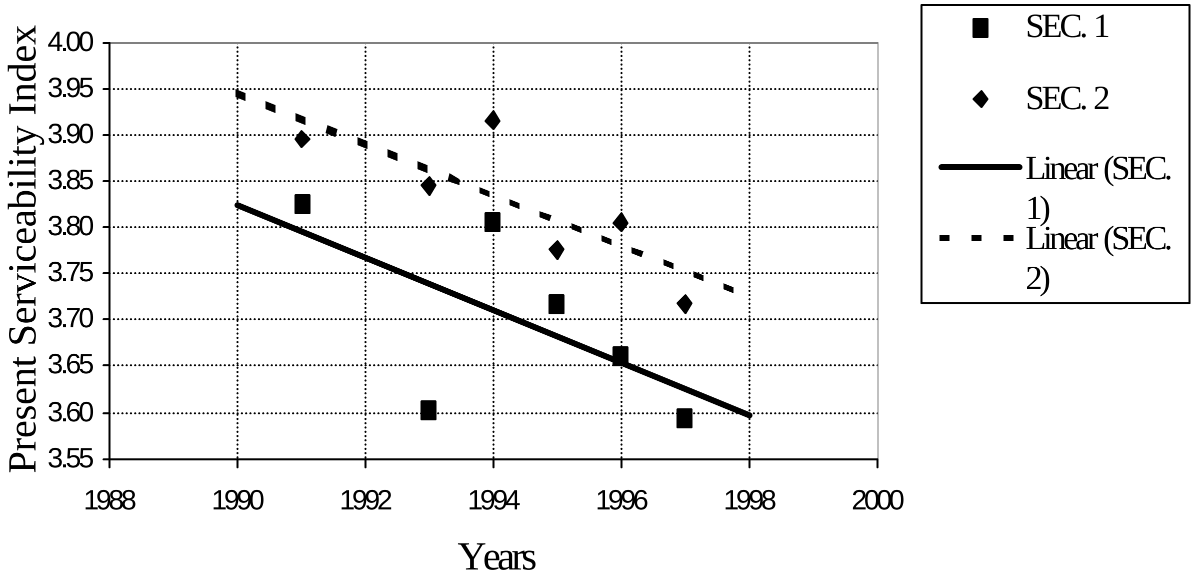
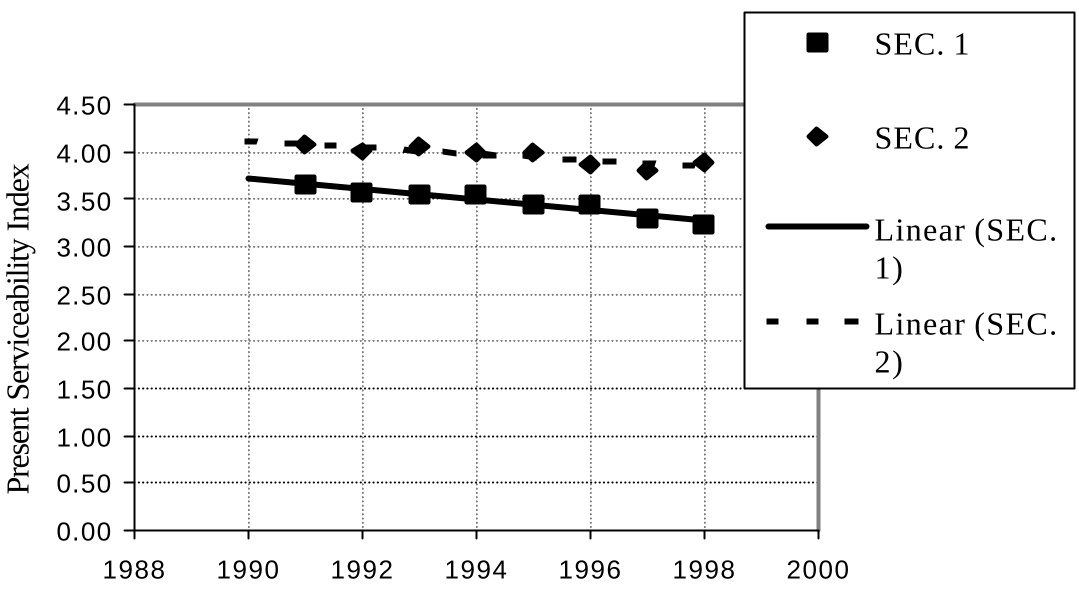



**Figure B.11. Trend of PSI with time for Site 870504**



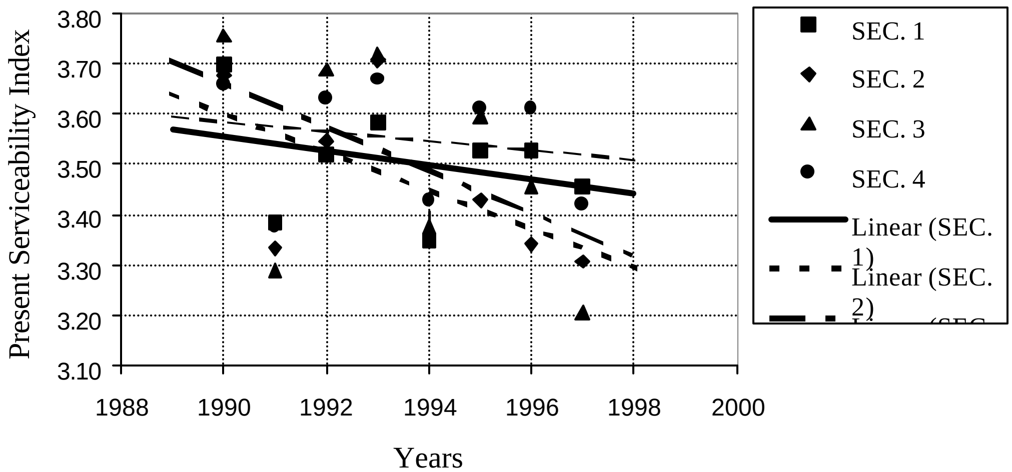



**Figure B.13. Trend of PSI with time for Site 880203**

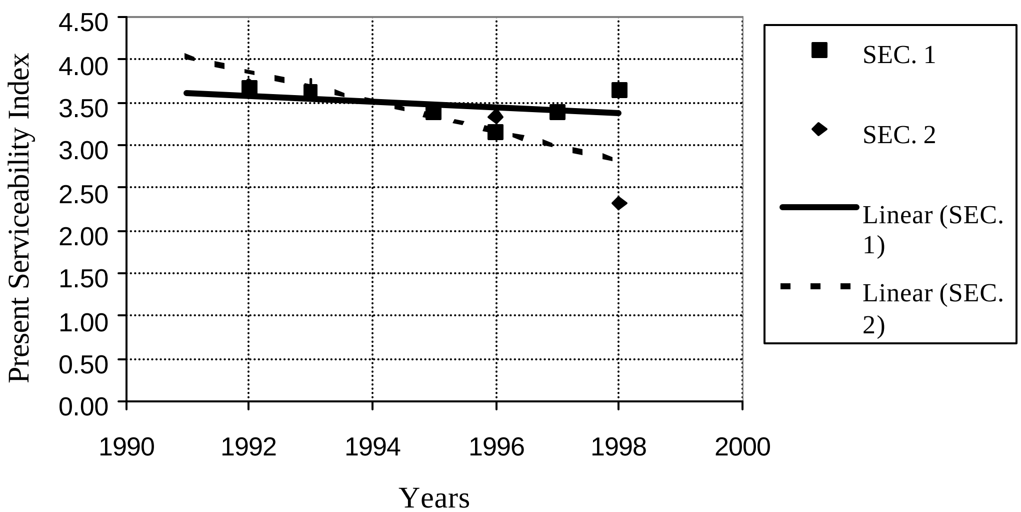



**Figure B.14. Trend of PSI with time for Site 890702**

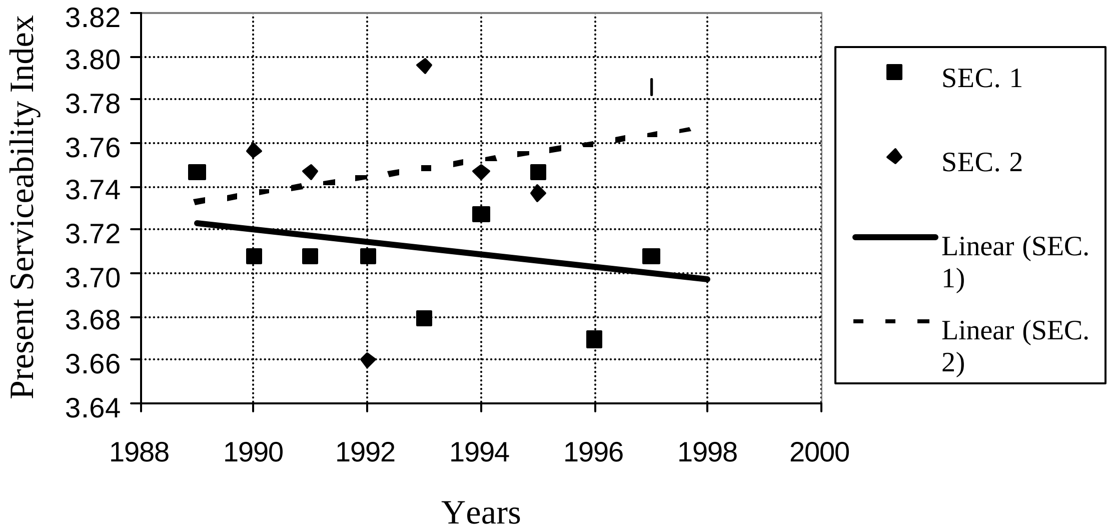



**Figure B.15. Trend of PSI with time for Site 900402**

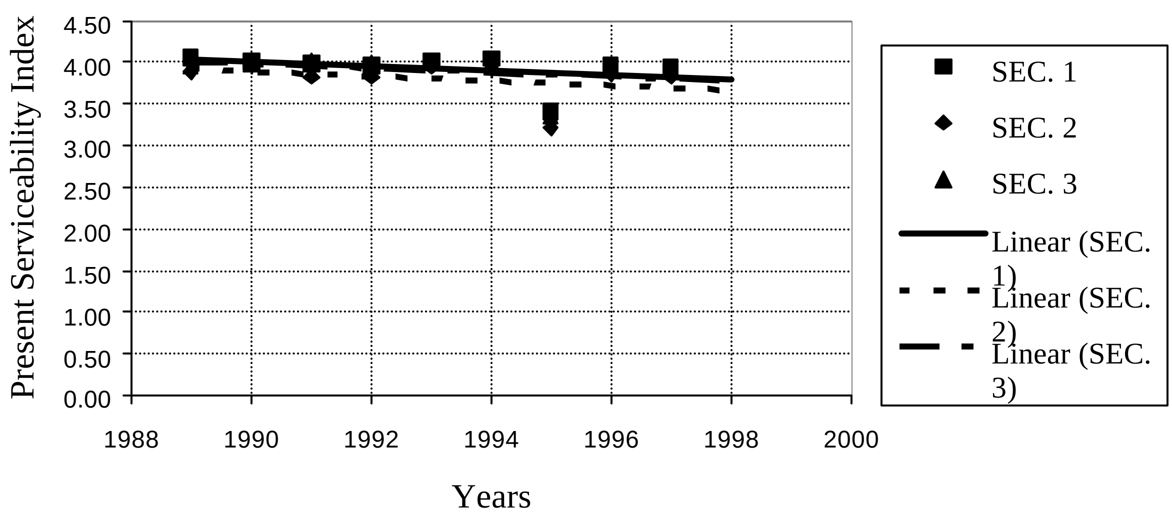



**Figure B.16. Trend of PSI with time for Site 900802**

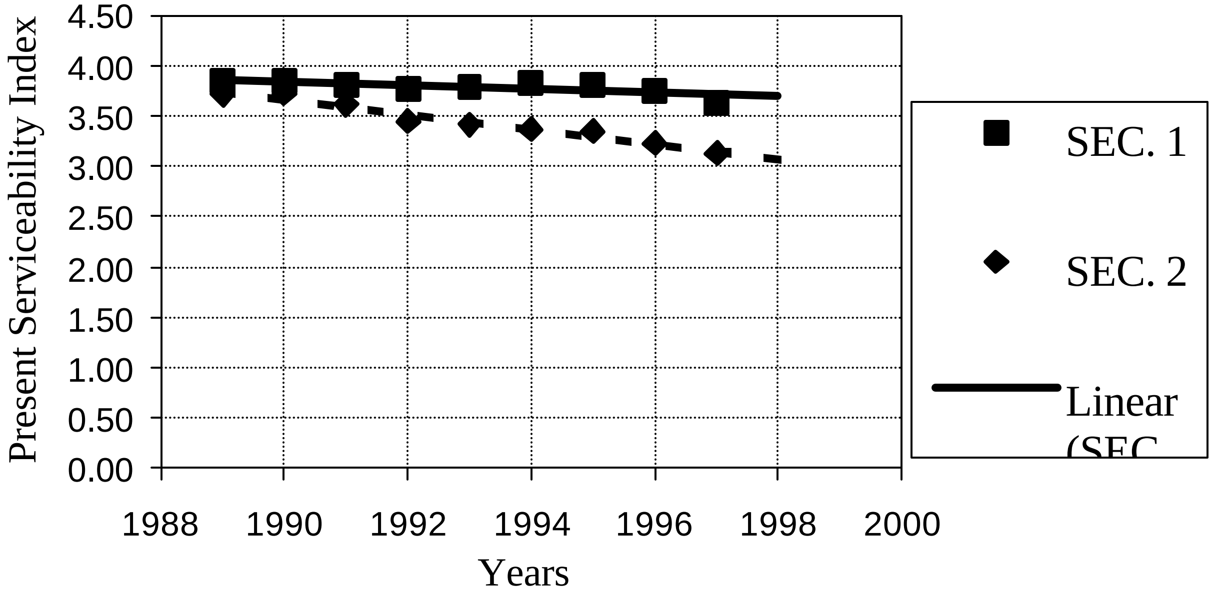



**Figure B.17. Trend of PSI with time for Site 900803**