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Transportation Research Division

Technical Report 09-1

A Winter Severity Index for the State of Maine

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Winter maintenance in the Sate of Maine consumes around twenty percent of the Bureau of Maintenance and Operations budget each year. Costs are directly related to the length and severity of a winter season. In addition, the cost of materials and equipment increases every year.

Maintenance has been experimenting with new methods, materials, and equipment to offset the increased cost. Up until 1998 the Maine Department of Transportation had been using a reactive approach to winter maintenance. This involved placing a mix of sand and salt on the road during a storm, then clean-up with salt only after the storm. In 1997 the Department experimented with a proactive method which consists of placing salt on the roadway as close to the beginning of the storm as possible followed by continued applications of salt and plowing when necessary. This method was very effective at keeping the roads bare during a storm and appeared to be less costly. By 2001 most Regions were using the proactive method.

With the switch from sand/salt mix to salt only it was necessary to upgrade the equipment to monitor and distribute salt more effectively. A number of spinners and hopper upgrades were experimented with. Evaluating each piece of equipment was based on observations and opinions. This method of evaluation is good but can be subjected to personal opinions.

Another tool that would help determine cost-effectiveness is a Winter Severity Index (WSI). A WSI rates a winter season between 0 for a mild winter to 100 for an extremely severe winter. Index numbers are generated from daily snowfall amounts and temperature. A WSI is a consistent rating that can be used to gauge equipment effectiveness during a winter season or a storm.

The Maine Winter Severity Index is a good indicator of seasonal winter conditions and correlates well with the quantity of materials used during a winter season. Correlation with seasonal costs are not as effective due to premium hourly pay and call outs for winter maintenance outside the normal working hours and the rising cost of materials.

Introduction

Approximately twenty percent of the Bureau of Maintenance and Operations budget is used for winter maintenance and the cost per lane mile of winter maintenance continues to rise every year. Total seasonal costs fluctuate with the amount of snowfall and length of season.

Up until around 1998 the department had been primarily using a reactive strategy to maintain winter roadways. This involved placing a mix of sand and salt on the road during a storm, then clean-up with salt only after the storm. This method did very little to prevent snow from bonding to the roadway making clean-up more difficult.

Around 1997 the department began experimenting with a proactive method of winter maintenance. This involves placing salt on the roadway as close to the beginning of the storm as possible in an effort to prevent snow from bonding. This is followed by continued applications of salt and plowing when necessary. This method greatly reduced roadway ice pack and made it easier to clean-up the roadway. By 2001 most Regions within the Department adopted the proactive method.

Anti-icing with salt brine was introduced shortly after the switch to a proactive strategy. This entails pre-treating the road with a salt brine spray prior to the storms arrival. This greatly reduces or eliminates snow bonding to the road reducing clean-up time even more.

With the change from sand-salt mix to salt priority it was necessary for the department to modify equipment to accommodate salt distribution. Modifications include adding ground speed controllers to regulate material output, adding or increasing the size of pre-wetting tanks on trucks, and purchasing salt brine manufacturing equipment. The Department has also been experimenting with switching the hopper material delivery system from a chain drive to a belt drive unit to improve flow of material to the spinner and by using directional spinners that give the operator greater control of salt placement.

With all these modifications it was difficult to determine if they are cost effective. Assessment was determined on a regional basis from operator comments, roadway observations and experience which although reliable can be influenced by personal opinions.

Another tool to help evaluate snow fighting effectiveness is a Winter Severity Index or WSI. A WSI is a number from 0 to 100 that rates the severity of each winter season. A WSI is a consistent measurement of winter severity from season to season.

This report will provide information regarding the methodology used to develop a Winter Severity Index for the State of Maine.

Problem Statement

Evaluating the effectiveness of a piece of winter maintenance equipment or the efficiency of a crew to maintain roadways can be a difficult task. Many variables including amount of snow, temperature during storms, time of day, number and duration of storms in a season, freezing rain, and individual opinions can affect the assessment.

A Winter Severity Index can be a useful tool when making evaluations. A WSI is a numerical rating from 0 for an extremely mild winter to 100 for an extremely severe winter. Index numbers are generated using daily snowfall amounts, ambient temperature, and liquid precipitation. The WSI, being a consistent measurement of each winter season, could be a valuable tool to evaluate the effectiveness of a new or experimental piece of equipment or a new method of fighting snow.

Methodology

Victor Nouhan from the National Weather Service in Caribou, Maine was instrumental in developing Maine's WSI. Mr. Nouhan developed a WSI in the mid 90's for Pittsburg, Pennsylvania and Goodland, Kansas. The principles he used for Kansas and Pittsburg were used for Maine's WSI with a few adjustments. Mr. Nouhan developed WSI values for each of the five MaineDOT regions displayed in Figure 1.

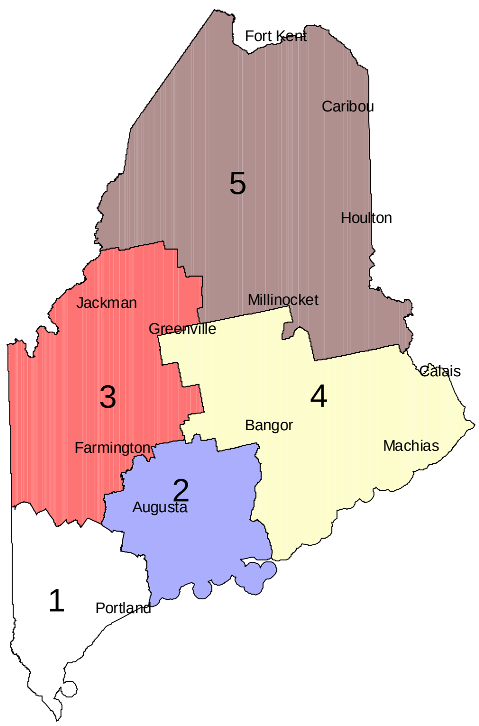

Figure 1: MaineDOT Regions

The procedures associated with this WSI are based on the properties of statistical Gaussian (or normal) distributions of weather data for the past 26 years. Historical weather information such as hi and low ambient temperature, total daily snowfall, and total precipitation from 1980 to 2006 is utilized for the initial database. To relate the 26 year database to extreme seasons, the season with the greatest and least amount of snowfall prior to the 26 year database were included which resulted in a database of 28 years of weather data.

Basically the method for developing a WSI involves collecting 28 years of weather data, assigning point values to daily snow events then combining point values into seasonal point values, calculate statistical variables for each Region using seasonal point values, then adjust seasonal point values so they correspond to a near zero Winter Severity Index for the lowest seasonal point value to a near 100 WSI for the highest seasonal point value.

Assigning Point Values

A winter season runs from October 16th to May 15th. Appendix A contains snowfall depths for each of the five regions. Snowfall depths are listed for each month from December to March and snowfall listed in the Other Months column represents data outside the December through March core period of the season. The last two rows of data represent the highest and lowest seasonal snowfall outside the 26 year database.

Seasonal snowfall is reduced to an event by event basis in order to generate point values for each monthly snowfall total. Daily snowfall amounts were assigned point values based on the following rules and the Individual Snow Event Point System in Table 1 and Mean Temperature Bonus Point System in Table 2.

1. Back to back snowfall days (two day snow events) were always combined to produce a single total event, unless the point total for each individual day was higher (only occurred with small snow events).

2. Generally, an event did not exceed two calendar days unless each day's contribution for a three or more calendar day event was 20 percent or greater.

3. Bonus points, awarded based on how cold an event was, were assigned based on the Mean Temperature Bonus Point System (Table 2) which was developed to account for the reduced ability of salt to melt ice at low temperatures.

Using these rules, months with above average snowfall with large snow events result in point totals significantly greater (up to 50 percent or more) than assigning a point value for the combined monthly snowfall.

Table 1: Individual Snow Event Point System

Snowfall (in)	Points	Snowfall (in)	Points	Snowfall (in)	Points	Snowfall (in)	Points
<0.5	0	7.0 to 8.4	10	18.5 to 19.9	30	30.0 to 31.4	64
0.5 to 1.9	1	8.5 to 9.9	12	20.0 to 21.4	34	31.5 to 33.4	70
2.0 to 2.9	2	10.0 to 11.4	14	21.5 to 23.4	38	33.5 to 34.9	76
3.0 to 3.9	3	11.5 to 13.4	17	23.5 to 24.9	42	35.0 to 36.4	82
4.0 to 4.9	5	13.5 to 14.9	20	25.0 to 26.4	47	36.5 to 38.4	88
5.0 to 5.9	6	15.0 to 16.4	23	26.5 to 28.4	52	38.5 to 39.9	94
6.0 to 6.9	8	16.5 to 18.4	26	28.5 to 29.9	58	≥40	100

Table 2: Mean Temperature Bonus Point System

Event Average Temperature	Additional Points
>32 Deg F	0
15.0 ≤ Event ≤ 32	0.2 of Event Snowfall up to 8 points
0.0 < Event < 15	0.3 of Event Snowfall up to 12 points
≤ 0 deg F	0.4 of Event Snowfall up to 16 points

Table 2 was added to account for salts decreased effectiveness at melting ice as the temperature decreases. Salt can melt ice only down to a temperature of about 15 °F. Salt placed on the roadway during storms above 15 °F partially melt the snow which slows accumulation and snow plowed to the shoulder tends to stick together and stay put due to its moisture content. When the temperature is below 15 °F snow has less moisture and does not stick together allowing it to blow around and drift. Maintenance crews plow roads without salt during these storms and the snow tends to blow back into the roadway creating snow drifts which, combined with the falling snow, tends to accumulate at a faster rate. It takes more effort for maintenance crews to clean up cold storms than warm storms and Table 2 accounts for this by adding Temperature Bonus Points to the Individual Snow Event Points.

Appendix B contains an example of snow event and temperature bonus point generation for the month of February, 1996 in the Northern (Calais) Region.

Calculation of Statistical Variables

Variables are calculated for each Region using total point values for each of the 26 winter seasons plus the highest and lowest snowfall season. Appendix C contains point values and statistical variables for each Region. The following variables were calculated from the Total columns in Appendix C:

Xmn = The lowest seasonal point value.
Q1 = In ascending order, the 7th lowest seasonal point value.
Mid = In ascending order, the 14th seasonal point value.
Xavg = The average of all seasonal point values.
Med = The average of only the highest and lowest seasonal point values.
Q3 = In ascending order, the 7th highest (or 21st) seasonal point value.
Xmx = The highest seasonal point value.
Sig = The calculated standard deviation of all seasonal point values.

$$XM = \frac{Mid + Xavg + Med}{3} \quad \text{(truncated)}$$

$$S- = \frac{\frac{2(XM - Xmn)}{3n} + Sig}{n+2} \quad \text{(truncated)}$$

$$\text{where } n = \frac{Abs\,(Xmn - (XM - 3Sig))}{Sig} \quad \text{(rounded to tenths and set to no less than 1.0)}$$

$$\text{or } S- = \frac{XM - Xmn}{3} : \text{if } XM - 3(S-) \leq 0$$

$$S+ = \frac{\frac{Xmx - XM}{4} + Sig}{2} \quad \text{(truncated)}$$

$$Z- = \frac{X - XM}{S-}$$

$$Z+ = \frac{X - XM}{S+}$$

$$\text{where } X = \textit{Total} \text{ seasonal point value}$$

The first eight variables are simple statistical values that describe the distribution of the Total column in Appendix C. XM is the modified mean of the distribution and S- and S+ are modified standard deviation values for above and below XM values. XM, S-, and S+ are calculated parameters that will be used to modify the Total Point distribution column so that lowest and highest Seasonal Point Totals correspond to standard deviation, or Z values, close to 3S- or 3S+. Z values for each Region are listed in Appendix D.

The first eleven statistical values are fixed parameters for a weather location. Z values and WSI values for each subsequent winter season will be generated using the fixed parameters.

Calculation of Index Values

Index (I) values are calculated from Z values for each Region using the following formula:

$$I = \frac{2(50 + 16.5Z) + 100Zp}{3}$$

where Zp corresponds to the left tailed cumulative probabilities found in a normal distribution table for corresponding Z values. I values smooth the drastic rate of change between the central and tail regions of a normally distributed data curve. Table 3 shows a numerical difference between I and 100Zp values for different values of Z and Figure 2 displays the smoothing effect of the Index formula. Appendix E contains Winter Severity Index Values for each Region.

Table 3: Unmodified Normal Curve (100Zp) vs Smoothed Index Curve (I)

Z	100Zp	I
-3	0.1	0.4
-2.5	0.6	6
-2	2.3	12.1
-1.5	6.7	19.1
-1	15.9	27.6
-0.5	30.8	38.1
0	50	50
0.5	69.2	61.9
1	84.1	72.4
1.5	93.3	80.9
2	97.7	87.9
2.5	99.4	94
3	99.9	99.6

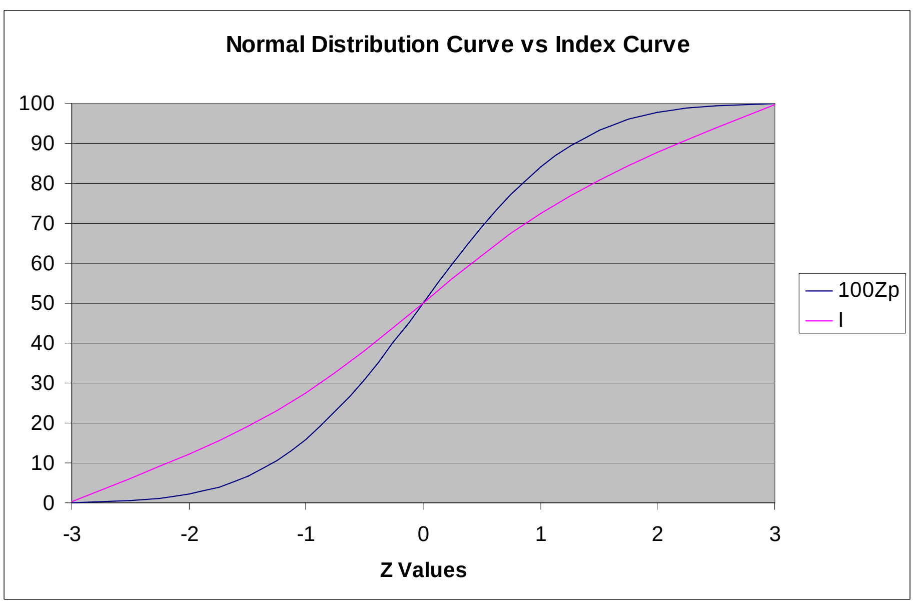

Figure 2: Smoothing the Normal Distribution Curve

Spreadsheet Generated WSI Values

When reviewing WSI values for each Region it was apparent that the index numbers represent a small portion of a large Regional area and may not necessarily portray the correct WSI for an area that may be 20 or 30 miles away. It's not uncommon for snow depths to differ by 4 to 8 inches or more for a single event or 10 to 20 inches or more for a total seasonal snowfall depth in a distance of 20 or 30 miles. For example the 2003/04 WSI values in the Southern, Mid-Coast, and Eastern Regions are 18, 65, and 29 with total snowfall depths of 46.7, 73.5, and 60.7 respectively. The distance between the Southern and Mid-Coast Region weather stations is 50 miles and the distance between Mid-Coast and Eastern Region weather stations is 60 miles. If you were to evaluate winter maintenance procedures for a maintenance camp located between the Southern and Mid-Coast Region, which WSI value would you use, 18 or 65. It would be more accurate to evaluate the same maintenance camp with a WSI value developed using weather data from a nearby weather station.

To accomplish this, a weather station must be close to a maintenance camp or group of maintenance camps. Appendix F contains a map of Cooperative Observer Program (COOP) weather station and maintenance camp locations throughout the state. The amount of weather data varies for each COOP. A WSI can be developed from a weather database of less than 25 years but the level of accuracy would be reduced. The blue triangle locations have more than 30 years of weather data, red between 25 and 30 years and yellow less than 25 years. Gray dots are maintenance camp locations. It would be wise to divide coastal, mid-coast, mountain, and northern areas into multiple sections based on the location and amount of available COOP weather data.

Mr. Nouhan generated the five Regional WSI summaries by hand. In order to generate multiple WSI locations it will be necessary to automate the process using a spreadsheet. Historical COOP data is available in ASCII format on the National Climactic Data Center (NCDC) website. This data can be imported into a spreadsheet for processing.

It's estimated that it would take three weeks to generate a WSI for one weather station. Most of the time is used to verify accuracy of the data or fill in missing weather data. The snowfall data from NCDC matched snowfall data from the NWS in Caribou for all but a few months. The reason for the discrepancies is that the NCDC uses an automated Quality Control program that compares snowfall amounts with surrounding COOP locations to verify accuracy. It's not uncommon for an isolated location to have a large amount of snowfall when the surrounding areas did not. In this instance the automated NCDC QC program may reduce the amount of snowfall in that location when comparing recordings from surrounding locations.

The process for generating a WSI with a spreadsheet is basically the same with the exception of assigning point values to snow events. Automating the assignment of point values based on the three rules mentioned earlier was difficult to achieve. WSI values generated using the automated point system is very close to WSI values generated by Mr. Nouhan. Appendix G contains a comparison of NWS WSI values and DOT spreadsheet values.

Ninety four percent of the DOT, or spreadsheet generated, WSI values are within ±10 index numbers of WSI values generated by Mr. Nouhan. To break it down further, eighty three percent of the DOT WSI values are within ±5 index numbers, eleven percent are within ±10 index numbers and eight winter seasons, or six percent, are more than 10 index numbers greater than NWS generated WSI values. All of the DOT values that are above 10 index numbers of the NWS WSI values are due to differing snowfall depth recordings. Highlighted values in Appendix G have conflicting snow depth values.

Freezing Rain Events

Freezing rain events occur when snowfall passes through a layer of above freezing air that is thick enough to melt the snow into rain drops. The rain then passes through a thin layer of below freezing air near the surface and the rain drops become supercooled or they cool to a temperature below freezing without actually freezing. When the supercooled drops make contact with a surface they instantly freeze forming a thin layer of ice. Ice thickness is determined by the amount of precipitation.

Maine typically has one or more freezing rain events per winter season. On January 7th, 8th, and 9th, 1998 the southern and central portions of the state experienced a severe freezing rain event that left more than one inch of ice coating every surface. The DOT WSI value for the winter season of 1997/98 in the Eastern Region is 56 which is a good indicator of the season when rating snowfall only but the freezing rain event should have added severity to the season. Mr. Nouhan agreed that freezing rain should be included in the Winter Severity Index and he developed the following equation and table to account for this.

$$FZRA\,Equiv = \frac{30}{30 + DeltaT^2}\left[Daily\,Precip\,Total - Daily\,Snfl\,(10:1\,ratio)\,Equiv\,Precip\right]$$

where $DeltaT = \text{Tmax} - 30$

Points are assigned based on the FZRA Equiv and point values displayed in Table 4. FZRA points are then added to snowfall points generated using Table 1. The temperature boundaries to use this equation are:

$$\text{Tmin} \le 30 \text{ and } 15 \le \text{Tmax} \le 45$$

Table 4: Individual FZRA Equiv Point System

FZRA Equiv	Points	FZRA Equiv	Points	FZRA Equiv	Points	FZRA Equiv	Points
<0.05	2	0.70 to 0.84	40	1.85 to 1.99	82	3.00 to 3.14	120
0.05 to 0.14	5	0.85 to 0.99	46	2.00 to 2.14	88	3.15 to 3.34	125
0.15 to 0.29	10	1.00 to 1.14	52	2.15 to 2.34	94	3.35 to 3.49	130
0.30 to 0.39	16	1.15 to 1.34	58	2.35 to 2.49	100	3.50 to 3.64	135
0.40 to 0.49	22	1.35 to 1.49	64	2.50 to 2.64	105	3.65 to 3.84	140
0.50 to 0.59	28	1.50 to 1.64	70	2.65 to 2.84	110	3.85 to 3.99	145
0.60 to 0.69	34	1.65 to 1.84	76	2.85 to 2.99	115	≥4.00	150

When the FZRA Equiv was calculated for the 1997/98 Eastern Region winter season the DOT WSI went from 56 or a ‘Hard’ rating to 103 which is an ‘Extremely Severe’ rating. The formula appeared to increase point values too much which inflated the WSI value.

This could be corrected by modifying the Point Values in Table 4 or another option would be to convert the excess liquid precipitation to snowfall then add the converted snowfall to the measured snowfall. This would create a modified snowfall which could then be assigned a point value using the Individual Snow Event Point System in Table 1.

To test this theory it was necessary to find a good snow to liquid rain ratio that would convert precipitation to snow for various temperature ranges. Snow density or its water content varies with temperature. If the temperature is below 12°F then the snow is typically dry, low density snow with little water content and it takes approximately one inch of precipitation to create 12 inches of snow. If the temperature is close to freezing it is usually a heavy, wet snow full of moisture with some melting taking place and one inch of precipitation would equal approximately 5 inches of snow. After researching numerous snow to liquid rain ratios the ratio in Table 5 was utilized.

Table 5: Snow to Liquid Rain Ratio.

Temperature Range (°F)	Snow to liquid rain Ratio
>12	12 inches of snow = 1 inch of rain
12 to 24	10 inches of snow = 1 inch of rain
24 to 28	7 inches of snow = 1 inch of rain
28 to 31	5 inches of snow = 1 inch of rain

It's also necessary to determine if freezing rain events cost more to control than snow events. A question was posed to a foreman in the Bangor, Maine maintenance camp; If you have two separate storms, each one producing one inch of liquid precipitation over a period of 6 hours, and one storm had 7 inches of snow and the other had 2 inches of snow with 0.75 inches of freezing rain would they cost the same to control? The foreman said they have to make additional runs and it takes more material to keep the roads clear during a freezing rain event than it would if it was all snow and that it typically costs between 20 and 30 percent more.

The following Modified Daily Snowfall formula was developed to account for freezing rain:

Mod Daily Snfl = (Est Daily Snfl (ratio) – Measured Daily Snfl) * 1.25 + Measured Daily Snfl

The temperature boundaries to use the formula are:

$$20 \leq Tmin \leq 30 \quad \text{and} \quad 25 \leq Tmax \leq 35$$

The formula converts the total daily liquid precipitation into snowfall creating an Estimated Daily Snowfall. The Estimated Daily Snowfall is reduced by the amount of Measured Daily Snowfall and the remainder is increased by 25 percent, to account for additional material cost, creating a Liquid Equivalent Snowfall. The Measured Daily Snowfall is then added to the Liquid Equivalent Snowfall to create a Modified Daily Snowfall. Points are assigned to the Modified Daily Snowfall based on the Individual Snow Event Point System in Table 1. If the Measured Daily Snowfall is equal to or greater than the Estimated Daily Snowfall the Modified Daily Snowfall equals the Measured Daily Snowfall. Figure 3 contains a graphical display of the formula.

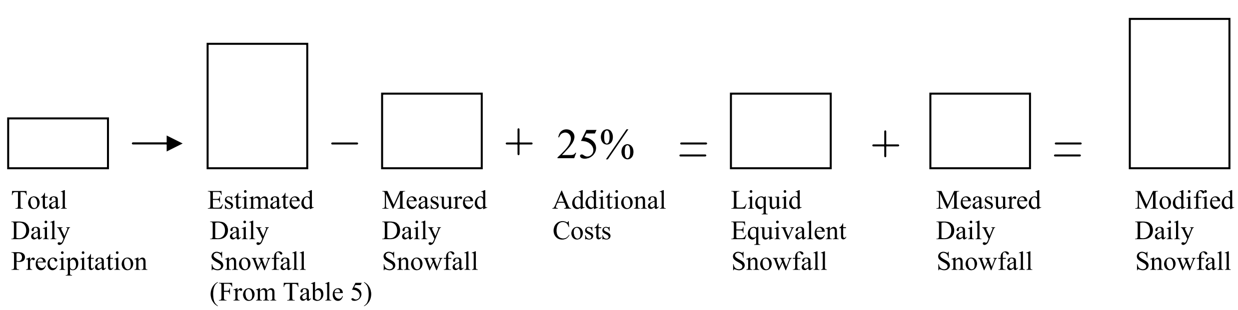

Figure 3: Modified Daily Snowfall.

Appendix H contains a comparison of DOT WSI values and WSI values with Modified Freezing Rain. Highlighted values in the 1997/98 season reveal that WSI values in the Northern Region increase very little which is consistent with ice storm results. WSI values in the Western, Eastern, Mid-Coast, and Southern Regions increased from 15 (Very Mild) to 44 (Average), 56 (Hard) to 69 (Severe), 6 (Extremely Mild) to 25 (Mild), and 36 (Moderate) to 62 (Hard) respectively. This coincides with the amount of ice in each region. The Southern, Mid-Coast, and portions of the Western Regions had heavier ice than the Eastern Region which had the lowest amount of ice according to NCDC January, 1998 Storm Data Publication for the state of Maine.

Winter Cost Comparison

The purpose of developing a WSI for MaineDOT is to gauge material use and justify winter snow control costs. To a lesser extent you may be able to use the WSI to monitor effectiveness of a new piece of snow control equipment.

Appendix I contains two graphs for each Region. The first graph compares WSI values to Total Snowfall and Event Count, which is a count of events during a winter season. The second graph compares WSI values to Regional winter costs associated with Activity 412 - Snow and Ice Removal and Activity 413 - Anti-Icing. Cost information is compiled from the MaineDOT Financial Activity Data Warehouse (FACT) and includes a summary of labor, equipment, and material costs from 2001 to 2008. FACT data is a record of Daily Work Reports submitted by every maintenance personnel and represents actual costs associated with each maintenance activity.

Region 1

Weather Comparison

The Southern Region WSI appears to follow the peaks and valleys of the Total Snowfall and Event Count. When Total Snowfall is high the resulting WSI is high and the same is true when Total Snowfall is low the WSI is low. The 2003/2004 and 2005/2006 seasons had similar snowfall amounts and number of events with differing WSI values. The 2003/2004 season had 16 events with 46.7 inches of snow and a WSI of 24 and the 2005/2006 season had 15 events with 47.2 inches of snow and a WSI of 14. Each winter season had a storm with slightly more than 13.5 inches of snow but the 2003/2004 season had three storms with snow depth between 6 and 7 inches while the 2005/2006 season were all less than 6 inches in depth which is why the WSI is ten points lower.

Cost Comparison

WSI values correlate well with Total cost amounts up to the 2004/2005 season.

The 2005/06 season has a low WSI value of 14 with significantly lower Labor and Equipment costs and higher Material costs than the previous season. Also notice that the 2004/2005 and 2007/2008 seasons have similar snowfall, event count, labor and equipment costs but the material costs are much higher. This is a result of the dramatic increase in the cost of materials over the past three years. For example, the average cost of rock salt from 2001 to 2004 increased from $35.00 to $45.00 per ton or about $2.50 per ton per year. The same material increased to an average of $50.65 per ton in 2005, $54.04 in 2006, $56.76 in 2007, and $72.34 in 2008. The high material cost has significantly increased Total Activity costs for the past three seasons and the low WSI values over the same time period do not reflect that cost increase.

Region 2

Weather Comparison

The WSI follows Snowfall and Event Count very well in this Region.

Cost Comparison

The WSI correlates very well with Total costs up to the 2005/2006 season when material costs increased.

Region 3

Weather Comparison

The Western Region is mountainous and at a higher elevation than the other Regions. Typically if there is any type of precipitation during the winter it falls as snow and most storms accumulate more snow than the surrounding Regions. This region uses more sand/salt mix than the remaining regions.

The WSI does not follow as typical a pattern as the other Regions. For example the 2002/2003 season had fewer events and less snow than the 2001/2002 season yet the WSI is higher by two points. When reviewing individual events, both seasons had six events with snow depth between 5 and 8 inches but the 2002/2003 season had one event with 19 inches of snow which added enough points to increase the WSI.

The 2003/2004 season appears to have an unusually high WSI at 69 while having a low number of events and typical seasonal snowfall of 87.4 inches. There were two major snow events that season, one with 40 inches of snow accumulation and the other with 15 and the remaining events were less than 5 inches in depth with the exception of one storm with 6.3 inches of snow. This should have resulted in ‘Average’ or at the most a ‘Hard’ WSI rating. It appears that the two large snow events significantly increased the WSI value.

The 2004/05 season has a WSI value of 56 which is more inline with the number of events and snow depth.

The 2005/06 season had three events with snow accumulation between 5 and 7 inches and the remaining events had less snow which equates to a very low WSI of 5.

The remaining WSI values appear to correlate well with snowfall and event counts.

Cost Comparison

The 2001/02, 2002/03, and 2003/04 winter seasons have very similar labor, equipment, and material costs. The WSI values are similar for the first two winter seasons at 19 and 21 while the WSI value for 2003/04 is very high at 69. Perhaps the Individual Snow Event Point System could be adjusted to reduce the effect of large snow events.

Activity costs for the 2004/05 season appear to be in line with the WSI value of 56.

In 2005/06, the WSI value is 5 or an ‘Extremely Mild’ rating which appears to reflect the number of events and amount of snowfall but activity costs appear to be high. Labor and equipment costs are lower than the previous season while material cost is higher, which is the result of increasing material costs.

Activity Costs 2006/07 and 2007/08 appear to be low for the WSI value.

Region 4

Weather Comparison

The WSI in Region 4 tends to follow the amount of snowfall and event count very well. The first three seasons had similar snowfall at 62.8, 62.3, and 60.7 inches and the number of events is 26, 20 and 20 while the WSI was 30, 37, and 30 respectively. The 2002/03 WSI of 37 is higher due to the low number of events combined with 62.3 inches of snowfall.

The remaining seasons are inline with event count and snow depth.

Cost Comparison

Total Activity costs follow WSI values very closely for the first four seasons.

In 2005/06 the Labor and Equipment costs are lower than the previous season but material costs are about the same. Once again this is a result of increased material costs beginning in 2005.

In 2006/07 the Labor and Equipment costs increased from the previous season while Material cost remained about the same. Many Regions conserved materials when possible due to the price increase which could contribute to the reduced Material costs.

Labor and Equipment costs increased dramatically in 2007/08 while Material cots decreased as compared to the previous season. This season had an unusually high amount of snow and number of events. Material shortages and conservation contributed to the low Material cost.

Region 5

Weather Comparison

The Northern Region WSI correlates well with Total Snowfall and the Event Count. During the 2001/2002 season there were 39 snow events with 91.2 inches of snowfall which resulted in a WSI of 23 or the lower side of a 'Mild' winter season. A majority of events had 3 inches of snow or less. Eleven had more than 3 inches of snowfall and three of the eleven had 5 or more inches of snow. The worst storm had a snow depth of 7.7 inches.

During the 2002/2003 season there were 40 snow events with a total snowfall of 117.3 inches which resulted in a WSI of 55 or the high side of a 'Hard' winter season. A majority of events had 3 inches of snow or less and twelve events had more then 3 inches of snow. Seven of the twelve events had snow depths greater than 5 inches including one event with 8.7 inches and one with 20.8 inches of snow. Even though each season had roughly the same number of events it was the number of events with greater than 5 inches of snow and the 20.8 inch storm which pushed the WSI into the 'Hard' category.

The 2005/2006 season has similar conditions as the 2001/2002 season with 39 Events and 96 inches of snow. The WSI value is 38 which is 15 points higher. This categorizes the season in the upper portion of the 'Moderate' range. There were seven events that had snow depth greater than 3 inches and two of the seven had snow greater than 5 inches in depth. Although there were fewer events with snow greater than 5 inches, one storm had 29.8 inches of snow which increased the seasonal point value and in turn increased the WSI.

The 2007/2008 season set snowfall records in the Region and resulted in a WSI of 111. The Region experienced thirteen storms with more than 5 inches of snow. Four of the thirteen had snow depths greater than 9 inches.

Cost Comparison

The WSI mirrors Labor, Equipment, Material, and Total costs very well up to the 2005/2006 season when material costs began to dramatically increase. Labor and Equipment costs during the 2005/2006 season are lower than the 2004/2005 season while Material costs are higher and this occurs when there are fewer events and less snow depth. Total Costs for the remaining two seasons do rise proportionally with the WSI. The 2007/2008 season shows unusually low Material costs with high Labor and Equipment costs. This was due to supply companies running out of salt and maintenance crews across the state had to ration the amount of salt used on the roadway so they wouldn't run out while the use of sand increased dramatically.

Material Usage Comparison

Another use for the WSI is to gauge the amount of material used during winter maintenance. MaineDOT tracks activities and material usage for every maintenance crew in the state using the Maintenance Activity Tracking System (MATS). The MATS database was introduced in 1999 and was modified over a five year period to store all daily maintenance activities. MATS were fully functional by 2005.

A summary of material usage for Activity 412 and 413 was generated for five maintenance crews from year 2005 to 2008. The Maintenance crews are located within ten miles of each Regional COOP weather station. Table 6 contains maintenance crew information such as Crew Number, Town Location, and Lane Miles Assigned for each winter season. MaineDOT has been consolidating winter crews and modifying plow routes since 2004 which is why the amount of Assigned Lane Miles may change from season to season.

Table 6: Maintenance Crew Information

			Lane Miles Assigned		
Region	Crew #	Town	2005/06	2006/07	2007/08
1	71103	Scarborough	103.29	103.29	85.96
2	71216	Augusta	134.56	115.26	157.83
3	71304	Farmington	80.60	79.98	105.06
4	71404	Bangor	348.57	348.57	431.44
5	71516	Caribou	178.43	178.43	183.03

Appendix J contains a graphical display comparing winter maintenance material quantities to WSI values, Storm Count, Total Snowfall, and Lane Miles Treated. Storm Count values are from the MATS database and may not match the Event Count generated by the WSI spreadsheet.

MaineDOT has been utilizing Salt, Sand, Salt Brine, Magnesium Chloride, Liquid Calcium, Flake Calcium, and Ice-B-Gone to clear roadways during snow storms. All five Regions use salt in combination with one or more of the other materials to clear roadways. Each Region has a slightly different method of winter maintenance.

Region 1 Maintenance Crew

Crew 71103 in Scarborough pre-wets salt with salt brine or magnesium chloride prior to placing on the roadway. This lowers the working temperature of salt and minimizes bounce and scatter. This Crew has completely converted from using a sand/salt mix to salt only.

The WSI closely follows seasonal material quantities in 2005/06 and 2006/07 but appears to be low for the 'Very Severe' rating in 2007/08. Assigned lane miles were decreased 17 percent during this period which may account for the reduced material usage.

Region 2 Maintenance Crew

Crew 71216 in Augusta continues to use sand on occasion and pre-wets salt or sand with a variety of liquids including Liquid Calcium.

The WSI follows Total Snowfall very closely all three seasons. Material Quantities for 2005/06 and 2006/07 appear to be about the same even though the WSI rating increased from a somewhat 'Mild' rating to a 'Hard' rating and Total Snowfall nearly doubled. The number of Assigned Lane Miles decreased 14 percent in 2006/07 to a total of 115.26 miles while the number of Lane Miles Treated for each season was about the same. This would account for the similar material use.

Snowfall accumulations during the 2007/08 season were well above normal and salt suppliers had a difficult time keeping up with demand. Maintenance crews had to rely on sand to keep roadways passable which would account for the increased amount of sand. In addition, Assigned Lane Miles increased 37 percent to a total of 157.83.

Region 3 Maintenance Crew

Crew 71304 in Farmington uses both salt and a sand/salt mix that is pre-wet with Liquid Calcium. Material Quantities are very similar for the 2005/06 and 2006/07 seasons while Total Snowfall for 2005/06 is nearly half the amount of 2006/07. Treated Lane Miles are nearly identical for both seasons which is mainly why material quantities are similar. Treated Lane Miles more than doubled in 2007/08 along with the amount of materials. The amount of sand use increased dramatically due to the shortage of salt.

Region 4 Maintenance Crew

Crew 71404 in Bangor has the greatest amount of assigned lane miles and uses a large quantity of materials. This crew has been experimenting with new equipment and snow fighting procedures to improve winter road conditions in the most cost effective manner. A sand/salt mix is used on occasion when necessary.

WSI ratings for 2005/06 and 2006/07 were 'Extremely Mild' and 'Mild'. Material quantities are similar for both seasons also.

The 2007/08 season has a rating of 'Hard'. Material quantities increased dramatically, including the use of sand which is due to the salt shortage. Flake Calcium also increased because it was blended with the sand.

Region 5 Maintenance Crew

Crew 71516 in Caribou typically has the greatest amount of snowfall. In fact a record amount of snowfall was recorded in Caribou during the 2007/08 season.

WSI values closely follow material quantities. The first two seasons were rated 'Moderate' and 'Average' and the amount of materials used did not change very much between seasons.

Sand use increased dramatically during the 2007/08 season due to the salt shortage and increased amount of snowfall. Lane Miles Treated nearly doubled for the same period. The cover photo is taken on a side road in the caribou area and gives you the idea of how much snow fell that season. Clearing snow after a storm is considered Treated Lane Miles and many lane miles were accumulated clearing snow from the shoulders to make room for more snow.

Summary

Overall the Winter Severity Index is a good indicator of seasonal winter conditions. WSI ratings follow winter costs very well when inflation, price fluctuations, and material availability are factored in.

The WSI is also a good indicator of material quantity use when changes in Assigned Lane Miles and Treated Lane Miles are factored in.

There are a few seasons when the WSI does not correlate well with cost or material use. To correct this, the Individual Snow Event Point System (Table. 1) could be refined to better represent each snow event. Point values could be assigned based on the number of trips a plow truck makes to clear the roadway for a range of snow depths. For instance trucks may make two round trips during a storm that has less than one inch of snow or three trips for storms with one to two inches of snow but could make five trips for a storm with two to three inches of snow and maybe seven for a storm with three to four inches, etc. Point values would have to be determined by interviewing maintenance personnel.

Winter weather in Maine is influenced by many factors. The coastline and southern areas have milder weather that is influenced by the ocean, western Maine is mountainous and at a higher elevation and typically has more snow, northern Maine also has more snow and a longer winter season because of its latitude.

The five Regional WSI values represented in this report cover large areas that may have very different winter conditions within each Region. To accurately represent a Region it will be necessary to generate WSI values for smaller areas. Coastal Maine should have a minimum of four areas, western and central Maine should have a minimum of 8 areas, and northern Maine should have a minimum of 3 areas. The National Weather Service has 32 Forecast Zones that could be used to determine WSI Zones as displayed in Figure 4.

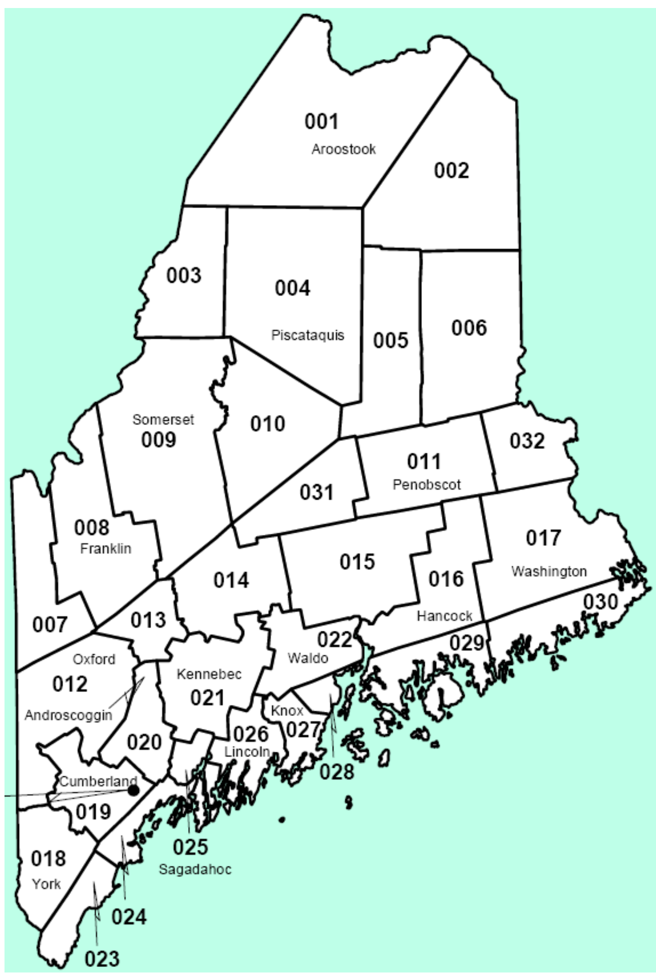

Figure 4: National Weather Service Forecast Zones

NWS Zones split the coastal, mountainous, central, and northern regions very well. NWS Zones could be combined to form WSI Zones such as:

001, 002 – WSI Zone 1
003, 004 – WSI Zone 2
005, 006 – WSI Zone 3
007, 008 – WSI Zone 4
009, 010 – WSI Zone 5
012, 013 – WSI Zone 6
014, 031 – WSI Zone 7
011, 032 – WSI Zone 8
018, 019 – WSI Zone 9
020, 021 – WSI Zone 10
022, 015 – WSI Zone 11
016, 017 – WSI Zone 12
023, 024 – WSI Zone 13
025, 026, 027, 028 – WSI Zone 14
029, 030 – WSI Zone 15

To build a WSI for each WSI Zone it will be necessary to process historical snowfall data to calculate statistical variables for each zone. Once the historical variables are generated the Winter Severity Index Values can be determined based on seasonal snowfall.

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APPENDIX A

NWS Southern (Portland) Snowfall (in)

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	08.9	13.0	09.2	04.6	03.1	38.8
1981/82	15.9	24.0	25.9	11.0	08.5	85.3
1982/83	00.6	05.7	12.4	24.5	02.1	45.3
1983/84	00.0	12.6	28.3	03.3	26.4	70.6
1984/85	02.4	17.0	12.1	07.2	13.1	51.8
1985/86	03.1	11.2	18.6	12.0	06.4	51.3
1986/87	08.6	04.0	50.7	00.8	14.3	78.4
1987/88	09.6	09.1	19.8	20.8	03.0	62.3
1988/89	00.7	03.5	04.0	13.8	08.9	30.9
1989/90	05.0	15.6	20.4	25.6	03.2	69.8
1990/91	00.2	06.8	13.4	06.3	05.7	32.4
1991/92	10.0	22.5	02.4	10.3	13.4	58.6
1992/93	13.9	02.1	17.1	33.5	49.0	115.6
1993/94	00.2	12.3	39.3	12.2	12.2	76.2
1994/95	02.0	01.0	15.5	17.3	01.4	37.2
1995/96	10.5	37.3	37.1	13.1	25.0	123.0
1996/97	03.6	01.2	20.3	10.5	23.4	59.0
1997/98	20.5	06.3	17.1	00.9	09.7	54.5
1998/99	00.0	11.7	19.2	05.1	17.5	53.5
1999/00	00.0	00.0	14.9	14.6	11.6	41.1
2000/01	00.3	18.8	15.5	24.2	40.5	99.3
2001/02	00.3	05.0	15.8	01.1	10.4	32.6
2002/03	08.6	17.4	18.7	16.8	02.4	63.9
2003/04	01.5	24.0	02.8	12.3	06.1	46.7
2004/05	00.0	08.8	37.3	23.5	32.5	102.1
2005/06	02.8	20.4	13.5	09.5	01.0	47.2
1970/71	09.2	54.8	17.2	35.6	24.7	141.5
1979/80	01.7	01.8	06.0	11.2	06.8	27.5

NWS Mid-Coast (Augusta) Snowfall (in)

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	08.8	08.1	10.1	07.2	06.7	40.9
1981/82	12.7	24.5	24.6	10.6	10.1	82.5
1982/83	01.4	06.9	16.8	21.5	02.0	48.6
1983/84	00.6	12.4	21.7	08.9	30.3	73.9
1984/85	08.5	25.9	14.7	04.5	10.6	64.2
1985/86	08.0	10.9	20.9	14.6	12.8	67.2
1986/87	16.3	05.7	47.0	05.5	16.1	90.6
1987/88	17.4	12.9	17.3	19.1	01.4	68.1
1988/89	04.5	09.8	09.7	15.4	17.2	56.6
1989/90	07.6	20.5	22.8	21.1	05.6	77.6
1990/91	00.1	09.2	20.2	08.4	11.1	49.0
1991/92	12.4	20.9	02.5	20.2	03.2	59.2
1992/93	09.9	03.3	13.3	39.2	40.2	105.9
1993/94	01.6	06.0	39.9	13.7	24.1	85.3
1994/95	04.0	07.4	16.6	28.0	03.2	59.2
1995/96	26.2	40.6	27.9	10.9	27.0	132.6
1996/97	07.4	08.9	19.8	09.5	24.7	70.3
1997/98	12.5	18.8	20.0	04.6	13.2	69.1
1998/99	00.3	12.0	20.8	07.2	31.7	72.0
1999/00	09.0	01.0	21.7	21.1	12.5	65.3
2000/01	02.5	18.8	08.8	37.5	36.2	103.8
2001/02	02.5	17.5	20.6	05.0	08.8	54.4
2002/03	06.2	19.6	23.7	15.4	02.1	67.0
2003/04	01.2	42.0	06.2	18.5	05.6	73.5
2004/05	00.0	08.1	30.2	27.0	23.2	88.5
2005/06	04.4	13.8	19.8	06.6	03.3	47.9
1957/58	15.5	07.1	38.9	35.7	29.9	127.1
1979/80	02.3	03.5	04.5	09.6	08.0	27.9

NWS Western (Farmington) Snowfall (in)

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	12.0	10.0	09.0	06.0	06.0	43.0
1981/82	16.0	33.0	27.0	13.0	17.0	106.0
1982/83	13.0	05.0	12.0	18.0	06.0	54.0
1983/84	05.0	14.0	15.0	14.0	32.0	80.0
1984/85	15.0	32.0	12.0	08.1	13.0	80.1
1985/86	16.0	14.0	24.0	14.0	11.0	79.0
1986/87	20.0	11.0	38.0	09.0	12.0	90.0
1987/88	18.0	18.0	22.0	22.0	02.0	82.0
1988/89	06.0	13.0	16.0	12.0	19.0	66.0
1989/90	16.0	22.0	34.0	21.0	09.0	102.0
1990/91	02.0	20.0	22.0	07.0	16.0	67.0
1991/92	11.0	26.0	04.0	27.0	01.0	69.0
1992/93	13.0	03.0	10.0	51.0	46.0	123.0
1993/94	03.0	11.0	42.0	09.0	30.0	95.0
1994/95	09.0	11.5	22.0	25.0	08.0	75.5
1995/96	32.0	40.0	27.0	17.0	17.0	133.0
1996/97	17.0	09.0	30.0	13.0	29.0	98.0
1997/98	08.3	23.0	15.0	05.0	20.0	71.3
1998/99	01.0	09.0	26.0	14.0	28.0	78.0
1999/00	05.2	00.1	22.0	22.0	13.0	62.3
2000/01	12.0	24.5	11.4	38.3	58.3	144.5
2001/02	15.0	14.1	28.7	06.6	16.1	80.5
2002/03	19.2	04.8	21.9	11.5	11.5	68.9
2003/04	02.1	55.5	07.3	18.0	04.5	87.4
2004/05	02.1	13.0	14.4	31.1	34.3	94.9
2005/06	11.7	11.6	23.8	01.0	03.5	51.6
1968/69	26.0	23.0	31.0	67.0	17.0	164.0
1979/80	06.0	05.1	07.0	10.0	16.0	44.1

NWS Eastern (Bangor) Snowfall (in)

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	11.8	11.9	14.9	07.9	02.7	49.2
1981/82	16.9	22.6	28.9	15.1	13.1	96.6
1982/83	00.7	10.8	10.8	18.0	01.9	42.2
1983/84	03.6	06.1	31.5	06.4	28.1	75.7
1984/85	07.4	24.3	08.7	03.6	08.3	52.3
1985/86	03.4	12.5	20.1	17.4	11.6	65.0
1986/87	08.7	03.5	46.7	07.4	22.2	88.5
1987/88	19.1	14.0	21.0	19.0	04.6	77.7
1988/89	08.1	04.6	10.7	19.5	13.3	58.2
1989/90	03.1	22.3	22.4	22.2	06.6	76.6
1990/91	00.4	07.4	12.5	04.7	10.0	35.0
1991/92	08.2	19.6	02.2	24.2	00.5	54.7
1992/93	09.5	06.9	07.4	27.7	34.3	85.8
1993/94	00.0	02.6	35.6	07.1	21.0	66.3
1994/95	05.5	01.0	29.0	20.5	05.0	61.0
1995/96	21.0	25.5	19.3	21.0	34.0	120.8
1996/97	02.0	01.0	09.5	02.0	21.0	35.5
1997/98	21.5	16.5	23.3	00.0	23.5	84.8
1998/99	00.0	10.0	13.0	06.0	28.0	57.0
1999/00	00.5	01.5	23.5	13.0	14.0	52.5
2000/01	10.0	14.8	17.0	22.5	24.0	88.3
2001/02	07.0	20.0	32.0	05.0	08.0	72.0
2002/03	18.2	06.2	12.8	17.1	08.0	62.3
2003/04	03.0	26.2	09.1	12.8	09.6	60.7
2004/05	00.3	03.1	23.6	29.3	19.0	75.3
2005/06	04.0	11.3	11.6	07.6	04.9	39.4
1962/63	41.6	47.5	28.9	38.1	25.8	181.9
1979/80	01.0	01.8	02.1	10.3	07.0	22.2

NWS Northern (Caribou) Snowfall (in)

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	13.8	28.9	35.2	08.6	36.4	122.9
1981/82	43.8	34.3	30.9	25.1	23.7	158.8
1982/83	19.4	04.0	22.8	22.8	13.9	82.9
1983/84	25.1	26.6	27.3	20.1	35.4	134.5
1984/85	10.9	30.7	10.5	26.8	11.9	90.8
1985/86	26.1	18.3	30.0	11.9	18.6	104.9
1986/87	33.7	08.5	26.4	04.1	12.3	85.0
1987/88	11.6	22.6	32.1	28.2	03.9	98.4
1988/89	24.4	11.5	18.4	16.6	11.9	82.8
1989/90	25.7	38.0	28.5	18.3	07.6	118.1
1990/91	14.5	22.6	21.5	12.2	24.0	94.8
1991/92	17.0	19.4	14.8	38.6	04.2	94.0
1992/93	12.8	15.9	05.6	22.8	23.4	80.5
1993/94	20.2	13.9	44.5	20.3	28.8	127.7
1994/95	17.7	25.9	31.0	40.9	15.7	132.3
1995/96	27.7	25.1	18.4	22.7	16.5	110.4
1996/97	21.9	14.4	35.5	30.2	28.9	130.9
1997/98	27.0	37.3	39.9	08.8	11.0	124.0
1998/99	21.4	21.9	36.7	18.5	30.3	128.8
1999/00	14.1	06.7	43.7	32.5	15.4	112.4
2000/01	24.1	32.7	14.2	30.5	30.6	132.1
2001/02	13.2	04.2	26.0	23.1	21.6	91.2
2002/03	24.7	15.0	15.2	39.1	23.3	117.3
2003/04	14.5	43.0	23.8	11.9	08.7	101.9
2004/05	16.8	24.2	24.5	25.4	37.6	128.5
2005/06	23.7	43.4	19.7	07.8	01.4	96.0
1954/55	07.3	49.4	38.5	38.8	47.1	181.1
1961/62	22.9	08.9	12.7	16.3	07.7	68.5

APPENDIX B

NWS Daily Point Values for Caribou, Maine the month of February, 1996

	Temperature (°F)			Prcp	Snfl	Point Values		
day	Tmax	Tmin	Tmean	(in.)	(in.)	Snfl	Temp	Total
1	2	-14	-6	T	T			
2	14	-20	-3	0.01	0.1			
3	2	-15	-6	0	0			
4	-1	-23	-12	0	0			
5	4	-22	-9	T	T			
6	12	-8	2	T	T			
7	22	-11	6	0.01	0.1			
8	33	22	28	0.07	0.7	10	1	11
9	34	26	30	0.68	6.8			
10	29	12	21	0.03	0.3			
11	17	-1	8	0.18	2.9	2	1	3
12	16	-9	4	T	T			
13	2	-15	-6	T	T			
14	12	-18	-3	0	0			
15	17	-6	6	T	T			
16	23	-8	8	0.18	3.6	10	2	12
17	20	16	18	0.2	3.9			
18	17	-3	7	0	0			
19	13	-13	0	0	0			
20	37	11	24	T	T			
21	43	36	40	0.04	0			
22	42	37	40	0.22	0			
23	43	34	39	T	0			
24	38	35	37	0.7	0			
25	37	32	35	0.23	2.1	2		2
26	34	26	30	0.03	0.3			
27	35	21	28	0	0			
28	27	14	21	0.11	1.9	1		1
29	15	5	10	0	0			
					Total	25	4	29

Appendix C

NWS Southern (Portland) Point Summary

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	13	14	11	06	02	46
1981/82	28	26	33	14	09	110
1982/83	01	07	14	37	02	61
1983/84	00	14	40	03	40	97
1984/85	02	18	12	08	17	57
1985/86	01	11	22	12	07	53
1986/87	08	04	77	01	17	107
1987/88	09	10	30	32	02	83
1988/89	00	02	03	17	09	31
1989/90	04	22	26	34	02	88
1990/91	00	08	17	07	08	40
1991/92	09	32	01	11	18	70
1992/93	17	01	20	48	64	150
1993/94	00	17	57	14	12	100
1994/95	02	01	19	26	01	49
1995/96	11	43	53	17	34	158
1996/97	03	01	24	13	28	69
1997/98	28	08	23	01	12	72
1998/99	00	15	23	07	20	65
1999/00	00	00	20	22	12	54
2000/01	00	23	18	34	57	132
2001/02	00	06	17	02	12	37
2002/03	09	30	24	22	01	86
2003/04	01	34	03	15	08	61
2004/05	00	10	50	32	51	143
2005/06	03	31	15	11	01	61
1970/71	10	97	21	48	23	199
1979/80	00	02	08	13	08	31
					Xmn =	31.0
					Q1 =	53.0
					Mid =	70.0
					Xavg=	83.3
					Med =	115.0
					Q3 =	107.0
					Xmx =	199.0
					Sig =	42.3
					XM =	89.0
					S - =	18.0
					S+ =	34.0

NWS Mid-Coast (Augusta) Point Summary

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	14	07	12	10	07	50
1981/82	20	30	33	11	10	104
1982/83	01	08	21	32	02	64
1983/84	01	18	35	10	44	108
1984/85	09	32	17	05	16	79
1985/86	07	16	34	16	18	91
1986/87	20	05	71	06	21	123
1987/88	21	18	26	29	01	95
1988/89	03	11	11	16	19	60
1989/90	06	30	33	29	07	105
1990/91	00	10	29	09	14	62
1991/92	12	29	02	24	03	70
1992/93	10	02	20	61	58	151
1993/94	02	06	63	16	29	106
1994/95	04	08	22	43	03	80
1995/96	32	59	38	13	42	184
1996/97	07	09	24	11	31	82
1997/98	15	23	25	05	15	83
1998/99	00	13	28	07	51	99
1999/00	12	01	31	31	17	92
2000/01	02	29	11	56	52	150
2001/02	02	24	23	07	13	69
2002/03	08	32	33	22	02	97
2003/04	01	78	06	28	05	118
2004/05	00	09	42	37	33	121
2005/06	06	18	23	11	03	61
1957/58	12	08	55	50	42	172
1979/80	00	04	06	12	11	33

Xmn =	33.0
Q1 =	70.0
Mid =	95.0
Xavg=	98.1
Med =	108.5
Q3 =	118.0
Xmx =	184.0
Sig =	35.6
XM =	100.0
S - =	24.0
S+ =	28.0

NWS Western (Farmington) Point Summary

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	19	14	14	08	07	62
1981/82	23	49	43	17	23	155
1982/83	17	06	17	28	09	77
1983/84	06	18	22	20	58	124
1984/85	21	46	17	10	21	105
1985/86	18	22	36	20	16	112
1986/87	29	15	58	13	20	135
1987/88	25	27	31	34	02	119
1988/89	07	19	22	16	27	91
1989/90	22	36	51	34	14	157
1990/91	02	30	33	09	23	97
1991/92	14	40	04	39	01	98
1992/93	20	03	14	87	75	199
1993/94	03	16	71	11	44	145
1994/95	11	16	31	41	10	109
1995/96	39	62	41	25	25	192
1996/97	22	14	49	20	42	147
1997/98	09	32	21	07	30	99
1998/99	01	12	41	18	41	113
1999/00	05	00	33	32	18	88
2000/01	17	38	16	66	79	216
2001/02	17	19	36	07	25	104
2002/03	26	05	37	14	15	97
2003/04	02	136	09	26	08	181
2004/05	03	18	18	50	54	143
2005/06	13	14	34	02	04	67
1968/69	33	34	51	148	63	289
1979/80	02	06	10	15	25	58
					Xmn =	58.0
					Q1 =	97.0
					Mid =	113.0
					Xavg =	130.1
					Med =	173.5
					Q3 =	155.0
					Xmx =	289.0
					Sig =	50.9
					XM =	138.0
					S - =	26.0
					S+ =	44.0

NWS Eastern (Bangor) Point Summary

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	16	14	17	12	03	62
1981/82	25	27	36	19	14	121
1982/83	01	12	12	28	01	54
1983/84	03	07	43	06	46	105
1984/85	10	31	10	04	11	66
1985/86	03	14	31	24	14	86
1986/87	07	04	72	08	28	119
1987/88	26	18	28	29	05	106
1988/89	09	04	15	26	16	70
1989/90	21	15	32	33	09	110
1990/91	00	09	16	05	14	44
1991/92	08	27	02	29	01	67
1992/93	15	09	12	39	55	120
1993/94	00	03	50	08	28	89
1994/95	07	02	45	31	07	92
1995/96	28	45	27	29	53	182
1996/97	02	01	12	03	28	46
1997/98	32	21	33	00	35	121
1998/99	00	11	20	09	44	84
1999/00	01	02	37	19	15	74
2000/01	12	18	22	33	34	119
2001/02	09	28	44	06	10	97
2002/03	24	09	19	23	10	85
2003/04	03	41	08	18	14	84
2004/05	00	03	31	52	29	115
2005/06	03	14	13	08	05	43
1962/63	65	89	38	57	36	285
1979/80	00	02	02	13	07	24
					Xmn =	24.0
					Q1 =	67.0
					Mid =	89.0
					Xavg=	97.3
					Med =	154.5
					Q3 =	119.0
					Xmx =	285.0
					Sig =	48.9
					XM =	113.0
					S - =	30.0
					S+ =	45.0

NWS Northern (Caribou) Point Summary

Season	Other Months	Dec	Jan	Feb	Mar	Total
1980/81	13	35	52	12	63	175
1981/82	78	47	41	33	30	229
1982/83	24	03	32	33	18	110
1983/84	28	37	35	28	77	205
1984/85	15	42	13	42	14	126
1985/86	33	24	48	15	25	145
1986/87	57	10	35	04	14	120
1987/88	13	26	47	48	03	137
1988/89	28	13	23	23	13	100
1989/90	31	63	36	23	06	159
1990/91	18	30	26	15	31	120
1991/92	15	26	31	42	19	133
1992/93	15	21	07	32	34	109
1993/94	22	19	76	34	35	186
1994/95	24	34	46	70	20	194
1995/96	31	33	22	29	20	135
1996/97	23	14	47	37	55	176
1997/98	28	43	51	09	13	147
1998/99	23	25	61	29	40	178
1999/00	11	09	59	55	21	155
2000/01	31	45	18	44	50	188
2001/02	20	06	31	29	30	116
2002/03	34	20	18	74	25	173
2003/04	12	83	37	15	11	158
2004/05	21	31	31	41	61	185
2005/06	22	89	24	08	01	144
1954/55	09	68	51	61	63	250
1961/62	21	09	13	21	08	72

Xmn =	72.0
Q1 =	120.0
Mid =	155.0
Xavg =	154.9
Med =	161.0
Q3 =	185.0
Xmx =	250.0
Sig =	40.5
XM =	156.0
S - =	32.0
S+ =	32.0

APPENDIX D

NWS Regional Z Values

	Region				
Season	Southern	Mid-Coast	Western	Eastern	Northern
1980/81	- 2.39	- 2.08	- 2.92	- 1.70	+0.59
1981/82	+0.62	+0.14	+0.39	+0.18	+2.28
1982/83	- 1.56	- 1.50	- 2.34	- 1.97	- 1.44
1983/84	+0.24	+0.29	- 0.54	- 0.27	+1.53
1984/85	- 1.78	- 0.88	- 1.27	- 1.56	- 0.94
1985/86	- 2.00	- 0.38	- 1.00	- 0.90	- 0.34
1986/87	+0.53	+0.82	- 0.12	+0.13	- 1.13
1987/88	- 0.33	- 0.21	- 0.73	- 0.14	- 0.59
1988/89	- 3.22	- 1.67	- 1.81	- 1.43	- 1.75
1989/90	- 0.06	+0.18	+0.43	- 0.10	+0.09
1990/91	- 2.72	- 1.58	- 1.58	- 2.30	- 1.13
1991/92	- 1.06	- 1.25	- 1.54	- 1.53	- 0.72
1992/93	+1.79	+1.82	+1.39	+0.16	- 1.47
1993/94	+0.32	+0.21	+0.16	- 0.80	+0.94
1994/95	- 2.22	- 0.71	- 1.12	- 0.70	+1.18
1995/96	+2.03	+3.00	+1.23	+1.53	- 0.66
1996/97	- 1.11	- 0.75	+0.20	- 2.23	+0.61
1997/98	- 0.94	- 0.71	- 1.50	+0.18	- 0.28
1998/99	- 1.33	- 0.04	- 0.96	- 0.97	+0.69
1999/00	- 1.94	- 0.33	- 1.92	- 1.30	- 0.03
2000/01	+1.26	+1.79	+1.77	+0.13	+1.00
2001/02	- 2.89	- 1.29	- 1.31	- 0.53	- 1.25
2002/03	- 0.17	- 0.13	- 1.58	- 0.94	+0.53
2003/04	- 1.56	+0.64	+0.98	- 0.97	+0.06
2004/05	+1.59	+0.75	+0.11	+0.04	+0.91
2005/06	- 1.56	- 1.63	- 2.73	- 2.33	- 0.38
Hi Year	+3.24	+2.57	+3.43	+3.82	+2.94
Low Year	- 3.22	- 2.79	- 3.07	- 2.96	- 2.63

APPENDIX E

NWS Regional Winter Severity Index Values

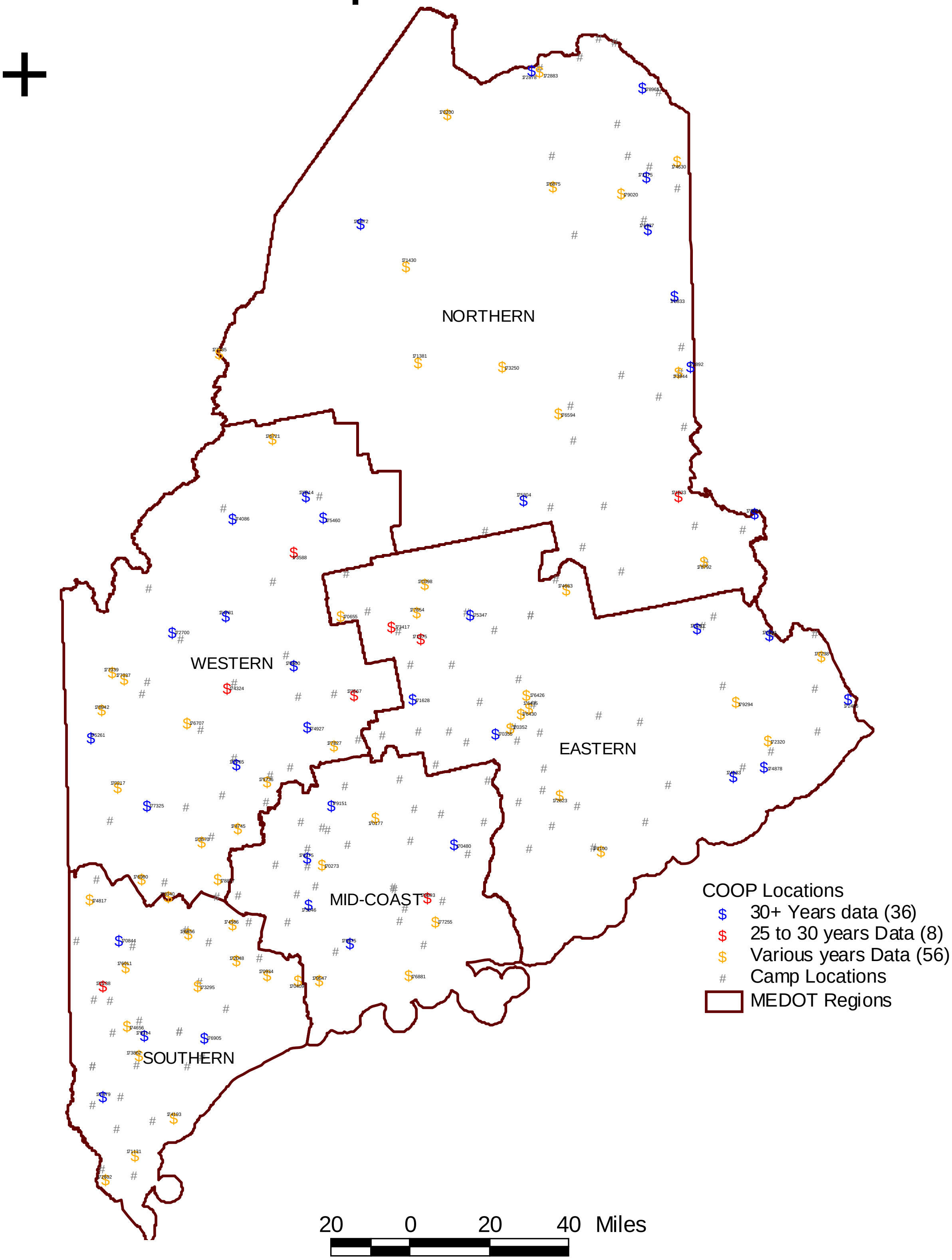
	Region				
Season	Southern	Mid-Coast	Western	Eastern	Northern
1980/81	07	11	01	16	64
1981/82	64	54	60	55	91
1982/83	18	19	08	13	20
1983/84	56	57	37	43	81
1984/85	15	30	23	18	29
1985/86	12	41	28	30	42
1986/87	63	68	47	53	26
1987/88	42	45	33	47	36
1988/89	00	17	15	20	15
1989/90	49	55	61	48	52
1990/91	03	18	18	08	26
1991/92	27	23	18	19	34
1992/93	85	86	79	54	20
1993/94	58	55	54	32	70
1994/95	09	34	26	34	76
1995/96	88	100	76	81	35
1996/97	26	33	55	09	64
1997/98	29	34	19	55	43
1998/99	22	49	29	29	66
1999/00	13	42	13	23	49
2000/01	77	85	85	53	72
2001/02	01	23	22	37	23
2002/03	46	47	18	29	63
2003/04	18	65	72	29	52
2004/05	82	67	53	51	70
2005/06	18	17	03	08	41
Hi Year	102	95	104	108	99
Low Year	- 02	02	- 01	01	05

Qualitative Threshold Index Rating Scheme

Index Value	Snow Removal Rating
< 10	"Extremely Mild"
10 - 19	"Very Mild"
20 - 29	"Mild"
30 - 39	"Moderate"
40 - 49	"Average"
50 - 62	"Hard"
63 - 74	"Severe"
75 - 87	"Very Severe"
> 88	"Extremely Severe"

APPENDIX F

Maintenance Camp and Weather Data Locations



APPENDIX G

WSI Comparison of NWS and DOT Generated Values

	Region									
	Southern		Mid-Coast		Western		Eastern		Northern	
Season	NWS	DOT	NWS	DOT	NWS	DOT	NWS	DOT	NWS	DOT
1980/81	7	8	11	9	1	-3	16	15	64	68
1981/82	64	62	54	51	60	57	55	55	91	93
1982/83	18	20	19	19	8	3	13	10	20	22
1983/84	56	51	57	57	37	37	43	49	81	85
1984/85	15	14	30	38	23	25	18	19	29	25
1985/86	12	22	41	39	28	23	30	30	42	42
1986/87	63	61	68	70	47	44	53	55	26	23
1987/88	42	39	45	43	33	30	47	45	36	32
1988/89	0	-3	17	15	15	10	20	22	15	13
1989/90	49	55	55	56	61	62	48	45	52	45
1990/91	3	3	18	19	18	14	8	8	26	24
1991/92	27	31	23	24	18	13	19	21	34	24
1992/93	85	89	86	88	79	79	54	57	20	19
1993/94	58	56	55	62	54	55	32	36	70	63
1994/95	9	8	34	31	26	23	34	20	76	75
1995/96	88	87	100	99	76	78	81	75	35	38
1996/97	26	-2	33	25	55	56	9	21	64	62
1997/98	29	36	34	6	19	15	55	56	43	57
1998/99	22	25	49	44	29	30	29	51	66	63
1999/00	13	13	42	43	13	10	23	38	49	50
2000/01	77	77	85	75	85	89	53	57	72	70
2001/02	1	0	23	13	22	19	37	29	23	20
2002/03	46	43	47	50	18	14	29	29	63	57
2003/04	18	23	65	49	72	70	29	31	52	49
2004/05	82	81	67	68	53	51	51	50	70	68
2005/06	18	19	17	8	3	0	8	8	41	38
Hi Year	102	102	95	98	104	103	108	109	99	101
Low Year	-2	0	2	0	-1	-3	1	1	5	4

Qualitative Threshold Index Rating Scheme

Index Value	Snow Removal Rating
< 10	"Extremely Mild"
10 - 19	"Very Mild"
20 - 29	"Mild"
30 - 39	"Moderate"
40 - 49	"Average"
50 - 62	"Hard"
63 - 74	"Severe"
75 - 87	"Very Severe"
> 88	"Extremely Severe"

APPENDIX H

WSI Comparison of DOT and Modified Freezing Rain Generated Values

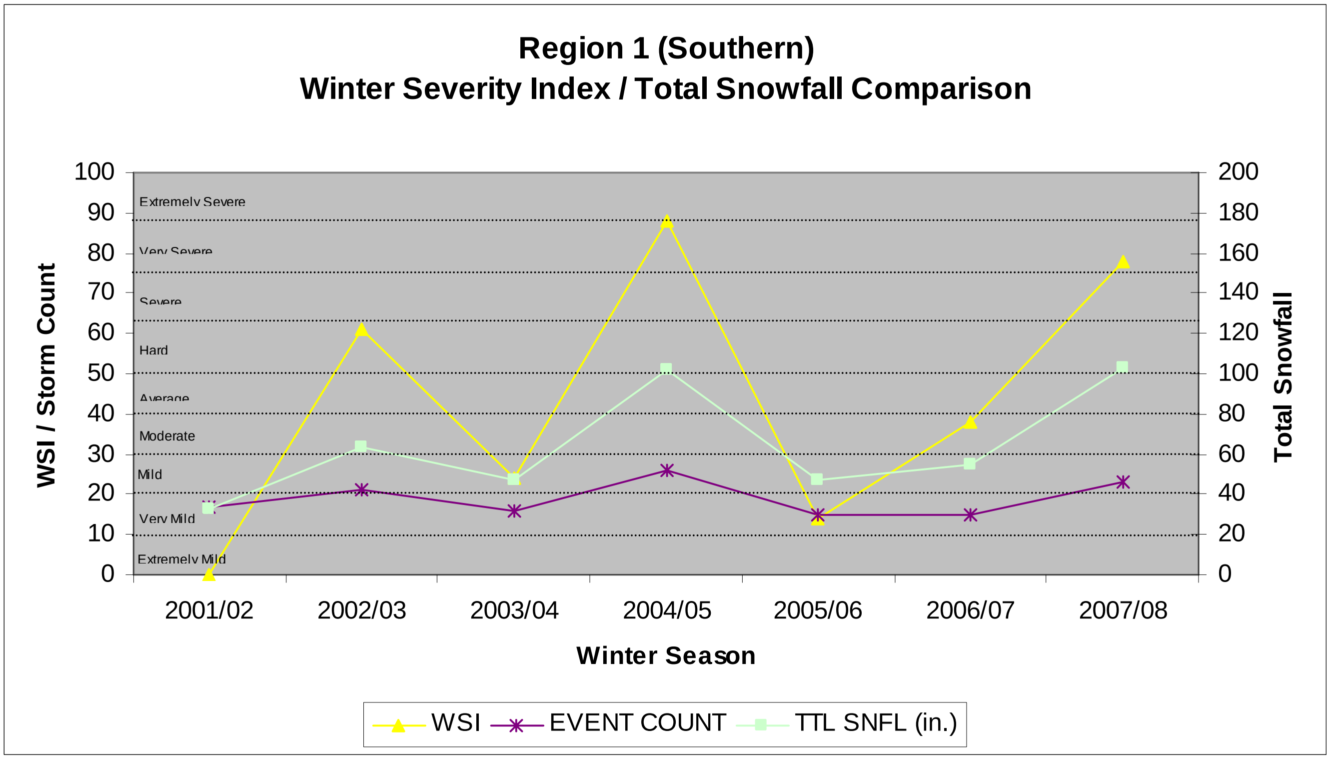
	Region									
	Northern		Western		Eastern		Mid-Coast		Southern	
Season	DOT	MFZRA	DOT	MFZRA	DOT	MFZRA	DOT	MFZRA	DOT	MFZRA
1980/81	68	61	-3	6	15	14	9	8	8	7
1981/82	93	91	57	63	55	50	51	56	62	69
1982/83	22	29	3	4	10	10	19	15	20	15
1983/84	85	91	37	45	49	56	57	57	51	50
1984/85	25	29	25	23	19	19	38	38	14	13
1985/86	42	39	23	31	30	30	39	36	22	23
1986/87	23	25	44	43	55	51	70	69	61	55
1987/88	32	33	30	29	45	49	43	39	39	31
1988/89	13	15	10	12	22	23	15	19	-3	-4
1989/90	45	45	62	57	45	49	56	51	55	51
1990/91	24	29	14	24	8	11	19	21	3	3
1991/92	24	24	13	19	21	20	24	23	31	24
1992/93	19	20	79	79	57	51	88	87	89	88
1993/94	63	64	55	56	36	30	62	63	56	56
1994/95	75	79	23	23	20	23	31	50	8	11
1995/96	38	43	78	77	75	71	99	97	87	81
1996/97	62	64	56	62	21	20	25	36	-2	3
1997/98	57	62	15	44	56	69	6	25	36	62
1998/99	63	63	30	29	51	51	44	45	25	23
1999/00	50	55	10	12	38	49	43	39	13	12
2000/01	70	71	89	86	57	61	75	76	77	77
2001/02	20	23	19	19	29	30	13	32	0	0
2002/03	57	55	14	21	29	37	50	57	43	61
2003/04	49	51	70	69	31	30	49	38	23	24
2004/05	68	70	51	56	50	45	68	63	81	88
2005/06	38	38	0	5	8	7	8	10	19	14
2006/07	45	45	62	57	24	23	55	57	25	38
2007/08	109	111	77	80	62	57	87	89	78	78
Hi	101	100	103	105	109	108	98	102	102	102
Low	4	5	-3	-2	1	0	0	0	0	-2

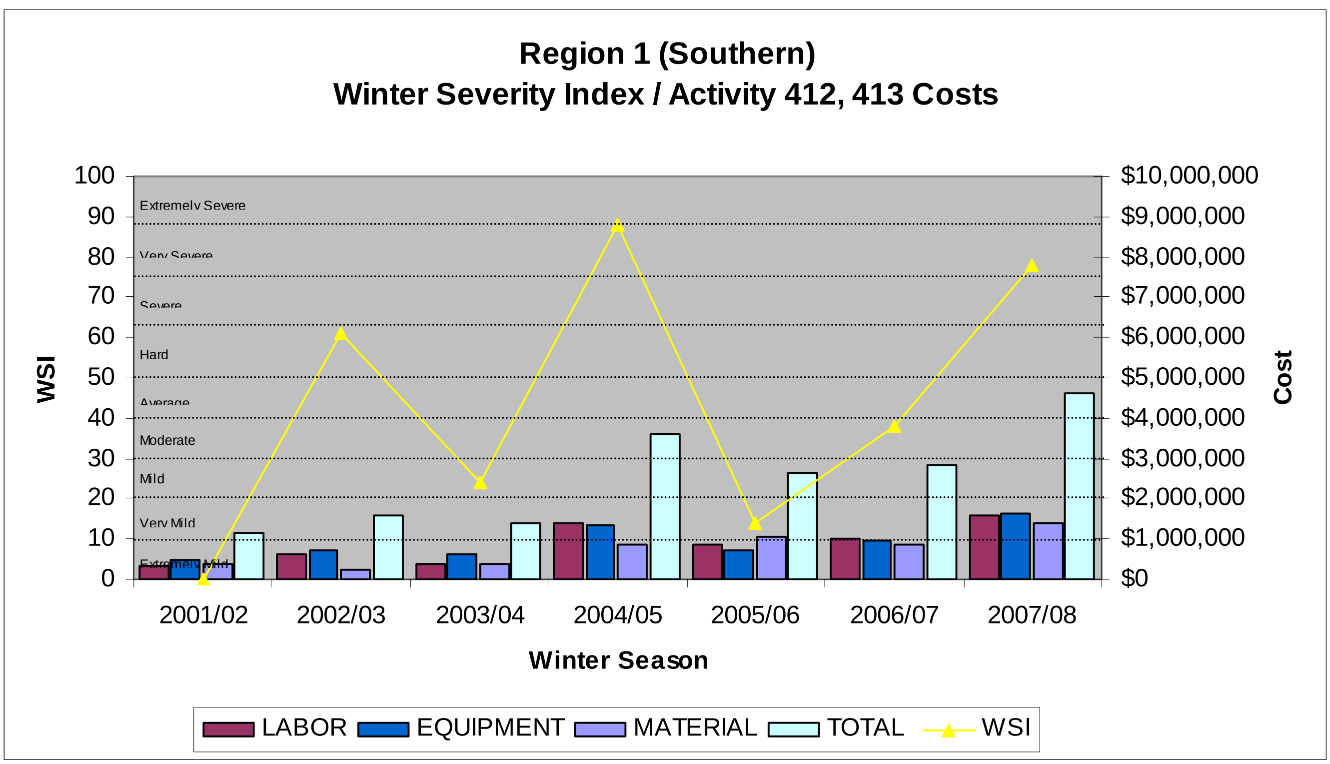
Qualitative Threshold Index Rating Scheme

Index Value	Snow Removal Rating
< 10	"Extremely Mild"
10 - 19	"Very Mild"
20 - 29	"Mild"
30 - 39	"Moderate"
40 - 49	"Average"
50 - 62	"Hard"
63 - 74	"Severe"
75 - 87	"Very Severe"
> 88	"Extremely Severe"

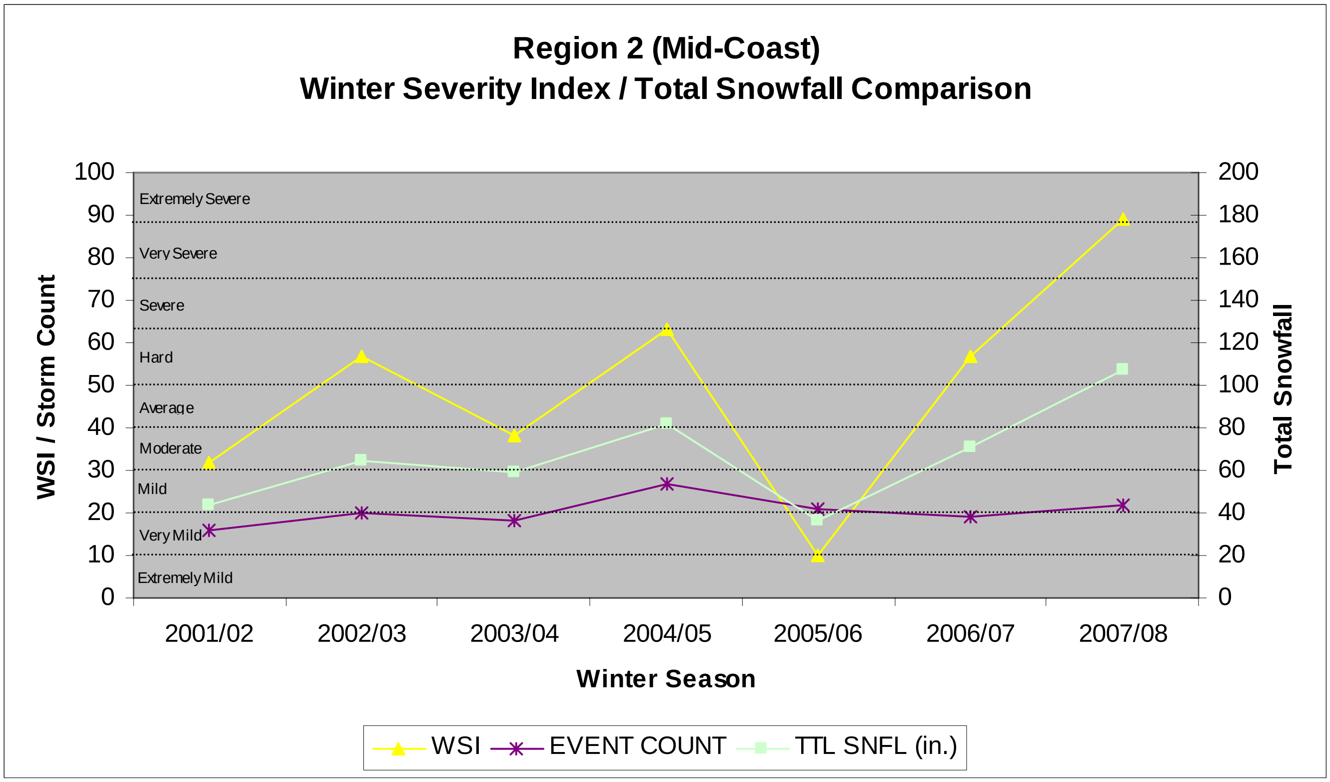
APPENDIX I

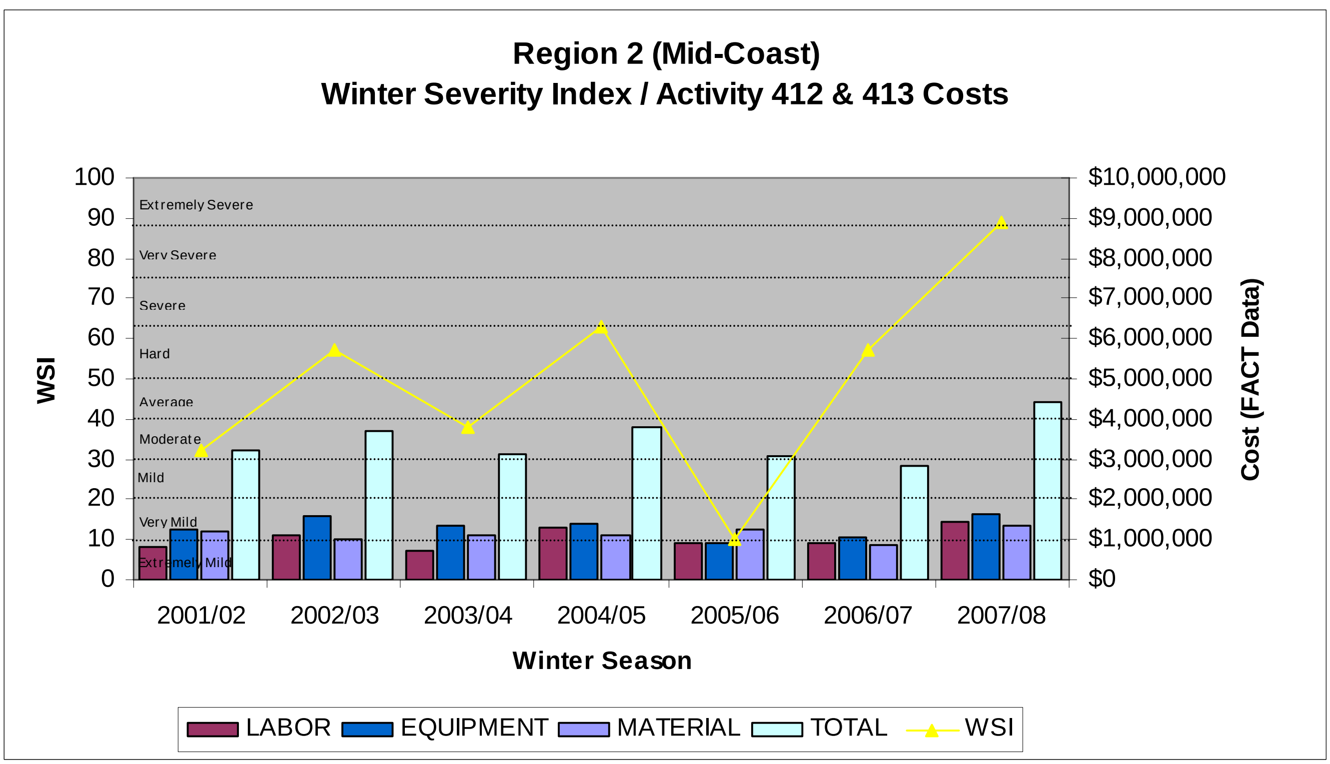
Southern Region



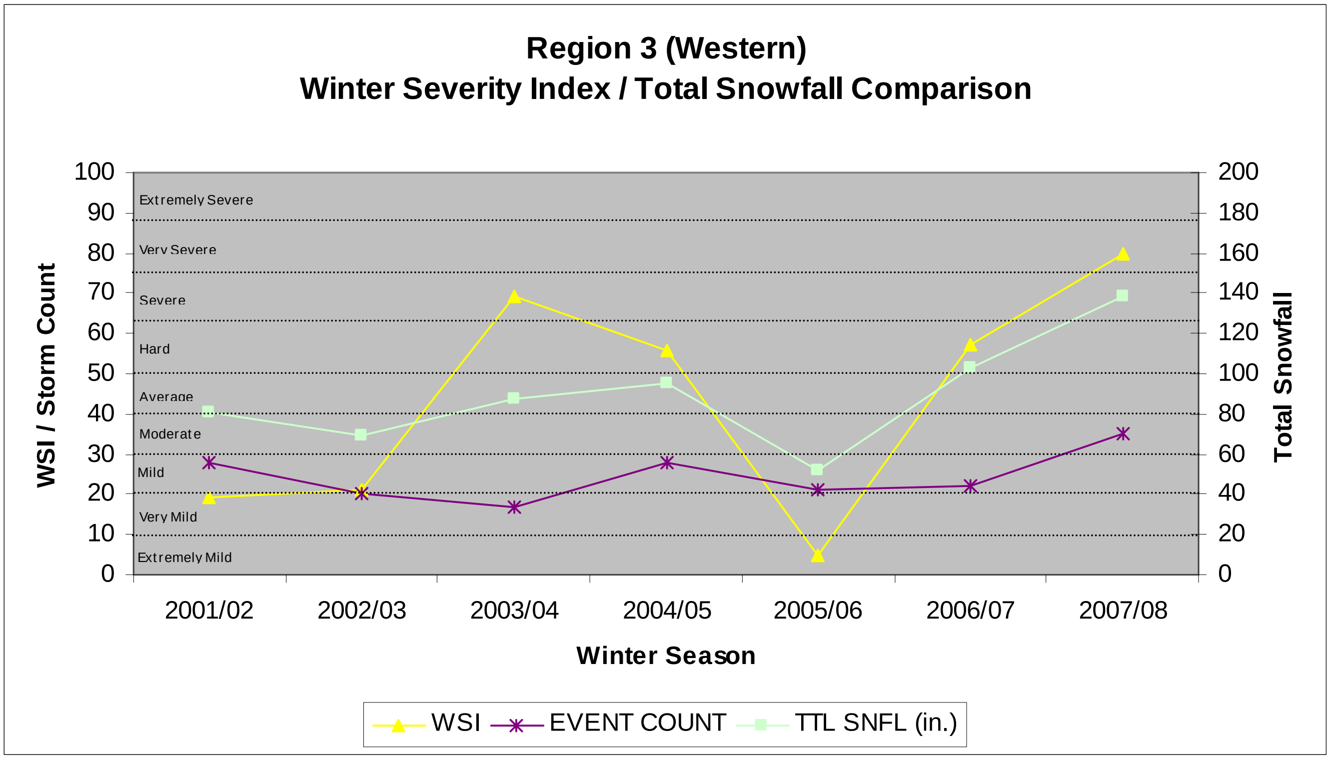


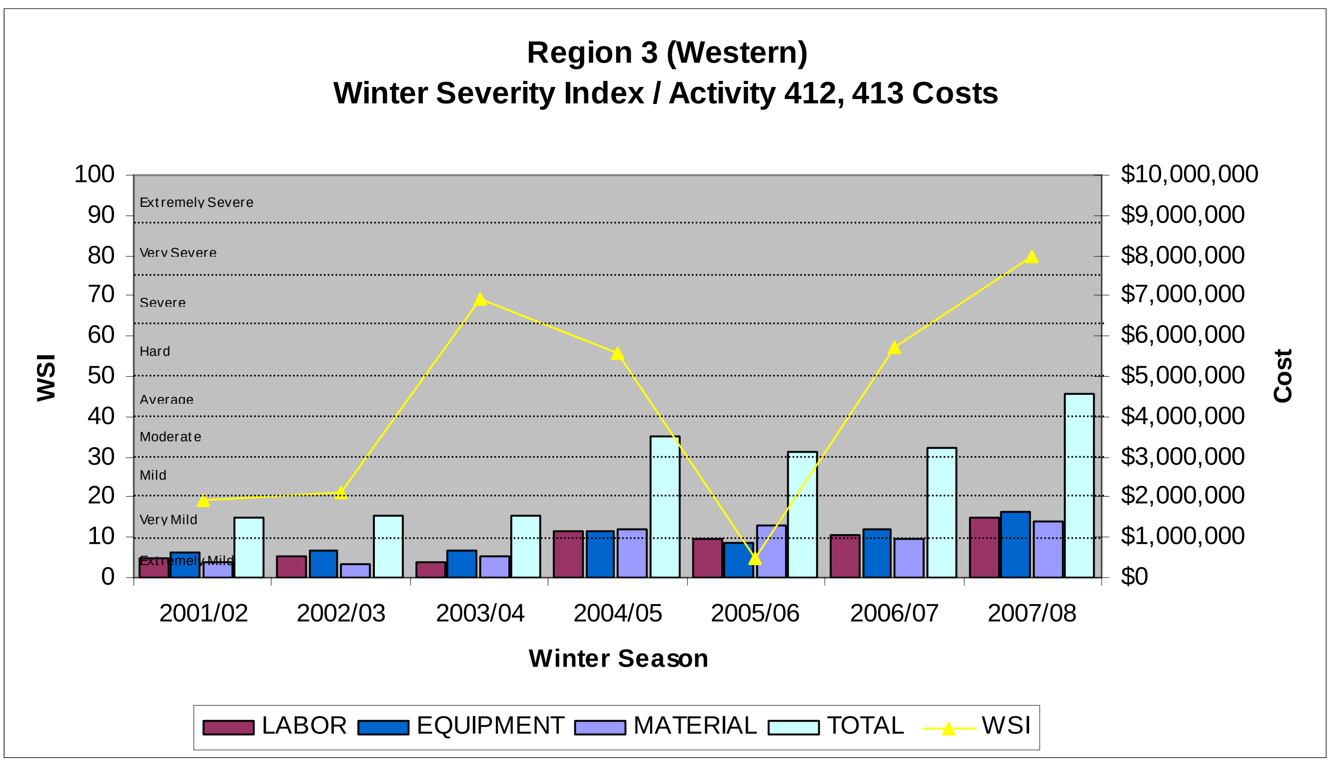
Mid-Coast Region



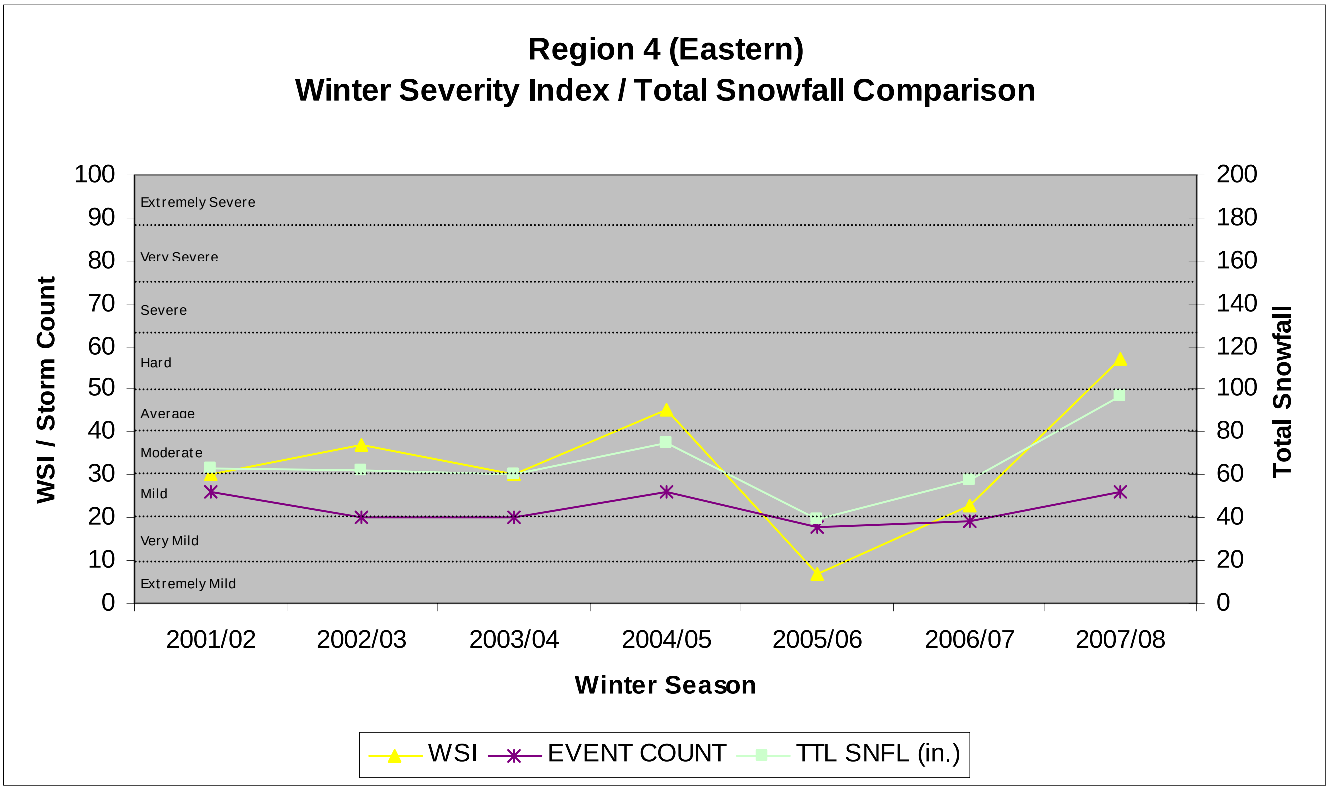


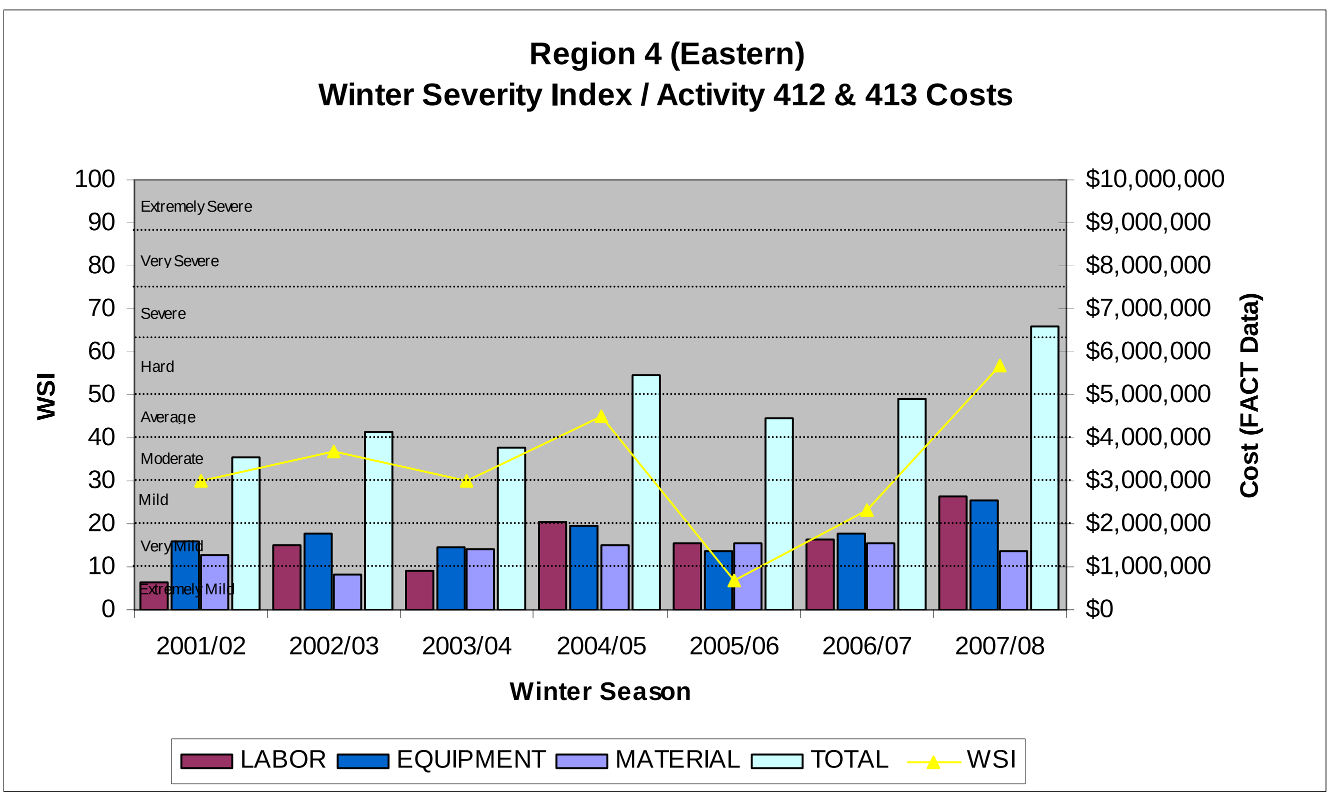
Western Region



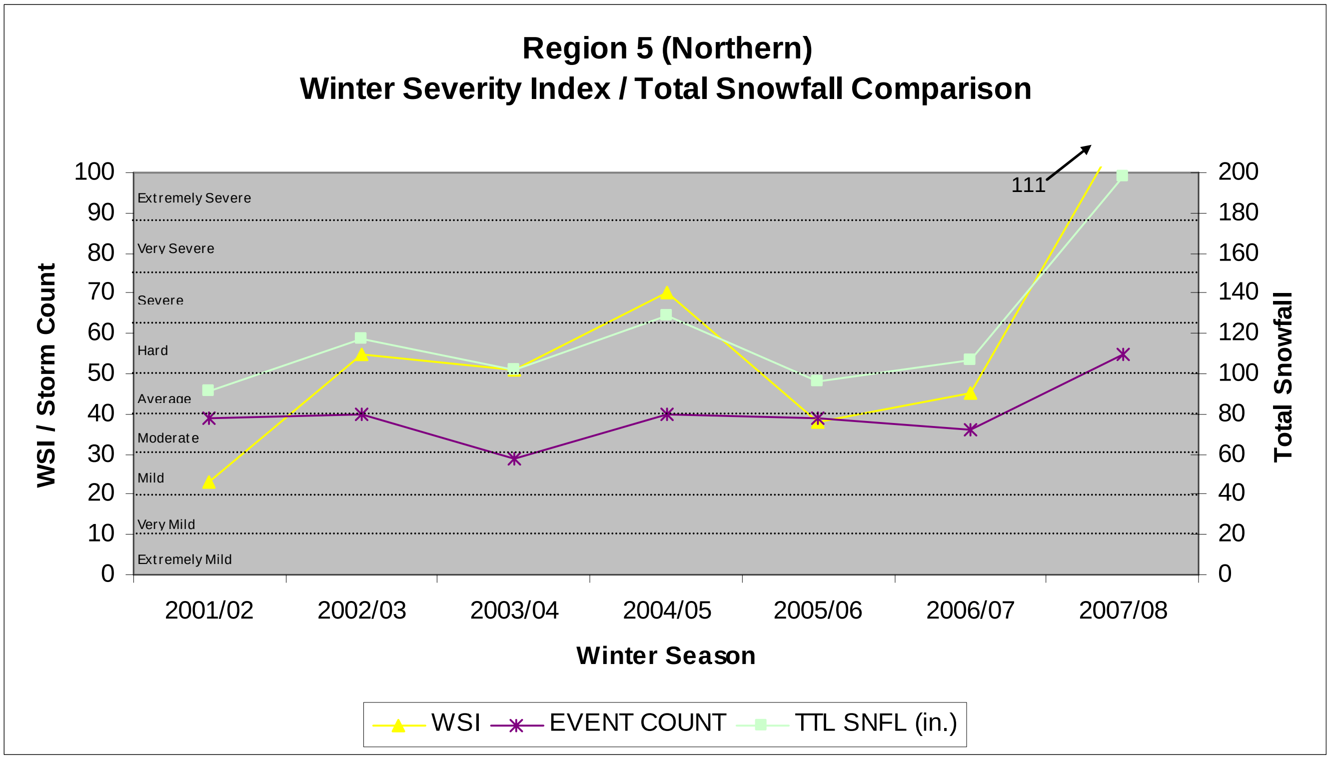


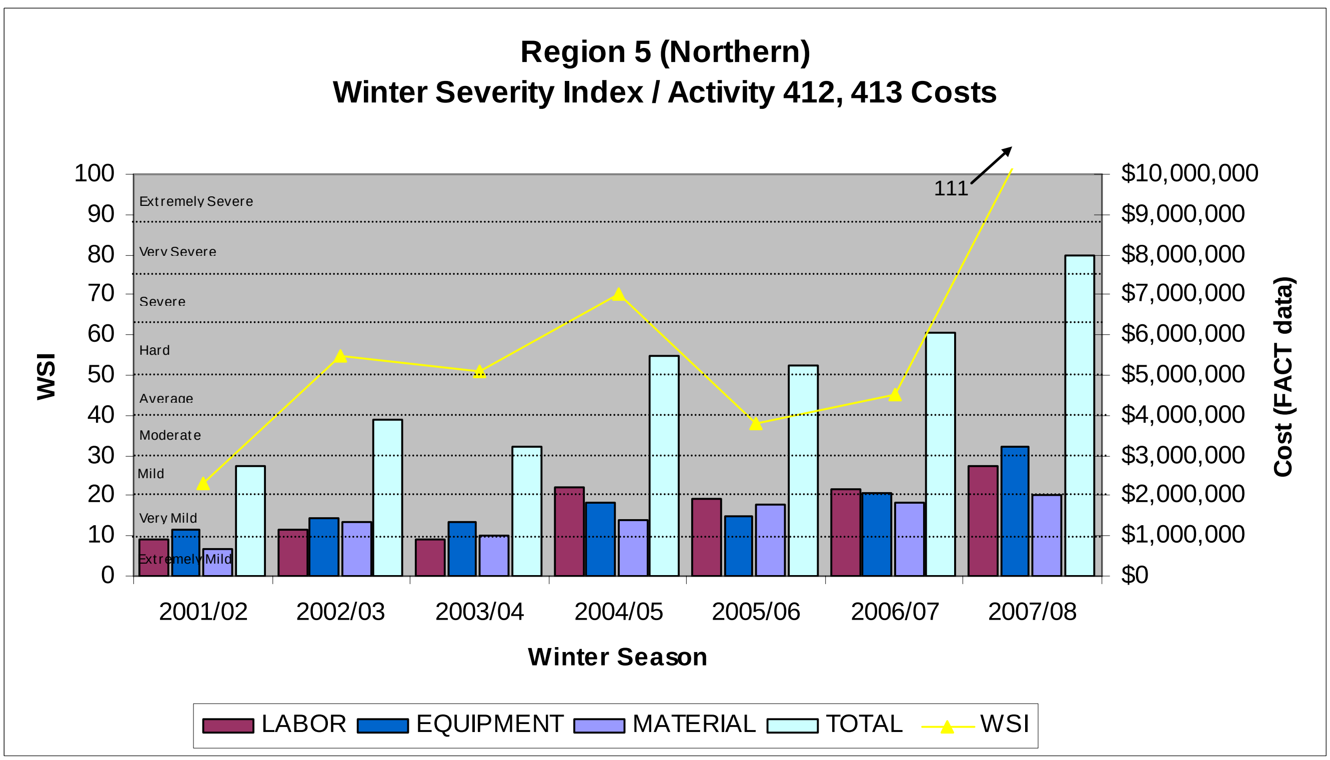
Eastern Region





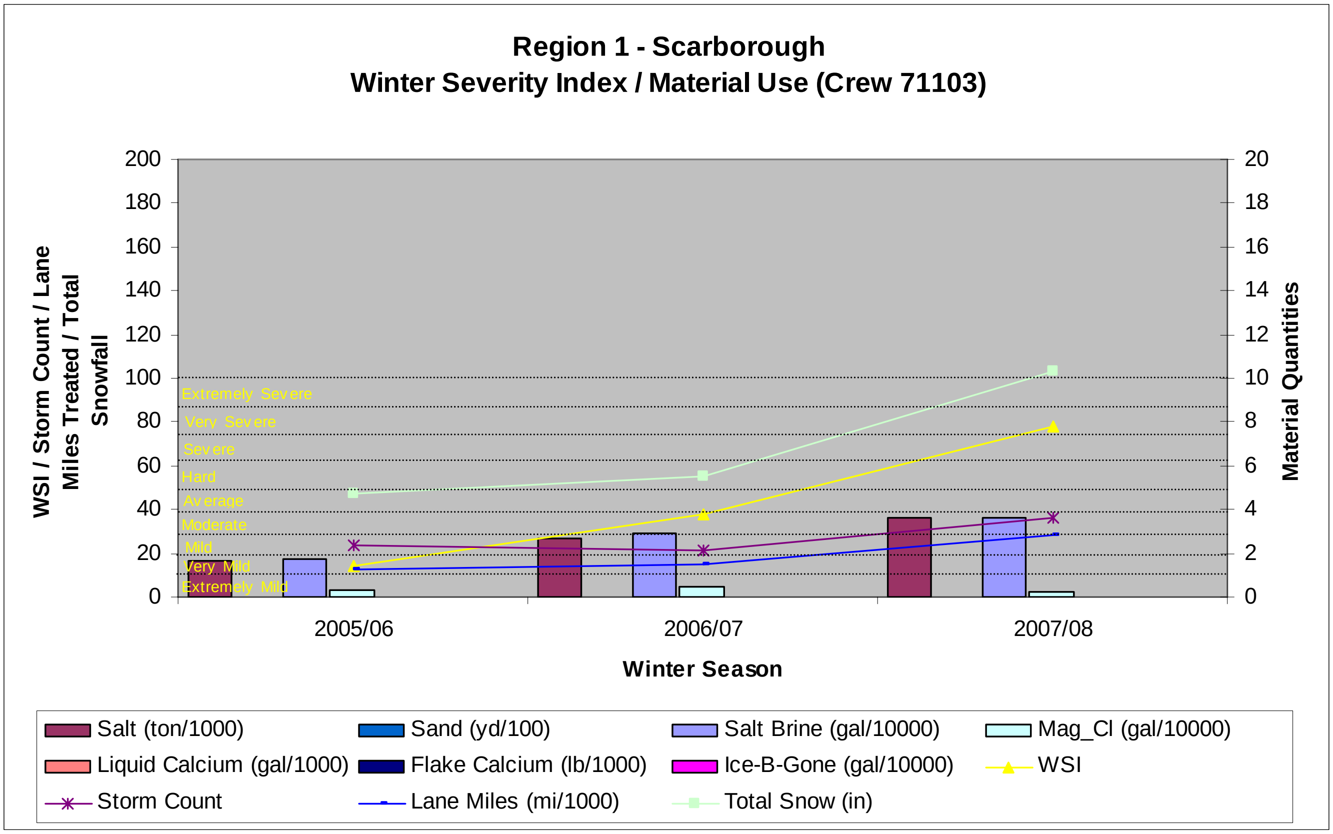
Northern Region



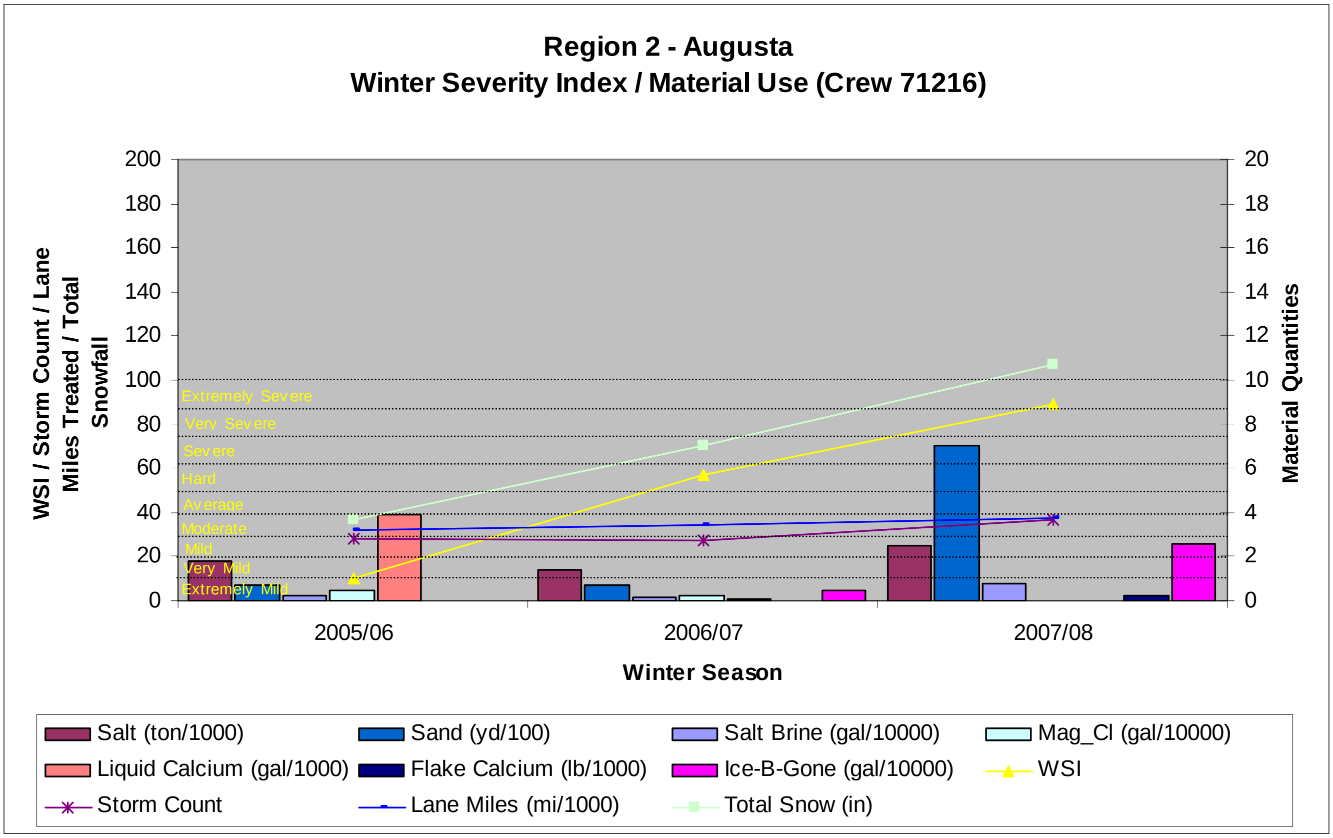


APPENDIX J

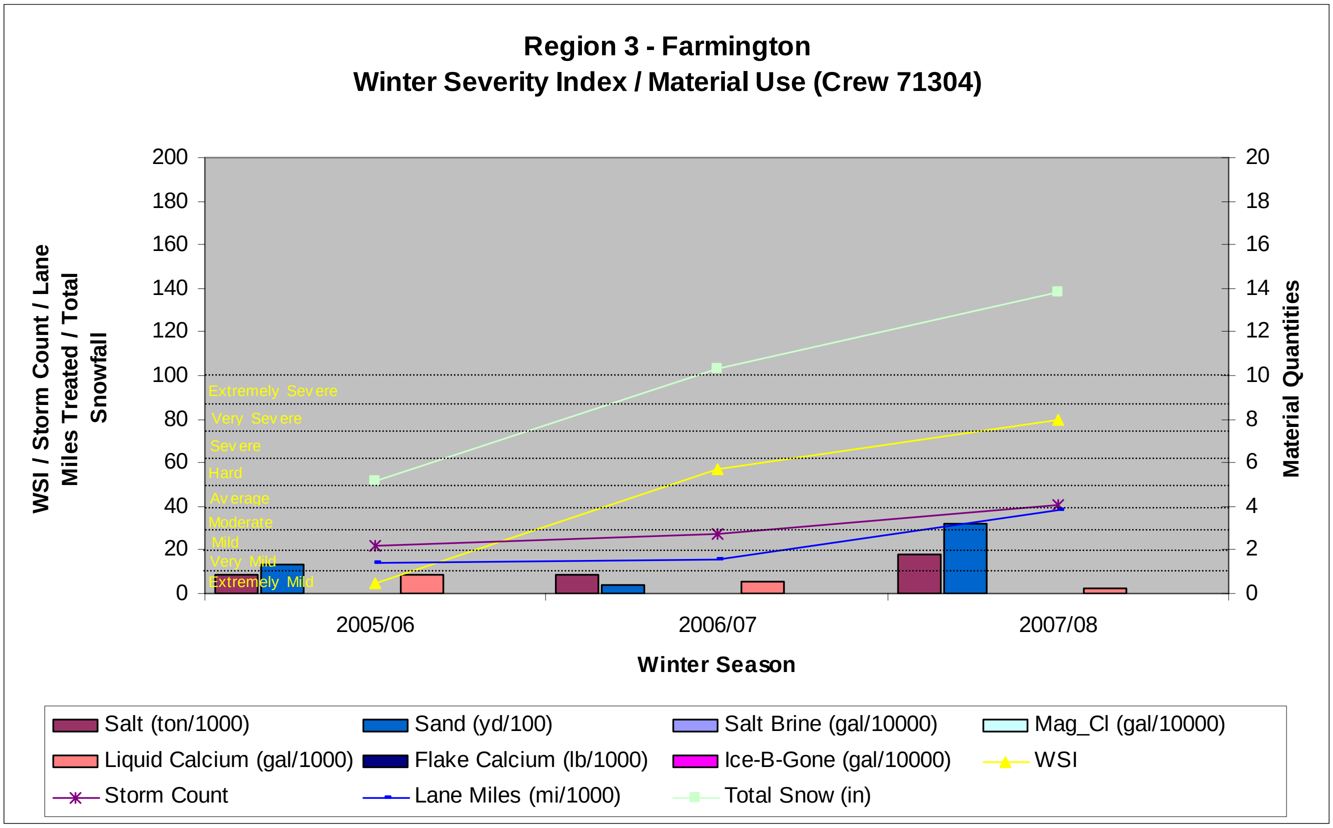
Southern Region 1



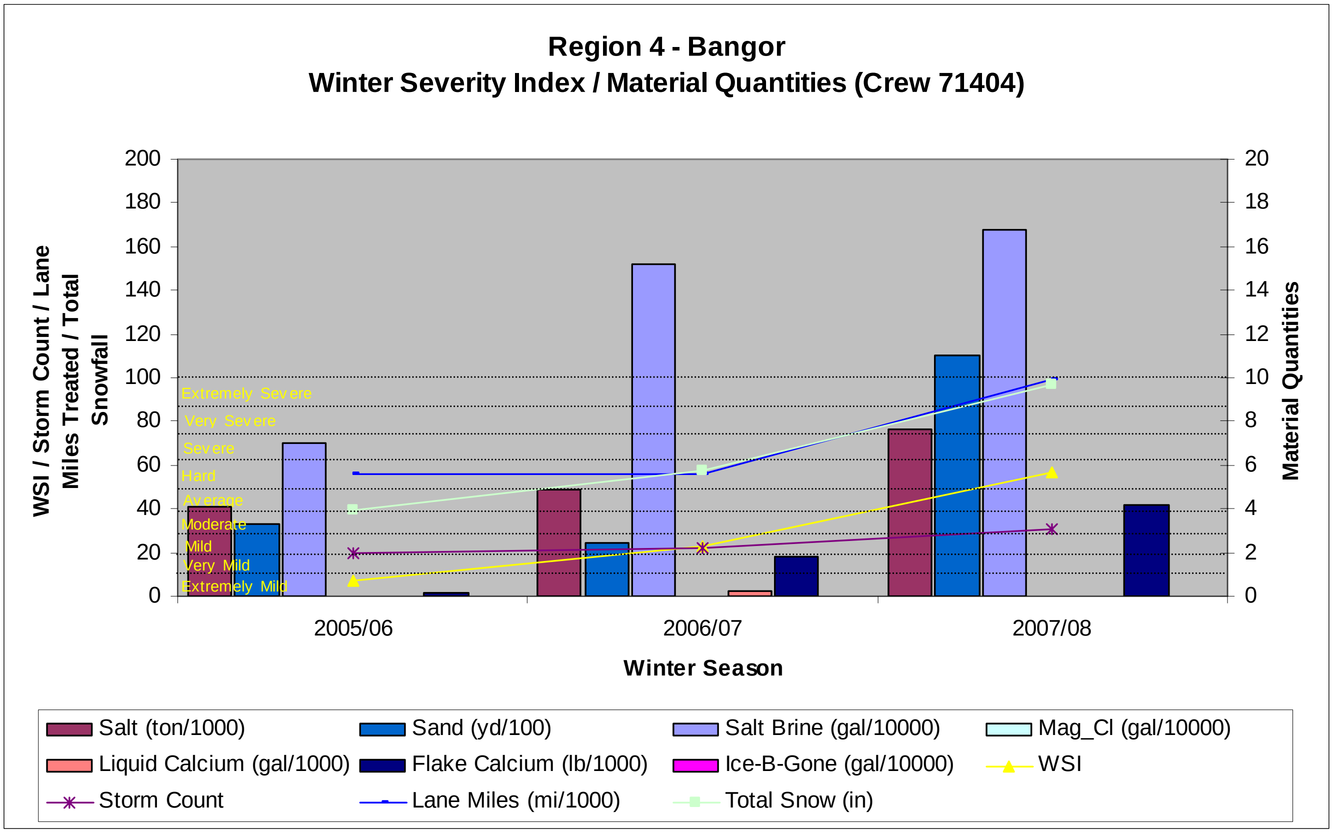
Mid-Coast Region 2



Western Region 3



Eastern Region 4



Northern Region 5