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MARYLAND DEPARTMENT OF TRANPORTATION
STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

SEVERE WEATHER INDEX

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16. Abstract

A severe weather index (SWI) was developed and tested using RWIS data from 2012 to 2020. The developed SWI model has an overall adjusted $R^2 = 0.67$. The severity bounds are defined as low (0 to 1.2), moderate (1.2 to 8), and severe (greater than 8). The SWI model was tested quantitively and qualitatively using 2019-2020 winter weather data and input from maintenance managers. The SWI was found to perform well at identifying low and severe storms. Future work calibrating the SWI will help to better define lower and upper bounds of the moderate severity category. Key outcomes of this effort outside of the development of the SWI model include the identification of locations where blowing and drifting snow impacts the road network, the identification of future sites for RWIS stations, survey results describing RWIS use by MDOT SHA maintenance crews, and a detailed review of the RWIS network and data. In addition to the development of the SWI, extensive recommendations have been made that aim at improving the SWI and overall winter maintenance operations.

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Executive Summary

Accurately assessing winter operations is a challenge faced by many state departments of transportation (DOT). One tool that has shown promise for addressing this need is the severe weather index (SWI) tool. In this research effort, an SWI was developed for Maryland Department of Transportation State Highway Administration (MDOT SHA) based in part on the Maine DOT's SWI, other SWIs that have utilized road weather information systems (RWIS) based data, and significant input from MDOT SHA.

The developed RWIS-based SWI utilized the following data:

- Location;
- Date and Time;
- Air Temperature;
- Wind Speed Average;
- Precipitation Differential (Diff.); and
- Surface Temperature.

For this effort a "storm" was defined as pavement temperature at or below 35ºF and the presence of precipitation. A storm ended when precipitation had not occurred for 4 hours. (Therefore, a storm could oscillate above and below 35ºF.)

The developed SWI model has an overall adjusted $R^2 = 0.67$. Using the information available from 2012-2019 (2012-2013 winter through 2018-2019 winter) the storm severity bounds as defined by the developed SWI model are:

- Low less than 1.2
- Moderate 1.2 - 8
- Severe greater than 8

The model was tested using the winter 2019-2020 data and compared to the visual assessment of severity and effort by maintenance personnel from District 6 (the Western Maryland climate zone). When the SWI values were compared to reported field conditions, the model was found to accurately identify low and severe storms. Where the model is less accurate (re: less tested and defined by field-based observations) is in determining the distinction between low and moderate storm events. Based on the data resolution and quality, the SWI model considers variations in the climate across the State and provides regional SWI values that apply to defined climate zones.

Moving forward, MDOT SHA is encouraged to compare operator-defined effort and severity for each storm event to the calculated SWI. This will allow for quicker calibration of the SWI in accurately defining low, moderate, and severe storm events and the required maintenance activity to treat these conditions. When the SWI values reported by the model do not fall within expected values, MDOT SHA should attempt to identify why there is disagreement. Using this information in an iterative approach, the model's accuracy can be improved over time. How this

is handled by MDOT SHA will determine the level of buy-in, support, and implementation it receives throughout the organization.

Key outcomes of this effort, outside of the development of the SWI model, include:

- the detailed review of the current RWIS and historic network and the data provided,
- the identification of locations where blowing and drifting snow impacts the road network MDOT SHA is responsible for maintaining,
- survey results showing how RWIS data is used by MDOT SHA maintenance crews,
- the identification of future sites for RWIS stations to support a more robust network.

Recommendations and feedback include:

- The MDOT SHA should review how precipitation data is recorded, and the frequency with which it is recorded, to ensure data quality. If necessary, use of an alternative precipitation sensor or data source may warrant investigation.
- The need for an RWIS data manager, or point person, to perform quality control on data outputs and communicate directly with the contracted company to ensure timely maintenance and calibration of all RWIS sites and sensors.
- The need for timely and consistent input from local maintenance shops on RWIS locations, reporting of issues with RWIS stations, etc.
- A more detailed and automated Emergency Operations Reporting System (EORS) reporting method that allows for inclusion of pictures, field-verified precipitation values (snow depth, ice thickness, etc.), and the indication/description of maintenance activity that is associated with conditions that RWIS stations are not good at identifying – such as blowing and drifting snow.
- Archiving RWIS data. Currently RWIS data is purged after 2 years. MDOT SHA should consider working with the vendor to extend it or storing the data locally for longer than 2 years. Five to 10 years of historical data should be sufficient for modeling purposes.

This initially developed SWI should be viewed as a starting place from which MDOT SHA can begin to understand the relationships between precipitation, resources applied, and achieved level of service. Of critical importance is the continual improvement of the SWI with each subsequent storm and winter season. The SWIs should evolve over time as:

- data quality and quantity improve,
- the understanding of how it works improves,
- the understanding of how each variable influences the model output improves, and
- as each storm is compared with EORS reports to better identify storm events and resources used.

Over 3,500 storm events across all sites in Maryland were identified. This equates to over 16,000,000 individual cells of storm-related data included in the database for SWI development.

1. Introduction

A challenge that many state departments of transportation (DOTs) face is the accurate assessment of winter maintenance operations. One tool that has been successfully used by DOTs for this purpose is the severe weather index (SWI). However, the creation and adoption of these tools is still an emerging field of research and practice. SWIs have also been called weather severity indices (WSI), storm severity indices (SSI), or winter weather indices (WWI). An SWI is a tool that can be used to assess the performance and related costs associated with winter maintenance operations, which considers the relative severity of each weather event and the relative severity of weather for that season.

The objective of this research effort was to develop a methodology and calculate an SWI for MDOT SHA, grouped, as feasible, by region, by maintenance shop, and for every winter weather storm event after the fact. The end goal is to allow MDOT SHA to apply the calculated SWI value to winter maintenance operation costs and effort for a storm and a winter season that can be compared to a historical storm severity baseline.

The following tasks were used to accomplish this:

- Literature review,
- Follow-up interviews with key individuals,
- Survey of MDOT SHA winter operations staff,
- Data acquisition, processing, quality assurance/quality control (QA/QC), and
- SWI model development and testing.

The subsequent chapters outline each task effort in detail and how the information gained was used to support the development of the SWI for MDOT SHA.

2. Literature Summary and Follow-up Interviews

Building from preliminary work identified and discussed in the background section of the proposal for this study (*Winter Severity Index: Analysis and Recommendation for Selection*, March 2017), a literature review was conducted that sought information on SWI data needs, data sources, and calculation methodologies. More specifically, relevant work on methods used to determine SWI by state DOTs, use of SWIs as performance management tools (including the impacts on costs incurred), and resources deployed (labor, equipment, and materials) were of particular interest. Additionally, information was sought on lessons learned, benefits of implementation, and post development/implementation progress. A summary of each reviewed paper, report, or conference presentation is presented in Appendix A – Full Literature Review, Table 16. In Table 16, an asterisk (*) can be found after the title where additional information was requested from the researchers.

The researchers found many different methodological approaches used to develop an SWI. An artificial neural network was used by Carmichael et al. (2004); one cited drawback was the large dataset required by this approach. McCullough et al. (2004) used multiple regression analysis using the SAS statistical analysis software program. Maze et al. (2009) used a mixed linear retrospective model. Other efforts that resulted in the development of SWI were not as clear. However, overall, the methodologies used were not consistent; instead, they depended upon the model developer.

For SWI methodologies that showed great promise, the research team conducted follow-up interviews with state DOT staff and researchers via phone and/or email to capture additional information. A summary of the outcomes of these conversations are included following the Appendix A – Full Literature Review.

2.1 Summary of SWI Calculation Methods

There are many unique methods that have been developed to calculate SWI, as highlighted in the summaries within Table 16, some more complicated than others.

Methods used to determine key variables to use in SWIs included:

- Availability of and good quality data,
- Regression analysis to determine statistically significant variables, and
- Practitioner input.

Many methods used a combination of the above to various degrees.

The research team investigated SWI calculation methods that identified specific factors important to MDOT SHA and that vary SWI calculations by eco-regions in the state, in addition to how ‘severity’ was defined. While some calculation methods are very complicated, incorporating many data sources and factors, other were found to be comparatively simple. One DOT interviewed recommended using a simple SWI to garner quality information, stating that it is much easier for the end user (the DOT) to use, which should increase the likelihood of its use once handed off.

From the outset of this effort MDOT SHA indicated it would like an SWI that could accurately be calculated down to the maintenance shop level, if feasible. From the literature review, it was found that one study developed an SWI at a regional/national scale, while all other studies calculated SWI at the state level and district/regional level. A few studies calculated SWI down to the sub-district or unit/shop level including the work by Baldwin et al. (2015) and Maze et al. (2009). From the literature review and follow-up interviews it was found that the resolution of sensor data, and the quality and quantity of overall data, will in the end determine the feasibility of the SWI being accurately calculated down to the maintenance shop level.

The literature review provided knowledge of key areas where SWIs are lacking (re: incorporating blowing and drifting snow, ice events); data sources that are not reliable, should be reconsidered, or should be used with caution; and the level of resolution of SWIs that can be expected (re: the quality and spatial resolution of the data sources will determine the level of resolution of the SWI). The best methods to address many of these identified limitations with SWIs have not yet been identified and researchers continue to work to find better solutions and improve existing SWIs.

2.2 Summary of Data Sources, Needs, and QA/QC

Below is a list of potential data sources that could be used in an SWI.

- Applied Climate Information System (ACIS)
- Automated Surface Observation Station (ASOS)
- Cooperative Observer Program (COOP)
- High Plains Regional Climate Centers Automated Weather Data Network (AWDN)
- Iowa Climate Summary (IA Climo)
- Meteorological Data Assimilation Ingest System (MADIS)
- National Aeronautics and Space Administration (NASA)
- National Centers for Environmental Information (NCEI)
- National Climatic Data Center (NCDC)
- National Digital Forecast Database (NDFD)
- National Oceanic and Atmospheric Administration (NOAA)
- National Snow and Ice Data Center (NSIDC) - Snow Data Assimilation System (SNODAS)
- National Weather Service (NWS)
- North American Land Data Assimilation System (NLDAS)
- Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks – Climate Data Record (PERSIANN-CDR)
- Road Weather Information Systems (RWIS)
- Snow Telemetry (SNOTEL)

The researchers found many different datasets used to develop severe weather indices. Carmichael et al. (2004) used National Climatic Data Center (NCDC) and Iowa Climate Summary (IA Climo) data. McCullough et al. (2004) used National Oceanic and Atmospheric Administration (NOAA) weather data. Strong et al. (2005) made use of road weather information system (RWIS) data, crash counts, annual average daily traffic counts, and monthly adjustment factors. Idaho Transportation Department (ITD) uses RWIS data, has greatly expanded its RWIS network in part to support their effort, and created a position in the agency that is tasked with "owning the data" to ensure consistency and quality. The Maine DOT made use of Cooperative Observer Program (COOP), Financial Activity Data Warehouse (FACT), and Maintenance Activity Tracking System (MATS) data. Baldwin et al. (2015) used MDSS weather variables. Boustead et al. (2015) used data from the Applied Climate Information System (ACIS) database. Matthews et al. (2017) made use of RWIS and weather station networks maintained by Environment Canada (EC). Overall, what was concluded is **there is not one consistently utilized data source**; it varies by state and by the background of who is developing the model. However, there were at least two instances in which RWIS data was used. The benefit of using RWIS data is, in large part, because it ties back directly to the resource (e.g. DOT maintained roads).

The list of data sources used by others is extensive and highlights that many data sources are regionally specific or used to access specific parameters, highlighting the difficulty in fully comparing prior SWI development efforts.

From the literature review, RWIS and NOAA weather stations were identified as potential data sources to be considered for use in this effort. Subsequently, the SWI developed for use in Maine was determined to include the most factors that geographically fit with Maryland (e.g., weather patterns and storm type).

For a comprehensive review of all data sources, weather station sensors, and a detailed explanation of SWI calculation methods, please see the Clear Roads Evaluation of SSI and WSI Variables project report (https://clearroads.org/project/18-03/).

2.3 Summary of Training and Implementing a SWI

It is recommended that internal training be developed for all staff levels. It's further recommended that a pilot group be identified for the initial training, which should be delivered while the SWI is being tested and/or implemented. According to interviews, some agencies felt internal resistance from veteran staff at implementing new data collection and management tools while other DOTs, to mitigate such resistance, suggest sharing with staff why and how the SWI is being used, and what goes into it. By sharing the why and how of using an SWI early in the process, staff from plow drivers, RWIS maintenance crews, shop supervisors, and district managers, up to higher level management, are more likely support and embrace the new tool.

For the ITD, following development of the SWI, a winter season was used to calibrate the SWI based on conditions encountered. Agency staff members were able to identify where the SWI did not work adequately and create exemptions for specific conditions.

Interviews indicated a lack of use of a developed SWI by some DOTs, and, in contrast, significant use by other DOTs in part due to 'top-down' support. For two DOTs, lack of implementation or growth in the use of the SWI beyond the pilot or initial project area occurred. Both situations likely occurred due to loss of key personnel or support within the organization. The opposite of this was observed as well, where some DOTs implemented the SWI across the state with 'top-down' support and have found great success. The point from this is that MDOT SHA should consider identifying key agency personnel (and potentially succession personnel) to implement the SWI, conduct training, and encourage its use across the agency.

2.4 Performance Measurement Tool

Many transportation agencies have successfully used the SWI entirely or as part of a performance management tool for winter maintenance operations. MDOT SHA indicated its desire to utilize the SWI output as a performance measurement tool for level of service, salt use, person hours, etc., which can be accurately quantified when the severity of both an individual storm event and winter season are considered. Many state DOTs have realized significant cost savings from efficiency improvements and have been able to show a return on investment (ROI) in short periods of time from using performance measurement tools, including SWIs.

2.5 Key Points from the Literature Review & Interviews

The following bullets are key points from the literature review and interviews conducted for this project:

- A SWI makes a lot of sense in terms of performance measurement in winter maintenance operations. There are very precise and very broad ways to develop and use a SWI; the method depends on what outcomes you want. The level of detail can in part be determined by the level of investment [in the data source].
- SWI values can differ across a single town as much as they do across an entire state, this can occur for many reasons, natural variability in weather, mixing data sources, inadequate resolution of weather stations, etc.
- Every data source has its pros and cons. These should be defined and understood prior to the selection and use of the data in a SWI.
- There is a general issue with how precipitation data is collected, both electronically and manually. This issue needs to be further investigated to better serve the road weather community.
- There can be issues when combining historical data, as sensors change overtime. The sensor resolution and reporting frequency varies. There are also changes in maintenance and calibration over time, with limited documentation of these changes.
- The importance of knowing what sensors are on each station, how they have changed over time, how the data is collected and reported, the quality of data coming from them, and how often they are calibrated and maintained cannot be overstated.
- A SWI can be started and developed by a single motivated individual.
- SWIs require time to be calibrated and will evolve over time.
- An SWI is a tool that reports on measured conditions; other critical information (e.g. plow driver reports, photos, etc.) should be collected and integrated with the SWI output.

3. Summary of Maintenance District Survey Results

A survey of operations staff from each of MDOT SHA's twenty-eight maintenance shops was conducted in order to obtain information on key variables and data used to make decisions about winter maintenance operations (Figure 1). In this section, a high-level summary of the survey results is provided. The complete survey results can be found in Appendix B – MDOT SHA District and Maintenance Shop Survey Results.

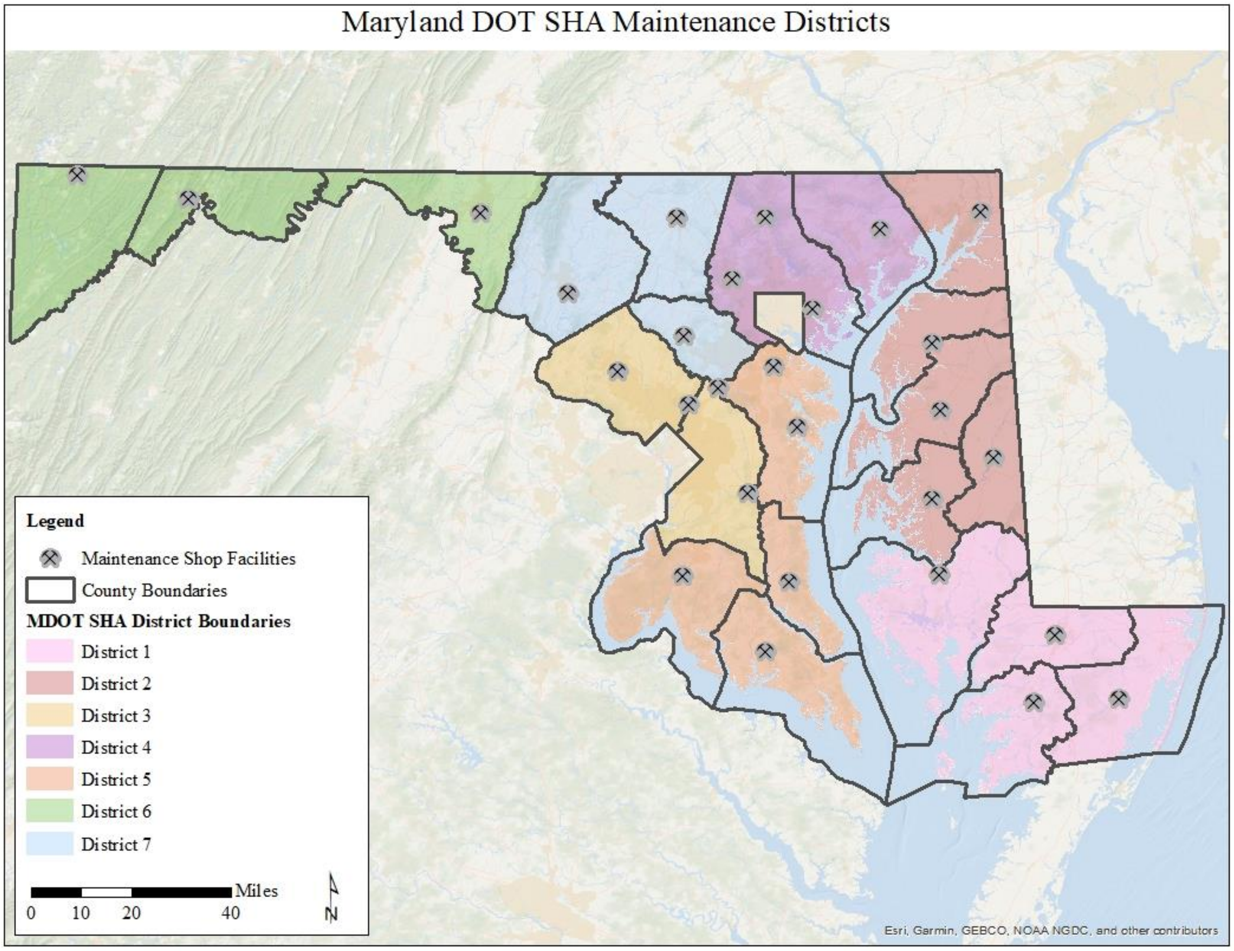

Figure 1. MDOT SHA Maintenance Districts and locations of maintenance shop facilities.

Air temperature, pavement temperature, and precipitation type were identified as the most important variables used in winter maintenance operations in almost all of the districts. Wind speed was identified as least important in almost all districts, with the exception of Districts 4 and 5, which uniquely ranked storm variables as most and least important.

Interesting comments include: considering the timing of the storm event, i.e., whether or not it occurs overnight or during peak travel times like rush hour, weekend traffic to ski resorts, or whether or not they would expect for the precipitation to adhere to the pavement.

Key storm types and winter weather related issues identified by respondents are provided below by District:

- District 1 – freezing rain, ice storms with longest duration during severe events, drifting snow, extreme cold with longest duration during normal and severe events, heavy snow accumulation with longest duration during severe events, soil type = varying freeze/thaw patterns of roads.
- District 2 – wind/drifting snow with longest duration during severe events, freezing rain, extreme cold (-10°F), heavy snow accumulation with longest duration during normal events, staff believe they have high numbers because of conditions they deal with, although less so with ice storms.
- District 3 – Freezing rain, traffic during icing events, ice storms, wind/drifting snow, heavy snow accumulation which has resulted in upwards of 33 inches of snow and damage to infrastructure (respondents mentioned that since this District covers the Washington DC metro area, timing of the storm event is critical and that during rush hour they struggle with maintenance operations).
- District 4 – freezing rain with longest duration during severe events, ice storms with longest duration during severe events, drifting snow with high accumulation of snow during severe events and with longest duration during severe events, extreme cold with longest duration during severe events, heavy snow accumulation with very high accumulation during severe events and with longest duration during severe events.
- District 5 – heavy snow accumulation with longest duration during normal and severe events, freezing rain, ice storms, drifting snow with longest duration during severe events, extreme cold with high accumulation of snow during normal and severe events and with longest duration during severe events, traffic, and forecast accuracy issues.
- District 6 - wind/drifting snow causing high accumulation of snow in severe events, freezing rain, ice storms, drifting snow, extreme cold (-10°F) with high accumulation of snow during severe events, heavy snow accumulation – including conditions that have resulted in tree limb and powerline damage.
- District 7 – freezing rain, ice storms, heavy snow accumulation, drifting snow, and extreme cold.

As expected, freezing rain and ice storms had the lowest overall precipitation rates for normal and severe events, whereas heavy snow accumulation and drifting snow had the overall highest precipitation rates for severe events. Additionally, issues related to Doppler radar in some parts of the state were reported, contributing to the challenge of performing effective and efficient winter operations. Also, one survey respondent noted that variation in pavement between concrete and asphalt can have varying temperature profiles and may need to be treated differently.

4. Summary of Maintenance Shop Interviews

Phone interviews were conducted with each of the seven Maintenance Districts. While every Shop within a Maintenance District was invited to participate in the phone interviews, due to scheduling conflicts, not all were able to participate. The goal of the interviews was to capture additional information on some of the survey questions, discuss specifically the RWIS stations in the respondent's region, identify RWIS stations that best represent regional road weather conditions, discuss RWIS stations that are not working or report "bad data," and identify locations of blowing and drifting snow in each Maintenance District. A summary of the interviews is provided in Appendix C – Maintenance District Interview Summary, followed by images showing recommended locations for future RWIS sites that are regionally representative of road weather and where blowing and drifting snow occurs.

5. Severe Weather Index

5.1 Background

5.1.1 Climate Zones in Maryland

MDOT SHA is divided into seven maintenance districts (Figure 2). It was found the regions or climate zones that experience similar weather or weather patterns did not necessarily coincide with maintenance district boundaries. Because this research project is focused on how maintenance efforts are impacted by weather, the researchers recommended dividing the State into climatic zones.

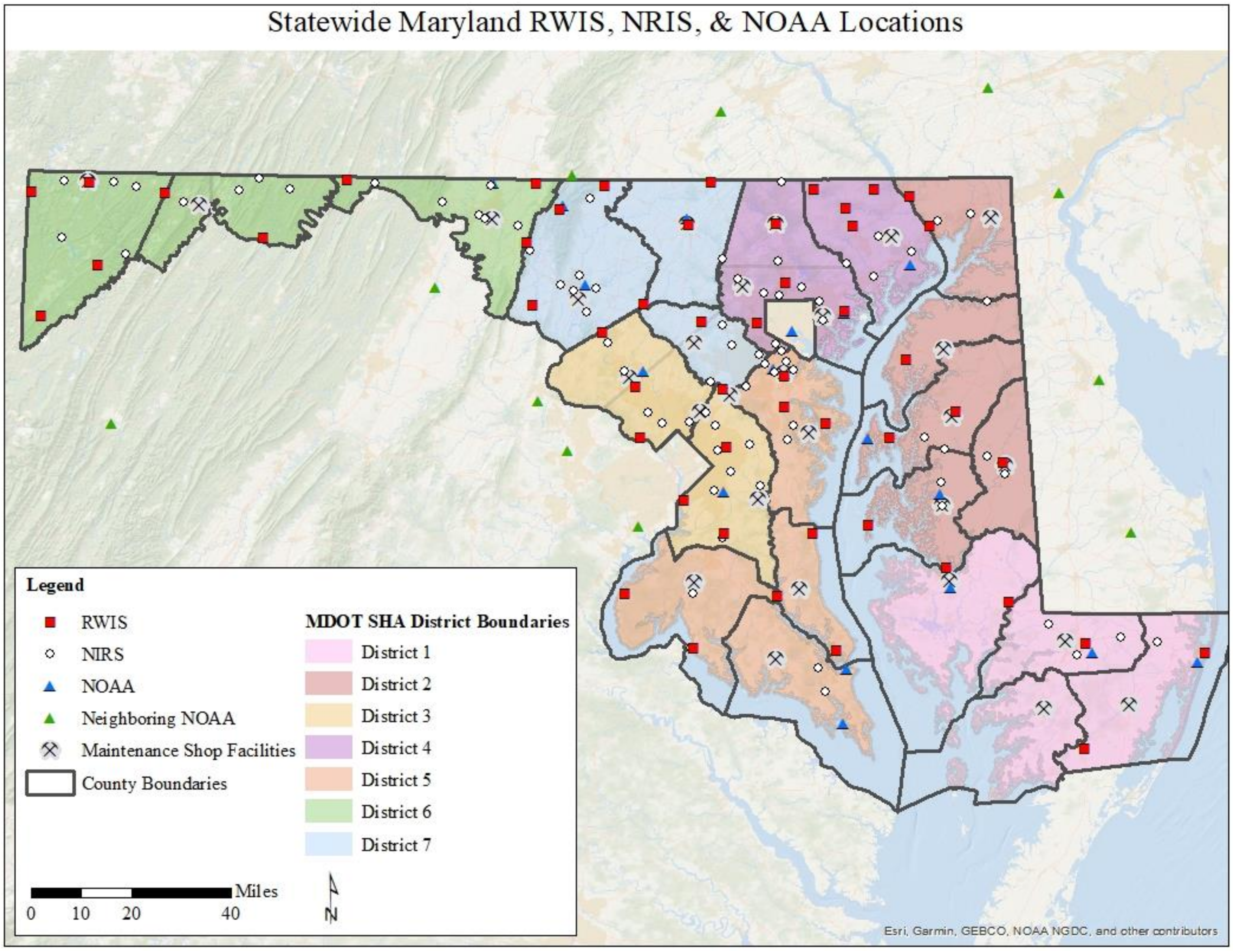

Figure 2. Map of MDOT SHA Maintenance Districts.

Climatic zones offer a logical way to look at larger geographic weather impacts in the state and allow data from RWIS stations within climatic zones to be combined. The following six climatic zones were identified with input from MDOT SHA: 1) Western Maryland (darker green) 2) Northern Tier (pink), 3) Metro (orange), 4) Upper Shore (bright green), 5) Southern Maryland (purple), and 6) Lower Shore (yellow) (Figure 3).

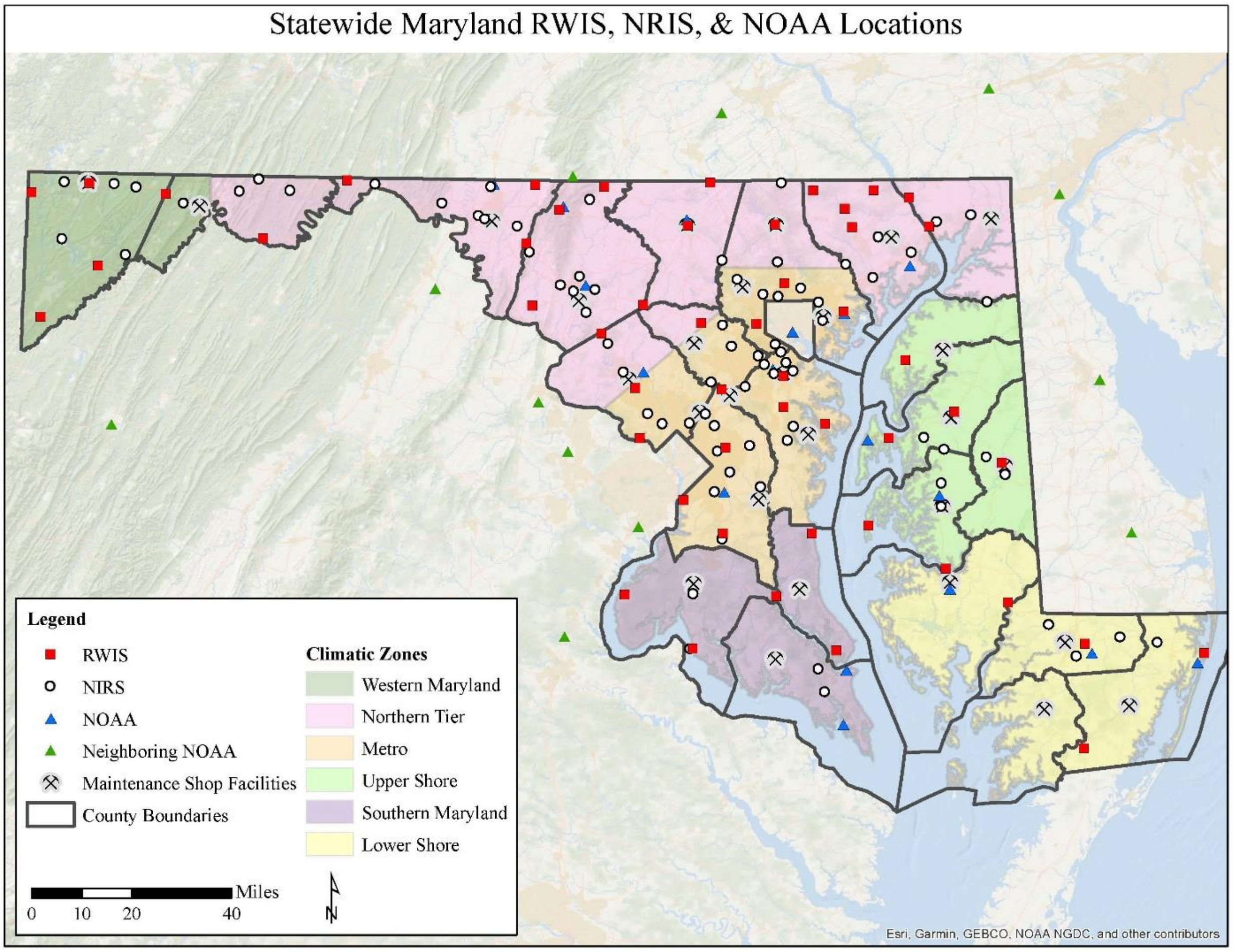

Figure 3. Map of Maryland's Climatic Zones.

Additionally, Figure 3 shows the location of the RWIS sites (n=54), Non-Invasive Road Sensors (NIRS) (n=74), NOAA atmospheric weather stations (including those in neighboring states), and maintenance shop facilities. [Note: The current weather data vendor, Lufft, maintains 128 RWIS and NIRS sites for MDOT SHA. All of these were considered as potential data sources that could be used in SWI development. Ultimately, only RWIS data was used because NIRS sites do not collect all of the data that was originally desired to be included in the SWI.]

5.2 Data

The researchers considered several sources of potential data: road weather information system (RWIS) units, non-invasive roadway sensors (NIRS), and weather data available from the National Weather Service and NOAA weather stations (Figure 3).

Ultimately, it was decided that the RWIS data sources were preferred, due to the pieces of information offered within the RWIS data as well as their direct relationship to the roadways maintained by MDOT SHA. As the project progressed, the researchers learned that MDOT SHA stores two years' worth of historic data from all RWIS sites, and then purges it due to storage capacity issues. For this reason and because the project started in 2018 and concluded in 2020, the 2016-2017, 2017-2018, 2018-2019, and 2019-2020 winters (defined as October – March) of

RWIS data was provided directly by the vendor, Lufft, to the researchers. As a result of some initial model development attempts, it was determined that the SWI could not accurately model using the initial two years-worth of winter data available. Additional historical data from the RWIS sites in Maryland was pursued and obtained from historical archives maintained by Iteris, MDOT SHA's prior vendor. Data from the 2012 to 2016 winter seasons was provided by Iteris to the research team with MDOT SHA's permission. This created a winter (October – March) weather data set for the project from October 2012 – March 2020, a sufficient amount of data to allow for developing an SWI model for the state of Maryland.

The following section is a description of data available from each source (Lufft and Iteris), and the similarities and differences between the data. A major challenge, overall, when trying to combine the two data sources, was the lack of a "data dictionary[1]." **One recommendation from the data processing that was performed is that a data dictionary should be developed**. The creation of a data dictionary will not only ensure that future data users understand what data is being collected by each sensor, but it will track any changes to the data/sensors over time to ensure that the historic data remains useable in the future. Furthermore, the researchers recommend that MDOT SHA consider storing historic data for a longer period of time than the current two years for just this purpose. Review of the data also found a need for more thorough maintenance and calibration of the RWIS sites and sensors, as indicated by "ERROR," "-1000" readings or blank cells, to ensure high quality data is maintained.

5.2.1 Sampling Data from Current Vendor

RWIS data was requested from MDOT SHA's current vendor, Lufft. This vendor provided data by winter season (October – March), for each RWIS site. As an example, data would be provided from the winter of 2017 (October through December) and 2018 (January through March), which represents the 2017-2018 winter season. Within each file, the following data fields (details regarding definitions can be found in Appendix F – Variables Considered and Used in SWI

) were provided:

1. **UTC Times (Coordinated Universal Time)**
2. **Air Temperature**
3. Dew Point
4. Relatively Humidity %
5. Air Pressure (hPa)
6. **Wind Speed Max**
7. **Wind Speed Avg**
8. **Wind Direction**
9. **Wind Direction Max**
10. **Precipitation Diff.**
11. Precipitation Type

[1] A data dictionary is a set of information describing the contents (e.g. units), format, and structure of a database and the relationship between its elements, used to control access to and manipulation of the database (google.com\dictionary).

12. **Surface Temperature 1 (aka Road Temperature1)**
13. Freezing Temperature 1
14. Water Film
15. Saline Concentration %
16. Road Condition (i.e., dry, wet)
17. Road Temp2
18. Subsurface Temp #2
19. FreezeTemp2
20. WaterFilm2
21. Saline Conc2
22. Road Condition #2
23. Salt Conc lbs/in mile2
24. Visibility feet
25. Visibility

The data elements in **bold** above had sufficient quality data (re: limited gaps in the data and errors) to use for preliminary SWI modeling. As an example, the UTC time stamp was not always completely accurate, and therefore did not result in perfect five-minute intervals. Furthermore, the data files sometimes started after the first day in a month or finished before the end of a month, resulting in lost data. Reviewing all of the data files is a key step to ensure data quality, but it requires a person to do it, an understanding of what that person is looking for, and a significant amount of time.

The following three variables were identified as key data that needed to be present in a file or the month was unusable: 1) UTC Times, 2) Precipitation Diff, and 3) Road Temperature/Surface Temperature. Air Temperature, Wind Speed Max, Wind Speed Avg., Wind Direction, Wind Direction Max, and Precipitation Type were retained for use in the SWI development to capture key attributes of the severity of winter storms as described by MDOT SHA.

Following manual QA/QC review of each data file, data associated with defined "storms" was pulled out for use in the SWI model development.

A "storm" was defined as pavement temperature at or below 35ºF and the presence of precipitation. A storm ended when precipitation has not occurred for 4 hours. (Therefore, a storm could oscillate above and below 35ºF.)

All data pieces from every defined "storm" were assembled into a storm summary database. To better understand how much variation occurred across the files originally pulled for testing from the vendor, consider Table 1, which shows a summary of some of the data pieces (the rest of which can be found in Appendix D – Data), and a few examples of the information found within each of these files.

For example, Table 1 shows, in the columns shaded white, the minimum, average, maximum, and standard deviation values for each data element in the sample files provided by Lufft for the Oct-March 2017-2018 winter season (column 1). Viewing the information in this format allows for a better understanding of whether there are gaps in the data across different RWIS sites. Column 2 shows if the data was available, as indicated by the presence of an “x” in the column. Columns 3-6 then show the minimum, average, maximum, and standard deviation values when considering all sampled RWIS sites. The columns shaded in blue, columns 7-12, show data from the 2017-2018 winter season for the specific RWIS site located at I-70 at the Frederick-Washington county line. Column 7 shows whether or not the data was present and if it had a similar or different name. If a different name was used, it is provided; whereas an “x” indicated that the same name was used. Column 8 references where in the original file the data was located; this helped to identify inconsistencies across files when trying to consolidate the data. Columns 9-12 provide the minimum, average, maximum, and standard deviation values for the RWIS site located at I-70 at the Frederick-Washington county line for the 2017-2018 winter season for each data element.

Primarily, Table 1 is shown to demonstrate the comprehensive methods used to track each data element throughout data acquisition, data QA/QC, and data processing phases of this project. **In particular, it demonstrates the need to have one name for each data element that is consistent over time and that data files are provided in a consistent format each time to reduce the amount of data processing needed, which can in part be accomplished by using a data dictionary.**

Table 1. Example of Data Differences.

	From Oct 1, 2017 through Mar 31, 2018	Minimum	Average	Maximum	Std Dev.	I_70_at_FrederickWash_County_Line	Column	Minimum	Average	Maximum	Std Dev.
UTCTimestamp						X		10/1/2017	-	3/31/2018	-
Time_Stamp (date and time)	X	10/1/2017	-	3/31/2018	-						
date											
time											
Air Temperature Â°F						X		-0.16	39.991805	81.43	14.939497
Road Temperature °F	X	-3.202297	39.613635	100.30986	16.952231	Road Surface Temp. Â°F	M	-3.86	41.888787	100.95	16.504776
Freezing Temperature °F	X	21.41061	31.775861	32	0.8790644	X	N	28.99	31.997337	32	0.0768908
Water Film Height milli-inch	X	0	0.2322541	61.496063	1.2639176	Listed as, "Water Film Height mil"	O	0	0.4245874	37.05	1.5331233
Saline Concentration percent	X	0	0.2075992	9.058531	0.8099672	Listed as "Salt Concentration %"	P	0	0.0024984	2.8	0.0721266
Salt Concentration lbs p.lane mile						X	X	0	0.0574853	249.7	2.2724712
Road Condition n/a	X	0	0.9229675	7	2.1418011	X	Q	Qualitative information (none, rain, etc.)			
Service Level lbs p.lane mile	X	0	0.5452396	768.619019	7.6280061						
Road Temperature °F	X	-3.282932	39.787988	103.40332	17.263797	Road Surface Temp. Â°F	S	5.08	45.664468	105.66	16.040302
Sub-Surface Temp. Â°F											
Temperature 1 °F	X	12.566509	41.775397	74.966888	12.790549						
Freezing Temperature °F	X	24.779057	31.896076	32	0.5585115	X	T	27.64	31.995515	32	0.101031
Water Film Height milli-inch	X	0	2.0960467	46.75	3.9509999	Listed as, "Water Film Height mil"	U	0	0.5307046	50.79	2.0723575
Saline Concentration percent	X	0	0.0967492	6.443899	0.5171864	Listed as "Salt Concentration %"	R	0	0.0138723	30.52	0.4339782
Salt Concentration lbs p.lane mile						X	V	0	0.004206	4.02	0.0946256
Road Condition n/a	X	0	1.3717278	7	2.385559	X	W	Qualitative information (none, rain, etc.)			
Water Film Height milli-inch	X	0	2.4153673	412.910736	15.608154						
Precipitation diff. milli-inch	X	0	0.1223098	77.952759	1.2521926	X; only listed as "mil" is this milli-inch?	K	0	0.1630245	148.82	1.8139602
Precipitation type unknown unit	X	0	4.6974822	70	16.917453	Only listed as "Precipitation Type"	L	Qualitative information (none, rain, etc.)			
Visibility miles	X	0.055302	1.1528706	40	0.3212434						
Temperature °Fahrenheit	X	-6.218899	35.184988	78.788269	15.98336						
Dewpoint °Fahrenheit	X	-12.52652	28.397444	72.15686	16.556043	X; different order	D	-7.89	31.964935	77.62	16.576943
Relative humidity percent	X	21.648075	78.353769	100	18.387461	X	E	25.3	74.871685	100	18.654123
Abs. air pressure Hecto Pascal	X	898.368042	923.87324	941.681519	7.0771702	Not listed as "absolute"	F	947.97	975.37451	996.15	7.6973019
Wind Speed (peak) miles/hour	X	0.67639	11.52619	50.174332	6.6906974						
Wind Speed [act] mph											
Wind Speed miles/hour	X	0	4.7151342	18.827705	2.711719	X; listed twice; if one peak?	G	0	11.505365	64.8	6.9834007
Wind Speed mph						X	H	0	4.6210793	27	2.6697255
Wind direction degree	X	0	210.40325	359.978973	91.81287	X	I	0	212.57795	359.85	96.924349
Wind direction degree	X	0.111938	224.2073	359.914978	82.460278	X	J	0	219.25516	359.98	97.460158
Visibility feet	Listed as "NULL"	0	no value	0	no value						
Visibility miles	Listed as "NULL"	0	no value	0	no value						

5.2.2 Historical Data Sampling from Previous Vendor

After a model was developed with the data available from the current vendor (Lufft), it was determined (as was noted previously and is discussed in more detail in the next section) the available data was insufficient to produce a model with statistical significance. Specifically, for some key data elements, such as wind, it was determined additional data was needed. To allow for more in-depth analysis of resources applied, it was particularly important to the MDOT SHA that some of the key variables known to impact severity of winter storms in Maryland be included. Therefore, it was determined that additional historical data should be used and was captured from the prior vendor (Iteris). Iteris was able to provide RWIS data from Maryland for the period from October 2012 through March 2016.

There were some challenges with integrating the historical data from Iteris with the more recent Lufft data. First, the researchers needed to understand what pieces of data were similar or different, as conveyed by Figure 4. The two columns in Figure 4 are the data elements provided by Iteris and Lufft, respectively. Connecting the two columns are colored lines showing where data elements are the same or potentially the same. Figure 4 also shows that there are many more data elements provided in the Iteris historical data than in the Lufft data. Direct communication with both Iteris and Lufft was required to clearly understand each data element; the units it collected, recorded, and reported in; values that were rounded; and other items to be better reconciled.

The data available from both vendors also influenced what data could ultimately be used to develop the model. For example, similar to that found from the Lufft data, there were many "ERROR" readings in the data provided by Iteris. It is important to note here that the error in the data is likely from a non-functioning sensor. Table 2 shows a selection of available Iteris RWIS data from specific stations from specific years: the orange cells represent no data file was provided by Iteris; the yellow cells represent text files were provided without data in them; the red text represents gaps in the data that were present for a month or more; and the grey/blue cells represent data that is likely to be complete enough to incorporate into the model. When data sets were found to have gaps or a significant number of error readings, the data was not used. From Table 2 it can be observed that consistently complete data was not available until October 2012, which is why the data used in model begins at this time.

Another challenge encountered with the historical data from Iteris was the method used to export the data. The method required the research team to significantly reorganize the data to be used in the model, more so than the current RWIS data. Additional details on this specific challenge can be found in Appendix D – Data, Processing Historical Data from Iteris.

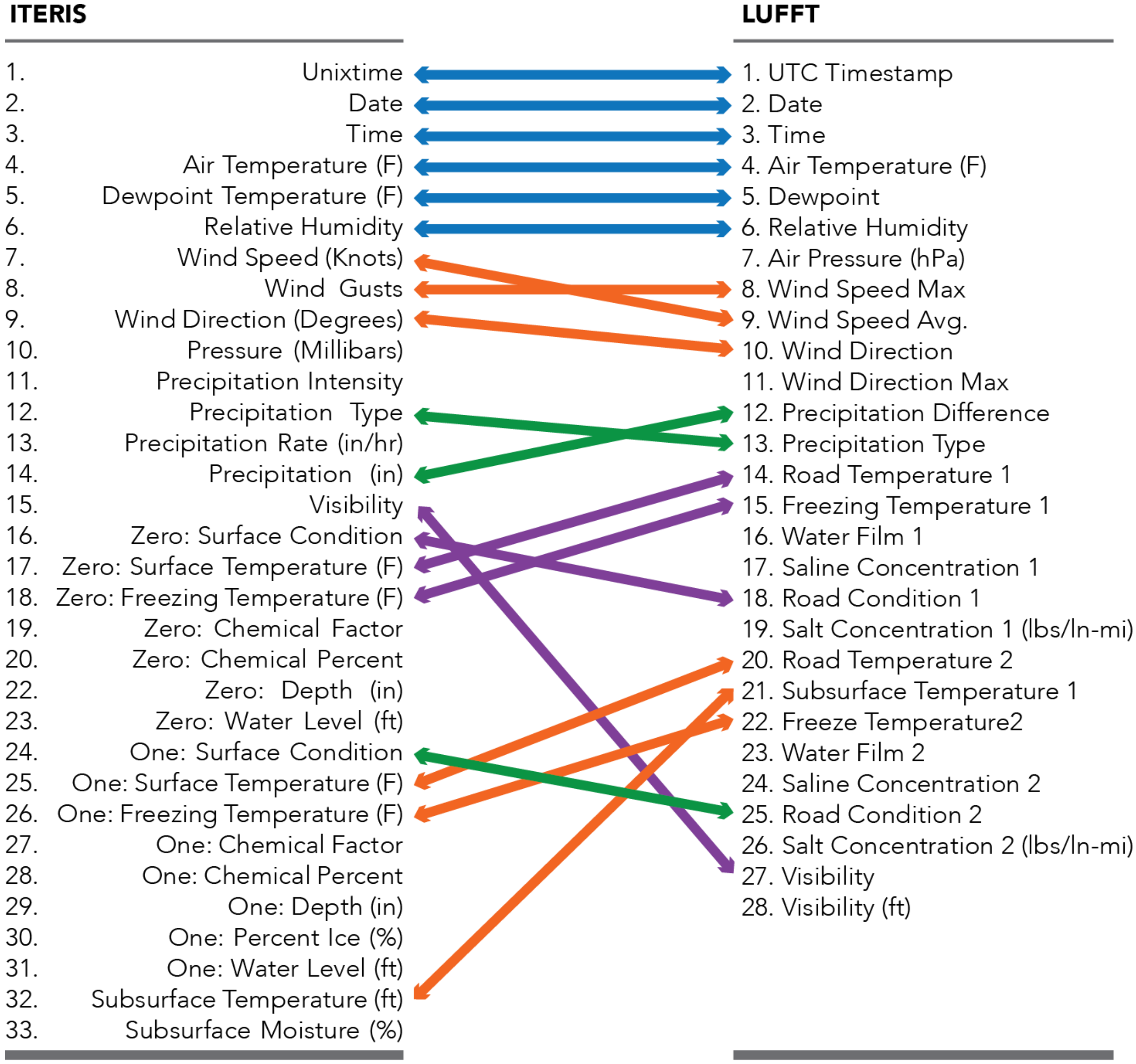

Figure 4. Comparing Vendor Data Fields.

Table 2. Example of Missing Data from Previous Vendor.

RWIS Number	Secondary Name	2010-12	2011-01	2011-02	2011-03	2011-10	2011-11	2011-12	2012-01	2012-02	2012-03	2012-10	2012-11	2012-12	2013-01	2013-02	2013-03
9	MDHER	**atmos; sub; unknown0; unknown1; unknown2**	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	No Data	No Data	No Data	No Data	No Data	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
10	MDGOR	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
11	MDSID	**atmos; sub; unknown0; unknown1**	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	No Data	No Data	No Data	No Data	No Data	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1

5.3 SWI Calculation

5.3.1 Developing the SWI Model

To date, there is no consistent approach to the development of a severe weather index (SWI). In some cases, weather data is used (e.g. Community Collaborative Rain, Hail & Snow Network (CoCoRaHS): https://www.cocorahs.org/Maps/ViewMap.aspx?state=usa). In other cases, road weather information system (RWIS) data or atmospheric data (NOAA, AWSSI - https://mrcc.illinois.edu/research/awssi/indexAwssi.jsp, etc.) is used. The approaches vary by state and by the background of the individual who is leading the development (e.g. meteorologist versus transportation engineer). The benefits of using RWIS data is that it is tied to the resource that the state DOT is trying to maintain: the roads. Therefore, it is often a better indicator of the condition of the roadway during inclement weather and the level of resources needed to address the conditions. However, there are still concerns with the quality of RWIS data in terms of sensor maintenance and calibration and the resolution or density of the RWIS network. This section of the report will provide information on:

1. **Early editions** of the model and why a larger pool of data was pursued,
2. **Weather conditions** considered, some of which were unsuccessful (e.g. blowing snow and whiteout),
3. The progression to the **final model** and how comparisons of the evolution of data sets helped to ensure quality control, and
4. How visual **photos** provided by the District 6 maintenance shop compare with the severity identified by the model.

5.3.1.1 Early Model Editions

District 6, one of the most mountainous regions in Maryland, was used for testing early models. It was chosen because: 1) a lot of data was available, as it was one of the first regions with RWIS, 2) the quality of the data could be verified, and 3) the bulk of the identified storm events occurred in District 6, which was within the Western Maryland Climate Zone. (Note: The researchers realized that the more maritime climate (of eastern Maryland) variables needed to be accounted for as well, but it was useful to start with a large volume of easily available, high-quality data.)

As discussed previously, the Maine DOT SWI was identified as a good starting point for the MDOT SHA's SWI due to similar weather patterns (e.g. Nor'easter impacts) and climate, albeit colder. The Maine DOT report, *A Winter Severity Index for the State of Maine* (Marquis, Nouhan, Colson, & Payeur, 2009), provided a very detailed explanation of how Maine DOT's SWI was developed and the weighting was used for initial SWI values, which is summarized below in Table 3.

Table 3. Maine Snowfall Weighting Values (Marquis et al., 2009)

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	4	13.5 to 14.9	20	25.0 to 26.4	47	36.5 to 38.4	88
5.0 to 5.9	5	15.0 to 16.4	23	26.5 to 28.4	52	38.5 to 39.9	94
5.0 to 6.9	6	16.5 to 18.4	26	28.5 to 29.9	58	≥40	100

The Maine DOT also added in modifiers for temperature, reflecting in part that salt functions effectively down to 15°F in the field. The additional SWI value modifier numbers based on temperature can be found in Table 4.

Table 4. Maine Temperature Weighting Values (Marquis et al., 2009)

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

The model was tested at this point and performed poorly. (Additional information on the preliminary model and its performance can be found in Appendix E – Early Model Performance & Testing Variables

Preliminary Model Performance.) Key variables that were expected to play a part in the severity of a storm were not found in this model: **precipitation and wind**. (Note: While technically precipitation is in the above model, it is as an indicator, not the actual measurement of precipitation.) Therefore, the researchers sought out more data sources (the historic Iteris RWIS data for Maryland) with the expectation that as the information about the phenomena grew, the model could better capture how these are related to the severity of the storm.

5.3.2 Variable Considerations

As the researchers considered many models throughout the process, the SWI was modified from the original version identified by Maine DOT to one that better represented how the severity of storms was described by the MDOT SHA. In particular, as precipitation is recorded by the RWIS station sensors in Maryland during one increment for every five-minutes, the summation of precipitation over a storm vastly differed from that identified for Maine. The climates between Maine and Maryland also generally have differences, as Maine can experience significantly colder temperatures. Furthermore, as MDOT SHA provided input on key factors that make its storms severe, other multipliers were added. Table 5 shows how precipitation (as snowfall) values were modified for the MDOT SHA and Table 6 shows how bonus points were added for road surface temperature. Although air temperature could be used as a proxy when surface temperature was not available, it is not ideal because winter maintenance operational decisions are most often based on pavement surface temperature.

Table 5. Maryland Snowfall Weighting Values

Snowfall (in)	Points	Snowfall (in)	Points	Snowfall (in)	Points
<0.066	0	0.737 to 0.803	15	1.474 to 1.54	55
0.067 to 0.133	1	0.804 to 0.87	18	1.541 to 1.607	60
0.134 to 0.2	2	0.871 to 0.937	21	1.608 to 1.674	65
0.201 to 0.267	3	0.938 to 1.004	24	1.675 to 1.741	70
0.268 to 0.334	4	1.005 to 1.071	27	1.742 to 1.808	76
0.335 to 0.401	5	1.072 to 1.138	30	1.809 to 1.875	82
0.402 to 0.468	6	1.139 to 1.205	34	1.876 to 1.942	88
0.469 to 0.535	7	1.206 to 1.272	38	1.943 to 2.009	94
0.536 to 0.602	8	1.273 to 1.339	42	≥2.01	100
0.603 to 0.669	9	1.34 to 1.406	46		
0.67 to 0.736	12	1.407 to 1.473	50		

Table 6. MDOT SHA Temperature Bonus Points

Event Average Temperature	Additional Points
>32°F	0
20°F ≤ Event ≤ 31.9°F	0.2 of Event Snowfall up to 8 points
10°F < Event < 19.9°F	0.3 of Event Snowfall up to 12 points
0°F < Event < 9.9°F	0.4 of Event Snowfall up to 16 points
≤ 0°F	0.5 of Event Snowfall up to 20 points

The development of the model was a cooperative effort with MDOT SHA, as the agency's in-depth knowledge of how operations performed helped inform what the model was trying to capture. MDOT SHA noted that **blowing snow**, which could result in **whiteout conditions,** relates to how it allocates resources for management of the roadways. Variables meant to represent blowing snow (air temperature colder than 25ºF and the presence of wind following precipitation) and whiteout conditions (winds above 35 mph, air temperatures below 25ºF, and more than two, five-minute periods of snow during a storm event) were attempted for inclusion in the model, but ultimately did not attain statistical significance. **Is it suggested that both blowing snow and whiteout conditions be reconsidered in future SWI model improvements.** An additional discussion of this process can be found in the Appendix E – Early Model Performance & Testing Variables, *Modeling with Blowing Snow*.

Whiteout Condition Variable

Whiteout conditions were defined as having winds above 35 mph, temperatures below 25ºF, and more than two, five-minute periods of snow during a storm event. Unfortunately, these conditions were found infrequently within the useable data sets. A model has a difficult time with data that lacks variability. Whiteout conditions were only recorded in 3 of 1,297 storms (0.2%) according to the defined criteria. [Note: A selection of data in the western climatic region was tested due to the time-intensive nature of creating the whiteout variable. Additional data would have been processed had the outcome shown promise.] Because of the low occurrence there was no possibility of statistical significance.

The researchers recommend that MDOT SHA **try to capture whiteout and blowing and drifting snow conditions by adding to the EORS report**:

1. if a storm had blowing snow,
2. the duration that blowing/drifting snow occurred,
3. note the location of the blowing snow on a map with the prevailing wind direction, and
4. capture photos of conditions.

The captured photos could serve many purposes. First, they could be used to generally show conditions. Furthermore, the photos could also tie specific conditions to SWI values calculated for the event. Finally, they could be used to qualitatively categorize variations in blowing/drifting snow. A qualitative variable could be used for future modeling.

"Day" Variable

The MDOT SHA noted that storms occurring during the day are often less severe because sunlight (e.g. increased ultraviolet radiation) and warmer daytime temperatures aid winter maintenance operations. Therefore, a variable was created to identify storms that strictly stayed within what was commonly accepted as "day" during the entire winter season, defined as occurring between 7:30am and 5pm. If a storm started in the five-minute interval before the day started at 7:30am but ended just after 5pm, the storm did not receive a one for the indicator variable.

Wind Variables

The MDOT SHA noted that wind, in particular, impacts how severe storms are. As an example, Maryland is impacted by storms (e.g. Nor'easters) that move onto land from the Atlantic Ocean (from east to west). For this reason, wind direction was originally retained within the dataset, although it ultimately proved unsuccessful to incorporate it into the SWI model. Furthermore, District 6 reported impacts from lake effect snow. Therefore, the researchers tried to incorporate these observed values into the model.

"High"-Wind Speeds

Based on feedback from MDOT SHA, high-wind speed was set at equal to or greater than 15mph. From here, MDOT SHA provided the following wind thresholds that caused problems for maintenance. It was ultimately recommended that the following thresholds be applied:

1. 0-8 mph (average wind speed during a storm event)
2. 8-15 mph
3. 15-50 mph

Defining a model with these thresholds did not have well enough distributed data and ultimately proved unsuccessful when trying to represent all three categories. In the final SWI model, wind was incorporated using a different approach (see 5.4.1.5 CALM).

Erroneous Readings

Some of the RWIS data seemed to have erroneous wind data. For example, at RWIS Location #17, values for minimum, average, and maximum wind **gusts** and minimum, average, and maximum wind **directions** were problematic for the 2013-2014 winter season. As a result, some "storms" were lost in the initial modeling effort, as these values were changed to -1000 in the data conversion; and the data was taken as erroneous. (Note: *average* wind speeds were not modified as they were in line with other values.)

Additionally, values for the maximum wind gust were problematic for RWIS Locations #34, #52 and #55. These outliers were observed by plotting each variable. For Location #34, one reading was 108.52 mph. This value was replaced with the next highest recorded value: 48.26mph. For Location #52, a gust of 107.336 mph was observed. It was replaced with the next highest reading: 92.08 mph. For Location #55, a reading of 81.19 mph was replaced with the next highest: 32.04 mph. These extremely high values for maximum wind gust speeds at these locations could not be validated. To avoid this issue, **routine calibration of the wind sensors is recommended,** as MDOT SHA suggested that wind strongly influences the severity of the storms in the state.

Defining Maximum Wind Speed and Wind Gust

Lufft identified the difference between 'maximum wind speed' and 'wind gust' as follows:

> *"The maximum **wind speed** is a single measurement peak value. As the measurement rate on Ventus (wind sensor) can be 50 meters per second (m/s) in high speed mode and 250m/s in standard mode, the maximum wind speed may reflect only a 50ms value. Short measurement intervals and maximum wind speed values are used in the wind energy market and whenever short reaction times are required. The **wind gust**, which is implemented now in the Ventus wind sensor, is technically the maximum value in a 3sec time interval, recalculated every 250msec. From a user's perspective, the advantage is that the wind gust value provides a better indication of the energy contained and thus of possible damage. In addition, it is also used to compare different sensors, as the maximum values are not comparable due to different response times and measurement rates of the devices. The wind gust standard value used in winter maintenance operations which is often measured by meteorological institutes. In [the] case of the Ventus wind sensor, the wind gust calculation is now fully integrated into the sensor."* (Personal Communication, L. Goodfellow; Lufft, 2020a).

Qualitative (Derived) Precipitation States

The RWIS data provided information about the qualitative state of the precipitation, also called "precipitation type": 1) hail, 2) freezing rain, 3) sleet, 4) rain, and 5) snow. The following are the definitions for each of these states (Manual R2S-UMB G. Lufft Mess- und Regeltechnik GmbH, Fellbach, Germany (Lufft, 2020b)):

1. Hail – number of hail particles per minute is greater than 40% (hail factor),
2. Freezing rain – number of rain particles greater than 90% and ambient temperature is less than or equal to 0ºC (32ºF),
3. Sleet – number of rain particles is greater than 20% and the ambient temperature can range from -5ºC to 4ºC (23ºF to 39ºF),
4. Rain – number of rain particles is greater than 50%, and
5. Snow – if none of the four above conditions were met, but particles were measured.

5.4 Final SWI Model

The MDOT SHA requested the researchers attempt to develop a model that would be specific to each maintenance shop. However, as a result of data issues outlined in the previous sections, a model using the comprehensive data was developed, with indicator variables created to allow for climatic-specific output. NLOGIT5 was the modeling program employed (Econometric Software, Inc., 2012).

The following variables, a selection of those originally considered, were analyzed for inclusion in the final model, with those in **bold** proving to be statistically significant in the final SWI model:

- Wet Precipitation Total During Storm (inches) **[WET_PRECIP]**
- Number of 5-minute blocks Over Which Storm Occurred (count)
- District Number Where Storm Occurred
- Road Weather Information System (RWIS) Number Where Storm Occurred
- Year (2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019) of Storm
- Month of Storm
  - October
  - November
  - December **[DEC]**
  - January **[JAN]**
  - February
  - March
- Day (storms must occur completely within the 7:30am to 5pm time frame) **[DAY]**
- Storm Duration (minutes) **[STORM_DURATION]**
- Average Air Temperature (Degrees Fahrenheit) During Storm
- Start Air Temperature (Degrees Fahrenheit) During Storm
- Average Surface Temperature (Degrees Fahrenheit) During Storm
- Number of 5-minute Observations Without Precipitation During Storm **[NUM_NO_PRECIP]**
- Number of 5-minute Rain Observations During Storm
- Number of 5-minute Sleet Observations During Storm
- Number of 5-minute Freezing Rain Observations During Storm
- Number of 5-minute Snow Observations During Storm
- Number of 5-minute Undefined Observations During Storm
- Number of 5-minute Total Observations During Storm **[TOTAL_NUM]**
- First Precipitation to Last Precipitation Type: Rain to Freezing Rain
- First Precipitation to Last Precipitation Type: Rain to Sleet
- First Precipitation to Last Precipitation Type: Sleet to Sleet
- First Precipitation to Last Precipitation Type: Sleet to Snow
- First Precipitation to Last Precipitation Type: Snow to Snow
- First Precipitation to Last Precipitation Type: Snow to Sleet

- Average Wind Speed During Storm (mph) **[AVG_WIND]**
- Minimum Wind Gust Speed During Storm (mph)
- Average Wind Gust Speed During Storm (mph)
- Maximum Wind Gust Speed During Storm (mph)
- Minimum Wind Direction During Storm (degrees)
- Average Wind Direction During Storm (degrees)
- Maximum Wind Direction During Storm (degrees)
- Climatic Zone
    - Northern Tier **[NORTH]**
    - Metro **[METRO]**
    - Western Maryland **[WESTMD]**
    - Southern Maryland
    - Upper Shore **[USHORE]**
    - Lower Shore
- Maryland Number (defined in 5.4.1.1 Maryland #)

Variables in bold that were incorporated into the final SWI model are explained in section 5.4.1 Variables Explained. Detailed definitions of all of the above listed variables can be found in Appendix F – Variables Considered and Used in SWIDefinition of all Data Variables. In addition, maps, showing minimums, means, medians, and standard deviations can be found in Appendix F – Variables Considered and Used in SWIFigures for Each Variable.

The following table summarizes maximums, minimums, averages, and medians for the dataset that had complete information for a total of **3,555 storms** (Table 7).

Table 7. Descriptive Statistics for Storms with Complete Data: 3,555 Storms

Variable	Minimum	Mean	Maximum	Std Dev.
WET_PRECIP	0.000390	0.0710	2.73	0.156
DAY	0	0.253	1.00	0.435
STORM_DURATION	3.00	367	4080	431.4
DEC	0	0.161	1.00	0.367
JAN	0	0.312	1.00	0.463
NO_PRECIP_RATIO	0	0.218	1.00	0.260
CALM	0	0.579	1.00	0.494
NORTH	0	0.375	1.00	0.484
METRO	0	0.206	1.00	0.404
WESTMD	0	0.280	1.00	0.449
USHORE	0	0.0743	1.00	0.262
Maryland Index Number	0	16.8	108	30.8

5.4.1 Variables Explained

5.4.1.1 Maryland #

The Maryland Severe Weather Index Number (Maryland #) is the dependent variable. It is derived using: 1) the wet precipitation and 2) wind.

5.4.1.2 Snow Density

A multiplier of 10, used by the MDOT SHA, is applied to the wet precipitation to get an estimate of its equivalent "snow" precipitation.[2] This value represents an average snow density for the whole state and was provided by the National Weather Service. However, it is understood that air temperature impacts that actual amount of "snow". Therefore, the assumption of a uniform snow density can provide some error. **In the future, researchers may want to consider a more detailed understanding of "snow" for SWI modeling purposes.**

[2] At this time the snow density multiplier of 10 is applied to convert wet precipitation to snow depth. The research team has provided additional information in this report to suggest that in future modifications of the SWI, MDOT SHA may want to consider using a snow density value that fluctuates based on air temperature, and consider ground truthing (validating) snow density values in both Maritime and Mountainous regions in the state.

5.4.1.3 RWIS Precipitation Data vs. Field Observations

As discussed in the data section, because the RWIS precipitation sensors currently capture wet precipitation in 1-minute units over a 5-minute period, there is a difference between total accumulated precipitation reported in the EORS reports and the totals extracted by storm from the RWISs. This presents an issue, because the model is using the RWIS precipitation data. Therefore, both the wet precipitation and Maryland # variables may cause a reduced severity in the SWI value as a result of how the data is captured. If the way in which RWIS stations capture precipitation data is changed in the future, such that precipitation accumulation over the entire 5-minute interval is reported, there will need to be changes to the model.[3] This is highlighted here because the current precipitation values reported by RWIS will vary from measurements collected in the field, with the RWIS data often under reporting precipitation. Therefore, **it is recommended that manual precipitation data be collected and recorded in all EORS reports**. This also means measurements recorded by maintenance shops will differ from what the RWIS is reporting.

5.4.1.4 NO_PRECIP_RATIO

The NO_PRECIP_RATIO is a measure of storm precipitation intensity. As mentioned earlier, the start of a "storm" was defined as occurring when the temperature dropped below 35ºF and there was precipitation measured concurrently during that 5-minute time period. The end of a "storm" was defined as when there was less than a four-hour gap between two 5-minute time periods with precipitation. Therefore, there is the possibility that some 5-minute periods, within the 4-hour interval defined as a "storm", did not have any precipitation within a 5-minute time interval. The number of 5-minute time periods, within the 4-hour period defined as a "storm" where no precipitation occurred, was called NUM_NO_PRECIP. The total number of 5-minute time periods in a storm was called TOTAL_NUM. Therefore, the ratio of no precipitation 5-minute time periods to the total number of time periods, NO_PRECIP_RATIO, is:

NO_PRECIP_RATIO = NUM_NO_PRECIP/TOTAL_NUM.

5.4.1.5 CALM

There was an interest in including some measure of wind, as MDOT SHA noted that it impacts the severity and, therefore, the resources applied to its winter storm operations. The agencyy identified 6 mph or lower as a "calm" storm. Therefore, if the average wind speed of a storm, AVG_WIND, was less than 6 mph, an indicator variable, CALM, was created and used to represent these storms.

When using the above desirable variables, the total number of storms that had complete datasets was 3,555. These storms were used to identify statistically significant variables (Table 8).

[3] Note that the current precipitation data collected for 1-minute of the 5-minute interval is controlled by how the station is wired. The data could easily be collected over the full 5-min interval, but this would require all stations to be changed consistently and the new precipitation data collection method noted, the data archived, and SWI model retested/redeveloped using the newer precipitation data.

Table 8. Model Using Storms with Complete Data: 3,555 Storms

Variable	**Coefficient**	**Standard Error**	**Z**	**Prob. |z|>Z***	**95% Confidence Interval**	
WET_PRECIP	112.6	2.222	50.7	0.0000	108.3	117.0
DAY	-2.203	0.7177	-3.07	0.0021	-3.610	-0.7964
STORM_DURATION	0.02439	0.0008400	29.1	0.0000	0.02275	0.02604
DEC	-1.764	0.8544	-2.06	0.0389	-3.439	-0.08966
JAN	-2.998	0.6746	-4.44	0.0000	-4.320	-1.676
NO_PRECIP_RATIO	-17.28	1.229	-14.1	0.0000	-19.69	-14.87
CALM	-1.293	0.6489	-1.99	0.0463	-2.565	-0.02093
NORTH	-3.390	1.291	-2.63	0.0087	-5.920	-0.8593
METRO	-3.096	1.356	-2.28	0.0224	-5.754	-0.4377
WESTMD	-5.952	1.311	-4.54	0.0000	-8.522	-3.382
USHORE	-5.947	1.603	-3.71	0.0002	-9.089	-2.806
Constant	10.19	1.298	7.85	0.0000	7.650	12.74

***, **, * = Significance at 1%, 5%, and 10% levels.

The model goodness of fit measure is $R^2 = 0.6697$ and $\bar{R}^2 = 0.6687$. As noted in Washington et al. (2003), the absolute value itself does not measure the goodness of fit; rather, an improvement can be sited only if a new level of understanding is concurrently seen within an improvement in the values. Compared to some of the earliest versions of the model, using a considerably smaller dataset, the goodness of fit measure substantially improved. This suggests that there is significant improvement when comparing the model initially created with this more robust, data-intensive version.

The researchers tried to re-integrate some of the "storm" data that originally needed to be discarded due to missing data. In going back to these files, many of the erroneous variables were related to wind. Therefore, **a recommendation would be for MDOT SHA to improve the performance, maintenance, and calibration of the wind sensors**.

The following is the model using the larger dataset, with 3,635 storms (80 additional storms) which were found to have complete data for the statistically significant variables (Table 9 and

Table 10).

Table 9. SWI Model Using Storms with Data for All Statistically Significant Variables.

Variable	**Coefficient**	**Standard Error**	**Z**	**Prob. |z|>Z***	**95% Confidence Interval**	
WET_PRECIP	113.7	2.204	51.6	0.0000	109.3	118.0
DAY	-2.233	0.7071	-3.16	0.0016	-3.619	-0.8472
STORM_DURATION	0.02414	0.0008200	29.3	0.0000	0.02252	0.02575
DEC	-1.620	0.8435	-1.92	0.0548	-3.273	0.03319
JAN	-3.058	0.6637	-4.61	0.0000	-4.359	-1.757
NO_PRECIP_RATIO	-17.25	1.209	-14.3	0.0000	-19.62	-14.88
CALM	-1.331	0.6390	-2.08	0.0372	-2.584	-0.07911
NORTH	-3.408	1.280	-2.66	0.0077	-5.917	-0.8999
METRO	-3.183	1.349	-2.36	0.0183	-5.826	-0.5397
WESTMD	-5.938	1.305	-4.55	0.0000	-8.497	-3.380
USHORE	-5.912	1.596	-3.70	0.0002	-9.039	-2.784
Constant	10.22	1.290	7.93	0.0000	7.696	12.75

Compared with the previous model (shown in Table 8), in addition to an overall improvement in individual independent variable statistical significance, the overall model goodness of fit improved, albeit slightly, with $R^2 = 0.6703$ and $\bar{R}^2 = 0.6693$.

Table 10. Descriptive Statistics for Storms with Complete Data: 3,635 Storms

Variable	**Minimum**	**Mean**	**Maximum**	**Std Dev.**
WET_PRECIP	0.0003900	0.07080	2.731	0.1550
DAY	0	0.2525	1.000	0.4345
STORM_DURATION	3.000	368.6	4080	431.3
OCT	0	0.004402	1.000	0.06621
NOV	0	0.06823	1.000	0.2522
DEC	0	0.1593	1.000	0.3660
JAN	0	0.3117	1.000	0.4632
FEB	0	0.2663	1.000	0.4421
MAR	0	0.1895	1.000	0.3920
APR	0	0.0005500	1.000	0.02345
NO_PRECIP_RATIO	0	0.2183	1.000	0.2601
NUM_NO_PRECIP	0	20.58	478.0	36.06
TOTAL_NUM	1	74.74	1089	87.82
CALM	0	0.5827	1.000	0.4932
NORTH	0	0.3865	1.000	0.4870
METRO	0	0.2036	1.000	0.4027
WESTMD	0	0.2746	1.000	0.4464
USHORE	0	0.07263	1.000	0.2596
LOWER	0	0.03714	1.000	0.1891
SOUTHMD	0	0.02559	1.000	0.1579
Maryland Index Number	0	16.83	108.2	30.65

5.5 Model Interpretation

The following quartiles were identified for the data (Table 11).

Table 11. Quartiles of Final Data

Quartile	Value
Minimum	0
10th	0.78×10^{-3}
20th	0.4×10^{-2}
25th	0.624×10^{-2}
30th	0.11740×10^{-1}
40th	1.0204
Median	2.0362
60th	4.0644
70th	8.0
75th	12.201
80th	24.192
90th	76.354
Maximum	108.19

Figure 5. (to the right of table) Three levels of severity for the SWI model based on the quartiles shown in Table 11.

Ultimately, the final model was then used to develop a qualitative interpretation of storm severity. A five-tiered system was initially considered based on MDOT SHA's preference, but the interior categories were not well-defined and so were simplified into the three tiers shown in Figure 5. The following cut-offs were used:

- Less than 1.02 (GREEN):
- Greater than or equal to 1.02 to less than 8 (YELLOW): and
- Greater than 8 (RED).

These cut-offs were determined by evaluating the distribution of the SWI values from the storms used in model development. Note that the severe category (red) ranges from 8 to greater than 100. This range in values is due in part to the severity of storm events not being linearly related, as well as the many factors including the length of the storm, the amount of snow or ice that occurs during a storm, and the average temperature throughout a storm - which are unique for each storm and add variability. For example, a long duration storm with consistent snow the entire time and cold temperatures could have a high SWI value in the severe range; whereas, an intense short storm could have a lower SWI value in the severe range. **Future work could focus on breaking up the severe range (8 to greater than 100) into subcategories.**

Table 12 provides a summary of SWI ranges for mean, median, minimum, and maximum for the RWIS data from 2012-2019. Figure 6 and Figure 7 show median and maximum modelled SWI values for the 2012-2019 RWIS data.

Table 12. Summary of SWI mean, median, minimum, and maximum range for the 2012-2019 RWIS data.

	SWI Value Range
Mean	7.8 to 31.2
Median	3.2 to 22.6
Minimum	0 to 10.1
Maximum	10.1 to 341.2

5.5.1 Median SWI Value

The median SWI values range from 3.2 to 22.6 (Figure 6, Table 12). Overall, the SWI median values are lower than the SWI mean values shown in Table 12. This is due to the greater distribution of values in the lower ranges, with fewer, but higher values, pulling the median below the mean. With more storms falling into the lower ranges, the researchers used the median to more accurately capture the large number of smaller, less severe storm events seen when grouping the data. The central portion of the Northern Tier climate zone and the northern portion of the Metro climate zone both have a cluster of values in the mid-range of SWI values. The southern portion of the state (both the Southern Maryland and the Lower Shore climate zones) tend to have mid- to higher-range median SWI values.

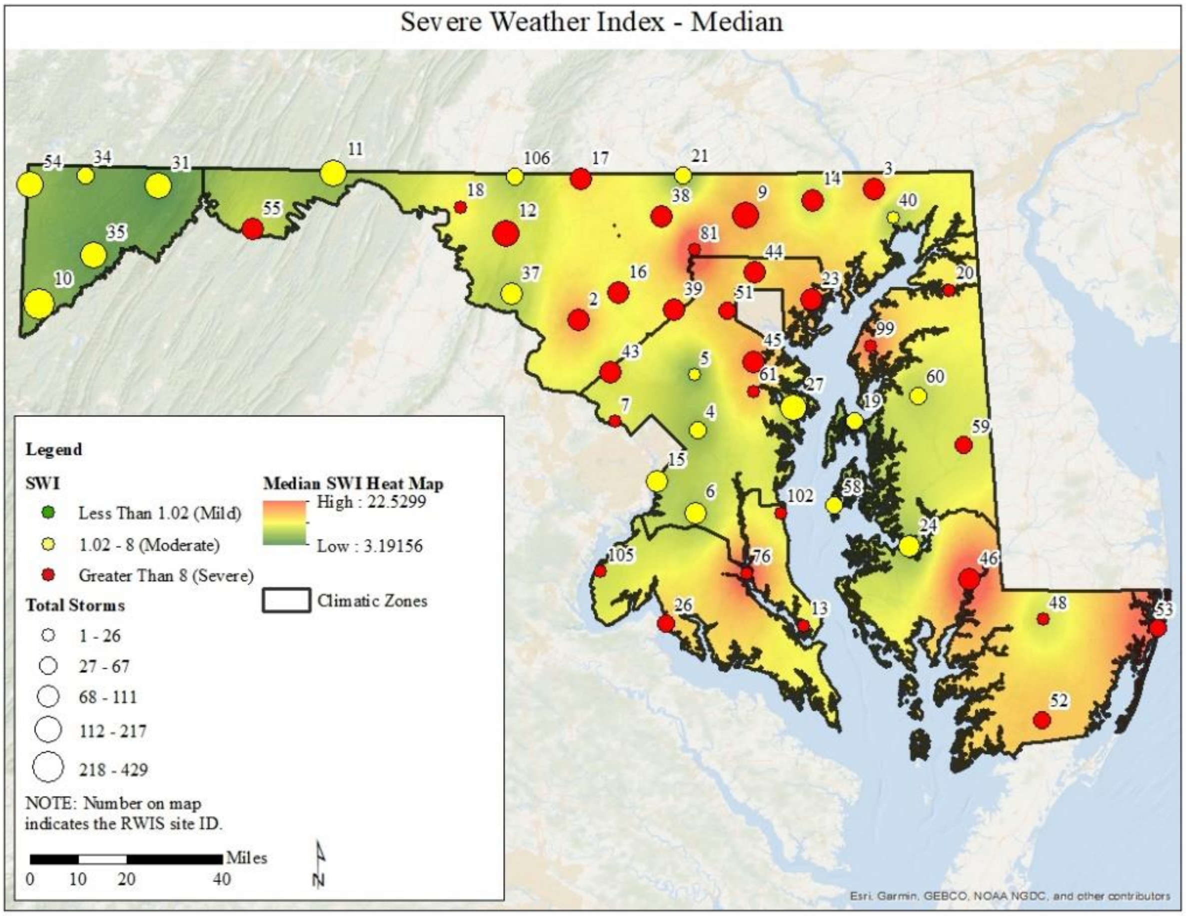

Figure 6. Shows the median SWI number from all storms identified from 2012-2019 in the state of Maryland.

5.5.2 Maximum SWI Value

The maximum SWI values range from 10.1 to 341.2 (Figure 7, Table 12). There is a cluster of mid- to higher-range maximum SWI values in the central portion of the Northern Tier and the northern portion of the Metro climate zone. Western Maryland tends to have some of the higher maximum SWI values. The Southern and Eastern portions of the State tend to have lower maximum SWI values.

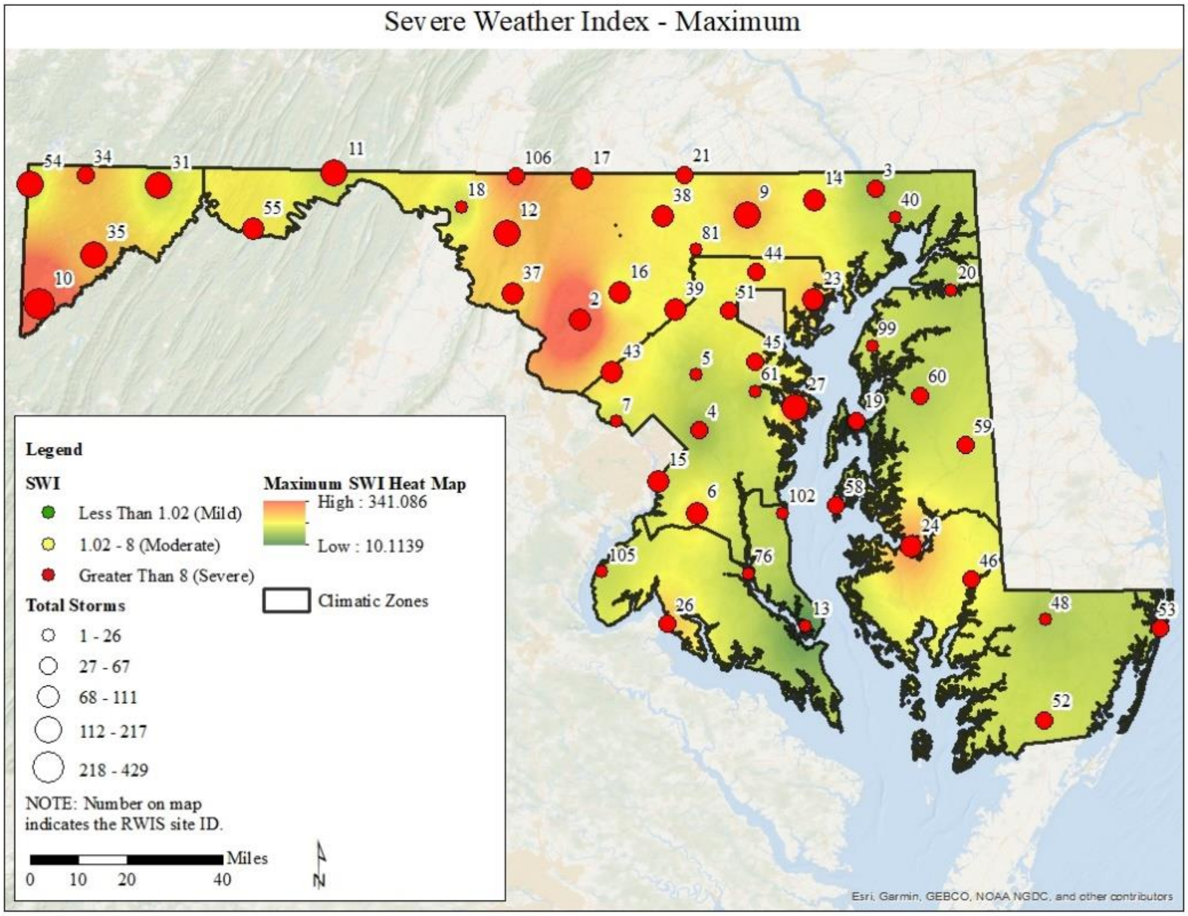

Figure 7. Shows the maximum SWI number from all storms identified from 2012-2019 in the state of Maryland.

Figure 6 shows the importance of the number of storms tied to each RWIS site (the size of the dots), where many of the RWIS sites with smaller dots, or fewer storms, show overall more severe SWI values. The median SWI value more accurately reflects the larger number of less severe storms that occurred in Maryland. This is supported by the minimum SWI value range shown in Table 12, which are very low across the State with a few exceptions, where limited numbers of storm data is likely skewing the results toward more severe (RWIS sites 13, 20, 40, 61, 81, 102). **For these RWIS sites MDOT SHA should consider working with the RWIS vendor to ensure the data is of the highest quality, and work to incorporate future storm data from these sites into the model to improve the accuracy of the SWI model**. The maximum SWI values shown in Figure 7 highlight where storms of greatest severity occurred, but overall show more moderate severity values across the central part of the State.

Overall, the median SWI values for the Western Maryland climate zone and central (south-west to north-east) portions of the State show consistently moderate winter weather (Figure 6). Compared to the maximum SWI values (Figure 7), it is apparent that western Maryland and other parts of the State do in fact have severe winter weather- when a storm is severe it is very severe. On the flip side of this, in Figure 6 the values for severe (red dots), when compared to the maximum severity, are much less severe overall (Figure 7). This appears to show that for many sites that have severe median SWI values, the overall winter weather is inconsistent, or spikey, and can range from mild, moderate, to severe during the winter season.

5.6 Model Performance

This section discusses the performance of the model, starting with visualizations of how individual storms were rated by severity across each RWIS site throughout the state, followed by a comparison of a photograph of the storm experience to the predicted SWI at each RWIS site nearest to where the photo was taken.

5.6.1 Individual Storm Model Performance

This section discusses the output of the model when considering individual storms. Table 13 shows the summary of the predicted SWI values for each RWIS site for three storms.

Table 13. Individual SWI Values by RWIS site, by Selected Storm

RWIS	Storm Date		
#	13-Dec-19	7-Jan-20	18-Jan-20
2	9.4	13.6	11.2
3		7.9	12.4
4		9.2	10.0
5		0	5.8
6			
7			9.4
9	2.9	11.7	13.6
10	0	6.9	35.0
11	2.9	9.5	8.2
12	11.8	17.0	32.6
13			
14	7.1		
15		3.6	10.0
16	6.4	11.6	30.7
17		22.2	22.5
18	14.2	24.9	34.6
19			0
20		0	3.3
21		27.6	41.8
23	2.0		
24			
26	6.5		11.0
27		5.7	20.2
31	0	0	37.4
34	0	0	20.4
35	1.9	10.9	29.1
37	5.0	9.2	12.0
38	9.7	17.3	33.7
39		8.9	12.0
40			6.0
43	0.527641	12.1	11.2
44	1.7	23.3	15.0
45		18.3	11.7
46		15.3	14.3
48			
51	0	20.7	14.9
52			4.0
53			
54	0	15.0	24.7
55	0	16.2	0
58			0
59		2.8	8.559398
60			
61		17.6	12.9
76			16.8
81		25.69592	16.7
99		8.4	16.0
102			5.1
105		16.1	5.5
106		20.1	33.5

These three storms were selected because one, December 13, 2019, was expected to be a “mild” storm, whereas the other two selected storms, January 7, 2020 and January 18, 2020, were anticipated to be “severe.”

Table 13 shows values and red, green, or yellow for storm severity, but in some cases, it also shows black. Black indicates that either there was no information, or a storm was not recorded at the individual RWIS site. The following details findings from RWIS sites with black fields:

- RWIS #6: No precipitation was detected the entire day and no storms were identified in the entire file. There is a possibility of a sensor error at the site.
- RWIS #13: The data file only contained date, time, and road condition data; there was no usable data.
- RWIS #14: It appears there was an error at this site with the sensors in general, because there were error readings for the precipitation type, but also intermittent recordings of data during the storm.
- RWIS #23: No information was available for: 1) precipitation, 2) total number of observations, and 3) average wind speed.
- RWIS #24: No new data was added. The storm on 1/18/2020 had sleet detected from 12:45-13:05 and 15:50 – 19:05 (along with intermittent readings between those two periods), but the air and road temperatures during this event were always above 35ºF, so the storm was never flagged.
- RWIS #48: Sleet/rain precipitation recordings started at 20:00 until 3:20 on 1/19/2020, but the road temperature (and air temperature) were above 35ºF, so the storm was not identified.
- RWIS #53: Data was not processed for this site since it was missing wind readings for the entire duration. There were possible sensor errors.
- RWIS #60: Sleet/freezing rain started intermittently at 18:25 until 23:40, but the road temperature was above 35ºF during the entire storm, so the storm was not flagged.

Figure 8, Figure 9, and Figure 10 show the results of each considered storm. These figures were created using ArcMap’s Inverse Distance Weighted (IDW) Interpolation to create a “SWI Heat Map”. IDW interpolation assumes things that are close to one another are more similar than things that are further apart. So, IDW works best when the sample points (in this case the RWIS station SWI values) are evenly distributed.

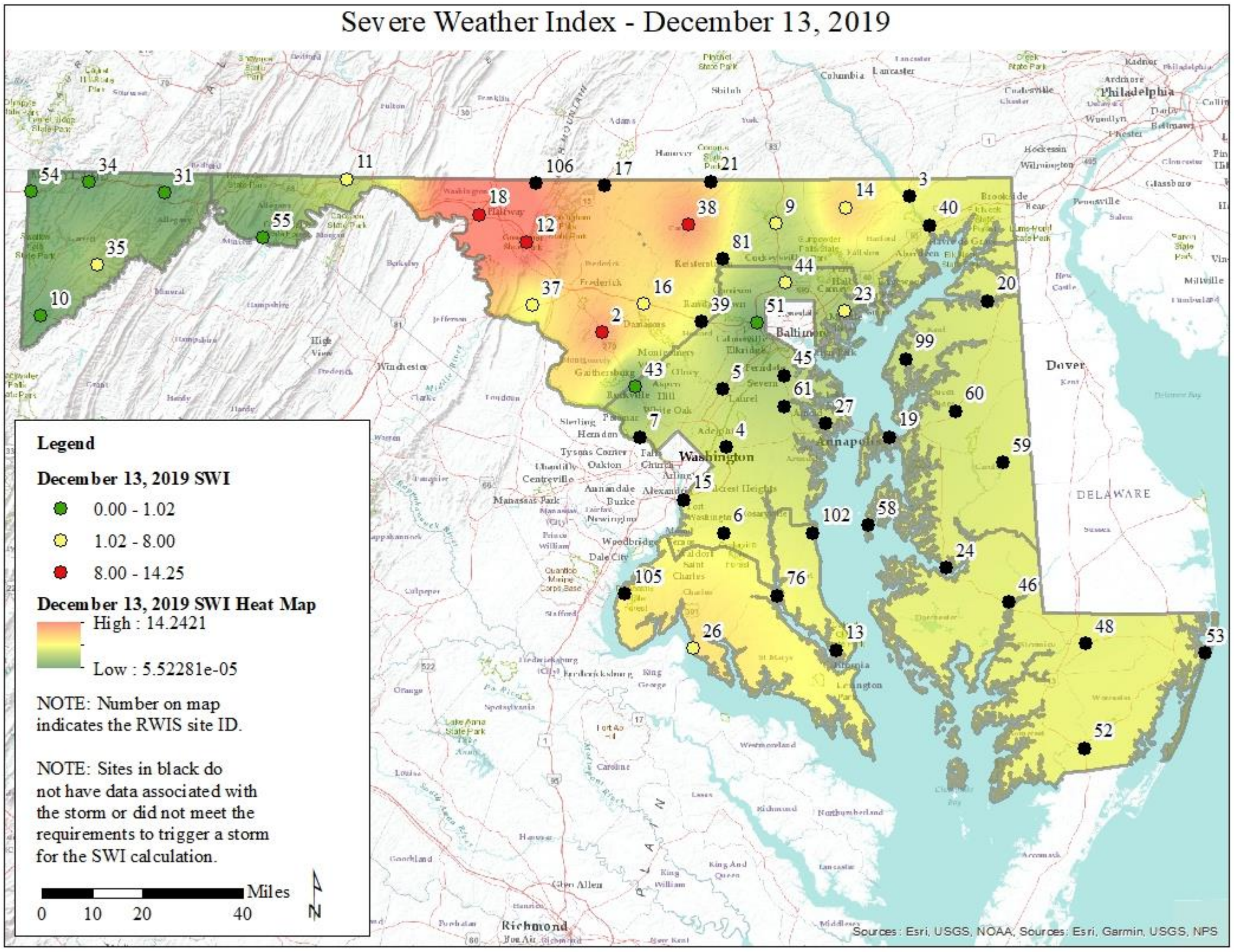

Figure 8. December 13, 2019.

Figure 8 suggests that both the definition of a storm as well as potential sensor errors limited the understanding of the severity of this storm across the state of Maryland (black dots). However, it would appear that the storm impacted the northern and western parts of the state, with the most severe being in the Northern Tier climate zone.

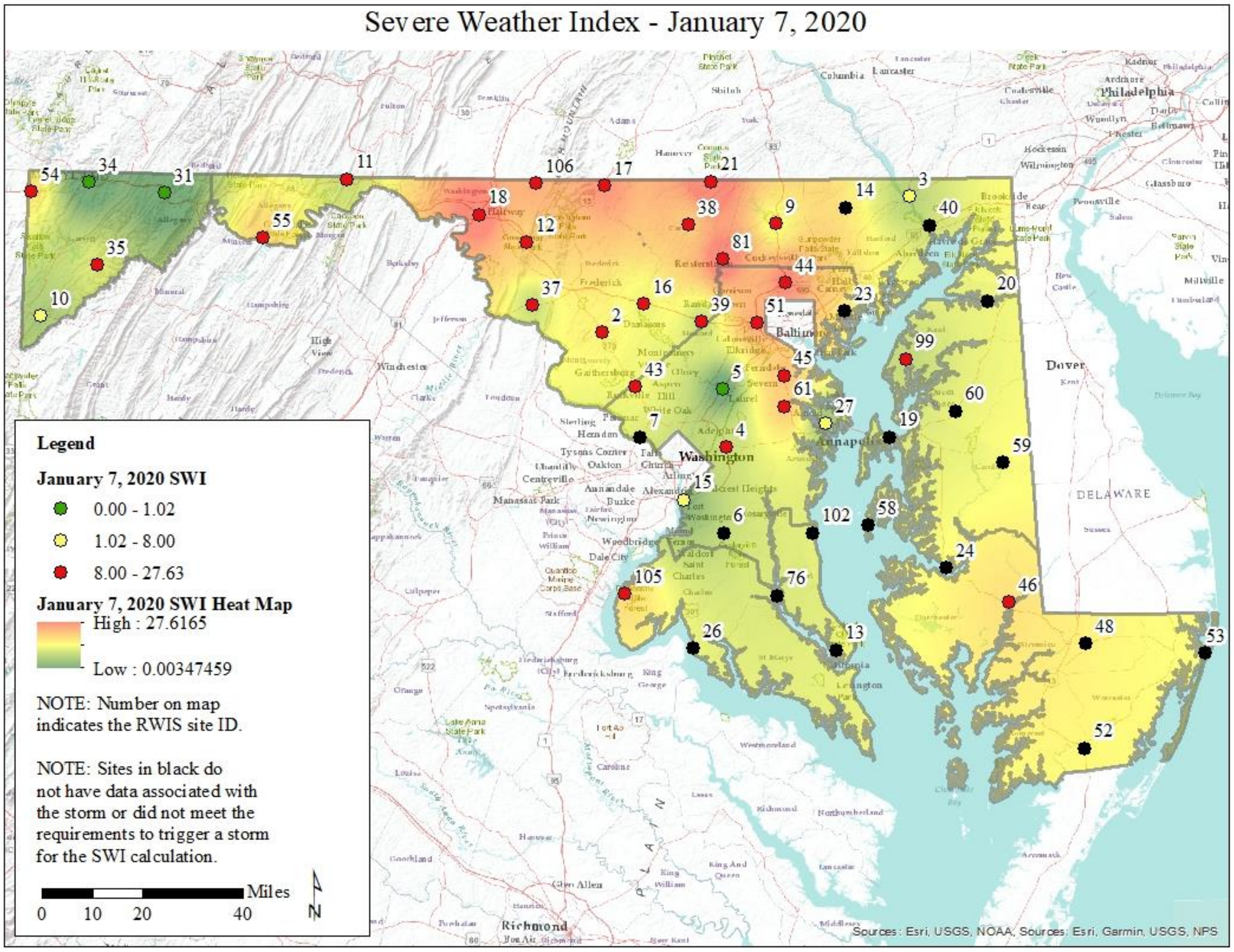

Figure 9. January 7, 2020.

As shown in Figure 9, overall the storm was not identified across the entire state and/or there were sensor errors (black dots). The storm identified for this date seems to have generally been severe across the entire State. The most severe impacts of the storm were in the Metro, Northern Tier, and Western Maryland climate zones.

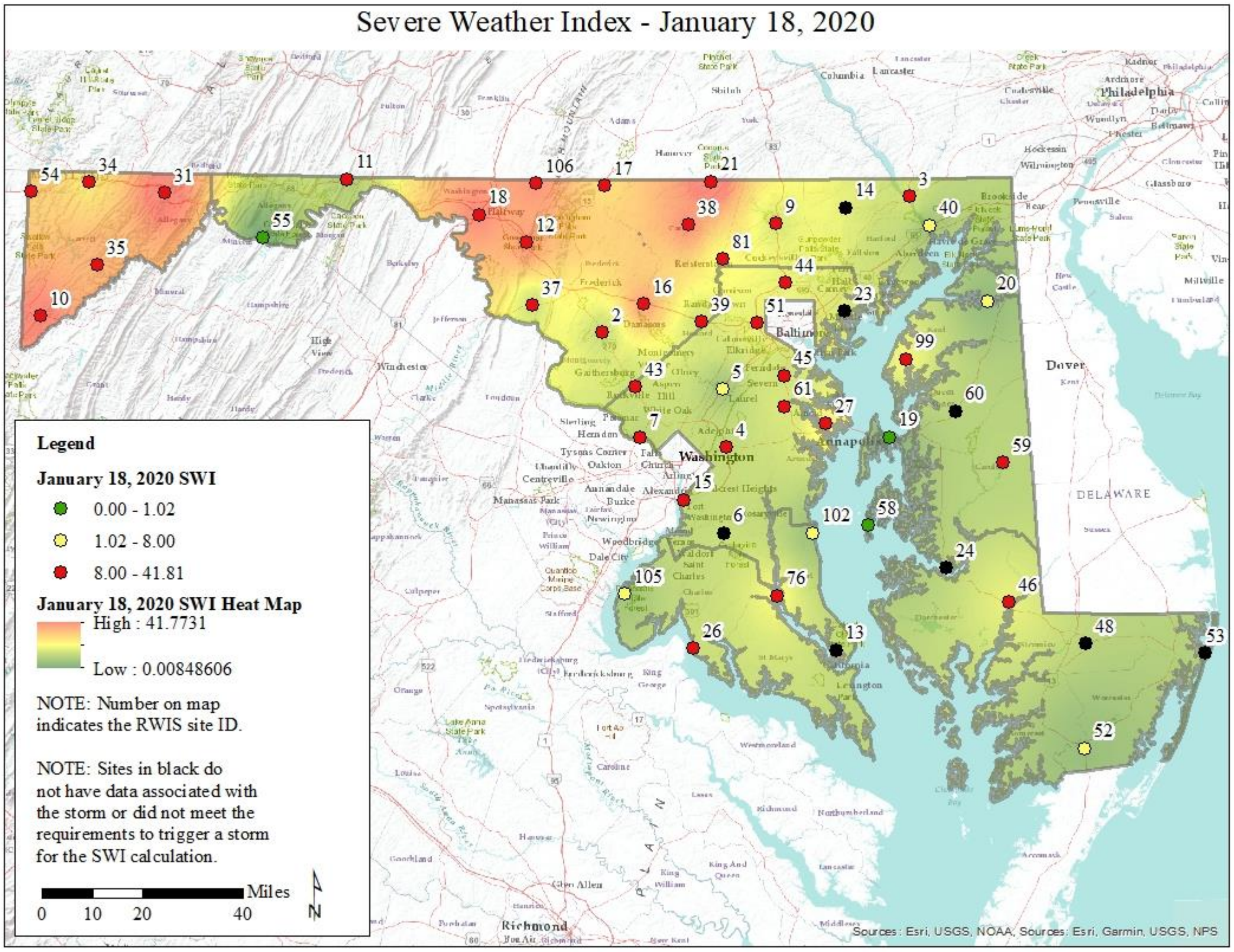

Figure 10. January 18, 2020.

In general, the storm that occurred on January 18, 2020 appeared to be severe for the Western Maryland and Northern Tier climate zones, and where the storm was identified, and information was available, less severe for the other climatic zones (Figure 10). Note that fewer black dots are present for this storm event compared to the previous two storms, suggesting that the definition of the storm may be a primary factor for data being included or excluded. **A recommendation would be for MDOT SHA to look at EORs reports and the SWI model output over time to determine if the storm definition is sufficient or if it can be refined in the future.**

5.6.2 Qualitative Model Performance

The researchers next sought to identify how quantitative (numerical value) and qualitative (green, yellow, or red) outputs from the developed SWI compare with qualitative visuals, photos from storms, and the severity assigned to the storm by an MDOT SHA Maintenance Engineer.

Some photos of mild storms were not identified as a storm using the SWI methodology[4]. The following storms are organized chronologically. Along with the photos, RWIS sites number, the SWI quantitative and qualitative output are identified, and the qualitative description provided by MDOT SHA staff is also identified.

Storm 1. October 21, 2018

Figure 11. October 21, 2018, Documentation of a "Mild" Storm, RWIS site #34

For this particular storm shown in Figure 11, the model provided a SWI value of 1.80, which would be defined as a MODERATE storm by the SWI. MDOT SHA indicated that this storm was "mild." Therefore, in this instance, the SWI and MDOT SHA assessments are inconsistent.

[4] These are instances where EORS reports will be critical to report road weather conditions and the associated winter maintenance operations. **Instances where the SWI model does not identify a storm that occurred should be flagged/noted for future work on the SWI to improve its sensitivity and ability to capture all events that require use of MDOT SHA resources.**

Storm 2. January 24, 2019

Figure 12. January 24, 2019, Documentation of a "Mild" Storm, RWIS site #54

For the storm shown in Figure 12, the model provided a SWI value of 0.75, which would be defined as a MILD storm by the SWI. MDOT SHA indicated that this storm was "mild." Therefore, in this instance, the SWI and MDOT SHA assessments are consistent.

Storm 3. March 22, 2019

Figure 13. March 22, 2019, Documentation of a "Mild" Storm, RWIS site #34

For the storm shown in Figure 13, the model provided a SWI value of 2.87, which would be defined as a MODERATE storm by the SWI. MDOT SHA indicated that this storm was “mild.” Therefore, in this instance, the SWI and MDOT SHA assessments are inconsistent.

Storm 4. December 17, 2019

Figure 14 through Figure 16 show an ice storm that occurred on December 17, 2019.

Figure 14. December 17, 2019, Documentation of a “Severe” Storm, Ice on Trees, RWIS site #34

Figure 15. December 17, 2019, Documentation of a “Severe” Storm, Ice on Powerlines, RWIS site #34

Figure 16. December 17, 2019, Documentation of a “Severe” Storm, Fallen Debris on Roadway, RWIS site #34

For the storm shown in Figure 14, Figure 15, and Figure 16, the model provided a SWI value of 118.86, which would be defined as SEVERE by the SWI. MDOT SHA indicated that this storm was “severe.” Therefore, in this instance, the SWI and MDOT SHA assessments are consistent.

Storm 5. March 15, 2020

Figure 17. March 15, 2020, Documentation of a “Mild” Storm, RWIS #34

For the storm shown in Figure 17, the model provided a SWI value of 11.87, which would be defined as SEVERE by the SWI. MDOT SHA indicated that this storm was “mild.” Therefore, in this instance, the SWI and MDOT SHA assessments are inconsistent.

Two additional photos were provided from a storm that occurred on April 15, 2020 through April 16, 2020 (Figure 18, Figure 19, and Figure 20). The storm required winter maintenance operations to be deployed. However, as discussed in the previous sections, since the SWI model is based on the winter season defined as October through March, this storm is outside of the range of the SWI model. (Note, that there were some April storm observations, but these are not comprehensive). Therefore, updates to the SWI could include collecting data for April, and potentially May and September, and maintenance shop staff should be consulted to help identify when winter storms occur outside of October through March bounds of the winter season.

In general, the model performed well in defining “severe” and “mild” storms; however, defining the bounds for the “moderate” storms needs to be refined, especially the low- and high-end of the bounds. **Over the course of the next winter season, the MDOT SHA could attach the SWI quantitative and qualitative output to storms, by RWIS site, and see how visual and qualitative input provided by maintenance shops might warrant modifications to the bounds of the three categories.**

Figure 18. April 15, 2020, Documentation of a “Mild” Storm, RWIS site #34

Figure 19. April 16, 2020, Documentation of a “Mild” Storm, Roadway Impact, RWIS site #34

Figure 20. April 16, 2020, Documentation of a “Mild” Storm, Bench Coverage, RWIS site #34

5.7 Add-ons

5.7.1 Blowing and Drifting Snow

An extensive amount of effort went into looking at methods to incorporate 6.2.1 Blowing and Drifting Snow (see sections 5.3.2 Variable Considerations and Modeling with Blowing Snow), and the associated effort on the part of MDOT SHA. Looking at data from District 6 (the Western Maryland Climate zone) it was determined that insufficient conditions were identified by the two methods to make a statistical analysis possible for this weather condition. **This highlighted the need to find a method to better characterize blowing and drifting snow, by identifying key variables that can be used when incorporating blowing and drifting snow in SWIs.**

To address the importance of blowing and drifting snow impacts on MDOT SHA winter maintenance operations, the research team and project panel agreed that adding on points after the SWI was calculated was the appropriate way to handle this weather condition at this time. The blowing and drifting snow add on is based on the cost value of staff time and equipment deployed to treat blowing and drifting snow over time. Table 14 was developed for MDOT SHA so that the agency can easily determine cost value and time in order to determine an appropriate add on quantity.

Table 14. Blowing and drifting snow table based on cost per person per equipment per hour

	Number of Active Routes						
Duration (hours)	0	1	2	3	4	5	6
	1	55	110	165	220	275	330
	2	110	220	330	440	550	660
	3	165	330	495	660	825	990
	4	220	440	660	880	1100	1320
	5	275	550	825	1100	1375	1650
	6	330	660	990	1320	1650	1980
	7	385	770	1155	1540	1925	2310
	8	440	880	1320	1760	2200	2640
	9	495	990	1485	1980	2475	2970
	10	550	1100	1650	2200	2750	3300
	11	605	1210	1815	2420	3025	3630
	12	660	1320	1980	2640	3300	3960
	13	715	1430	2145	2860	3575	4290
	14	770	1540	2310	3080	3850	4620
	15	825	1650	2475	3300	4125	4950
	16	880	1760	2640	3520	4400	5280

Cost per person per equipment per hour to treat blowing/drifting snow:	**$55.00**

Table 14 shows that as the number of staff that are deployed and or duration of the time treating blowing and drifting snow increases, the cost increases. From the values in the table, “points” are then added on to the calculated SWI value.

6. Future Considerations for SWI Modifications

Over the course of the next winter season, MDOT SHA could look at the SWI quantitative and qualitative output for storms, by RWIS site, and see how visual and qualitative input provided by maintenance shops might warrant modifications to the bounds of the qualitative categories (low (through 1.02), moderate (1.02 to 8), severe (greater than 8)).

6.1 Snow Density

A modification should be made on how snow density is calculated in the conversion from liquid film height (in milli inches) to snow depth. Currently, when converting liquid film height to snow depth, a conversation factor of 10 is used. This factor is based on a statewide average for Maryland and was provided by the National Weather Service. When a single snow density is assumed across the state and for all weather conditions, this grossly simplifies the calculation and can create additional error/variability in the SWI model. To show how much this could change the data, consider that when looking at two separate models used to calculate snow density based on other meteorological parameters (air temperature, wind speed (velocity), relative humidity, solar radiation, etc.) snow density can range from 50 to 250 kg/m^3, or snow density conversion factors ranging from 5 - 25 (Lafaysse et al., 2017; Hill et al. 2019). If considering air temperature alone, the following ranges could be applied (Table 15):

Table 15. Summary table showing air temperature and associated ranges of snow density (data used from Lafaysse et al., 2017).

Air temp (°F)	Snow density range (kg/m^3)
35.6	125 - >250
32	115 - 250
28.4	100 - 215
24.8	80 - 200
21.2	70 - 175
17.6	60 - 160
14	50 - 150
10.4	50 - 140
6.8	50 - 125

To improve the SWI model moving forward, MDOT SHA should consider building in a snow density conversation factor that considers climatological properties of the North-East and Maritime climates (Hill et al., 2019) and, from this, build a model/calculation within the SWI model that calculates a more accurate snow density. The conversion factor would consequently be based on, at a minimum, air temperature, but ideally air temperature, relative humidity, wind speed, and solar radiation. This will allow for a more accurate conversion of liquid-film-height-to-snow-depth.

6.2 Wind

Wind data is discussed at many points throughout this report (5.3.2 Variable Considerations, 5.4.1.5 CALM, 5.7.1 Blowing and Drifting Snow, Wind Speed, and Appendix E. Modeling with Blowing Snow).

The MDOT SHA may want to look at incorporating wind in a different capacity with improved data quality. Note that wind data was the limiting factor in using some storm data. With improvement of wind data – seen in improved identification of issues, maintenance, and calibration; additional wind-related factors could become significant in the model.

6.2.1 Blowing and Drifting Snow

The identification of blowing and drifting snow, as well as whiteout conditions, was attempted through a pair of approaches (as discussed in 5.3.2 Variable Considerations, 5.7.1 Blowing and Drifting Snow, and Appendix E. Modeling with Blowing Snow). Data from District 6 (Western Maryland Climate Zone) was used in the attempts to identify when blowing and drifting snow occurs, because District 6 had the largest number of storm events identified over the study period and good-quality, long-term data. The approaches used to identify these conditions were developed with input and feedback from District 6 personnel based on their experience. In developing these approaches, the limitations of RWIS data became apparent. Most significantly, visibility sensors were not commonly employed at most of the RWIS sites and were not available in the historic dataset (2012-2018). When these sensors were present, the data recorded was sporadic or questionable. Consequently, alternative approaches to identifying blowing and drifting conditions and whiteouts had to be developed.

Using these methodologies for blowing and drifting snow and whiteout conditions (provided in 5.3.2 Variable Considerations), it was found that limited occurrences of blowing and drifting snow and whiteout potential were present among storm events. That is not to say that these conditions were not present in many storms. Instead, the primary conclusion drawn is that these storm features are variable in terms of the locations where they occur. For example, it is unlikely that given shifting wind patterns, blowing or drifting snow will repeatedly occur at the fixed location of an RWIS station. Instead, locations, while they may occur repeatedly elsewhere due to terrain or other features, are more likely to vary from storm-to-storm. In order to collect this type of information and incorporate it into the SWI model in the future, additional data is needed from other sources. Visibility sensors at all, or critical, RWIS sites that are maintained and calibrated, would aid in identifying reduction in visibility and the degree of the reduced visibility.

Other data sources could also be considered. **One promising data source would be mobile RWIS, which, when combined with global positioning system (GPS) coordinates and automatic vehicle location (AVL) systems, could assist in pinpointing the location of blowing or drifting snow from storm-to-storm.** That locational information could then be tied to the meteorological conditions at the site as well as conditions at the fixed RWIS stations.

Plow cameras could also be used to identify blowing and drifting snow or whiteout conditions. This would require short intervals between photo captures and automated image processing software to automate condition classification. In using any or all of these approaches, future research could explore the possible trends that might be identified, which can feed into the SWI model and identify the likelihood of blowing and drifting snow and whiteouts.

6.3 Ice Events

From the outset of this effort, icing events like the December 2019 storm shown in Figure 21 (discussed in more detail in Storm 4. December 17, 2019), were identified as a winter storm type that MDOT SHA has to manage and would like to have incorporated into the SWI.

Figure 21. December 2019 storm event that caused severe ice buildup. Left image: tree covered in ice. Right image: close up view of a tree branch covered in ice with a hand for scale of ice thickness. Photos provided by MDOT SHA.

Based on the review of existing SWIs, methods to identify and incorporate icing events are limited, and there is no formal, agreed upon method to do this. For example, freezing rain is challenging to incorporate into SWIs, because it is difficult to observe using automated, ground-based sensors. Some methods used to detect freezing rain include: operator reports that indicate and note the duration of rain (Iowa DOT); Maintenance Decision Support Systems (MDSS) coupled with a pavement model and estimated ice accumulation features (Minnesota DOT); RWIS data including presence of precipitation, web bulb temperature (>34°F), and road temperature (≤ 32°F) or ice warning systems (Utah DOT). Utah's method of using of wet-bulb temperature presents perhaps the most thermodynamically correct way to estimate the occurrence of freezing rain using automated sensors. Other methods indirectly determine icy conditions, for example use of friction measurements (Idaho Transportation Department).

The following idea using automated instrumentation was proposed by University at Albany researchers working with New York State Department of Transportation (NYSDOT) as a modification to the Accumulated Winter Season Severity Index (AWSSI) and is still being tested: a proxy estimation of the occurrence of icing due to freezing rain may be possible using wind sensors from New York State's mesonet network of weather stations. Each mesonet site contains a propeller anemometer and a sonic anemometer. If the propeller anemometer is no longer reporting wind speed, but the sonic anemometer is still reporting, one may infer that the propeller anemometer has iced up and its propellers can no longer rotate (note: the sonic anemometer can still report with a light ice coating, and some models are heated). Some wind must be present for this method to work. Again, this method is only proposed at this point, and has not yet been validated.

Other ideas of how freezing rain could also be measured include, but are not limited to, using meteorologically modeled or observed vertical temperature and humidity profiles; or using the Community Collaboration Rain, Hail & Snow Network (CoCoRaHS) or the National Weather Service (NWS) Cooperative Observer Network (COOP) data.

Investigating and evaluating potential freezing rain measurement is recommended for future work and has by no means been solved or a best method determined.

MDOT SHA identified another method to incorporate icing events that could be useful. Whenever an icing event occurred (based on notations by maintenance staff in EORS reports), the storm event would be designated/classified as a "severe event," because the effort required by winter maintenance operations to manage and treat icing conditions are always significant (in terms of effort, person and equipment hours, material used, damage caused, etc.).

6.4 Incorporating Data from non-RWIS sources

Currently, MDOT SHA has additional road weather data being actively collected from non-invasive road sensors (NIRS), which are mounted on or near RWIS stations, and mobile RWIS units mounted on vehicles. At this time, the appropriate method to combine stationary, invasive RWIS sensor data and stationary non-invasive RWIS sensor data has not been determined. An active Aurora Pool Fund project is investigating this issue (https://aurora-program.org/research/in-progress/invasive-and-non-invasive-sensing-assessing-agreement-between-measurement-systems/). If a solution is found, MDOT SHA could incorporate this data into the SWI model.

Currently MDOT SHA has 65+ mobile mounted RWIS units on vehicles. However, at this time, the appropriate method to combine mobile and stationary road weather data has not been determined. It is recommended that future research investigate methods to combine these data sources to allow for use in SWI models.

6.5 Precipitation Data

An outcome of the project was the identification of a key gap in precipitation data collection. Out of the 5-minute interval over which precipitation is recorded, the data was only reporting one-minute worth of accumulated precipitation. This means that precipitation that fell during the other 4-mintues of the 5-minutes interval was not recorded. This created a significant underestimation of total precipitation per storm event that was recorded; and warranted an assignment of weights for the Maryland # (more information provided in 5.4.1.1 Maryland #). **MDOT SHA personnel were challenged to rectify the total storm accumulations that their EORS were recording with that recorded at the RWIS sites.** A related issue is that precipitation rate is critical but unknown with the way the data is currently collected. For example, a high precipitation rate will have significantly more accumulation over time compared to low precipitating rate storm event. The way the precipitation data is currently collected does not allow for precipitation rate to be accurately determined.

It was determined that the data is collected this way because that is how the RWIS stations were wired when installed. MDOT SHA has been informed of this issue. If the agency should have the RWIS sites rewired to collect precipitation data in a different format, how this impacts the SWI model will need be investigated.

6.6 Traffic and Safety Data

The SWI model does not incorporate traffic (e.g. average annual daily traffic, peak period traffic distributions) or safety data (property damage only, injury, and fatal crashes). There is a day/night variable that has been considered in the SWI model, but this is tied to daytime winter maintenance operations generally being less severe due to the input of solar radiation to the system (additional information on the Day variable can be found in 5.3.2 Variable Considerations, DAY variable). **Future work could look into how traffic and/or safety data could be incorporated into the model as an observed measure of storm severity.**

6.7 SWI Resolution

Currently, the SWI model provides a calculation for each RWIS station, but the accuracy of the model is at the more granular resolution of climatic zones. However, this is generally consistent with what is found in the Literature Review, where more aggregated estimates of storm severity were developed. **To improve the resolution of the SWI model, down to for example each maintenance shop, additional data is needed to fill in gaps in the existing RWIS network and the existing RWIS station data should be maintained to the highest level to ensure good, quality data.** This will enable the MDOT SHA to make most effective use of its investments. Interviews of the maintenance shops identified potential locations for future RWIS and can be found in Appendix C – Maintenance District Interview Summary, Recommended Future RWIS Site and Blowing and Drifting Snow Locations.

6.8 Other Considerations

Throughout the research effort, many ideas were brought forth for consideration but were not could not be addressed within the project scope. The following is a summary of these and how they relate to the developed SWI model.

6.8.1 Differing Pavement Types

Different pavement types, such as asphalt and concrete, can behave differently in winter. For example, asphalt is dark and benefits from absorption of ultraviolet radiation to aid in keeping pavement temperature warmer and melting snow and ice off of the roadway. By contrast, concrete, which is lighter in color, does not see the same benefits. In winter maintenance operations, anecdotal evidence suggests that asphalt road segments may require less deicer application. This tangentially relates to the application of SWI values, when the SWI is tied with performance management.

Many things would need to be considered before this could be done in Maryland. For example, just to name a few, the network of pavement types along maintenance routes would need to mapped; the location of RWIS stations in relation to these pavement sections would need to be captured and linked with automatic vehicle location (AVL)/global positioning system (GPS) data from plows reporting plowing, deicer applications, and pavement temperature; and potentially many other data variables would need to be collected. It is recommended that pavement considerations be included as a future research idea.

6.9.2 Changes in LOS Guidelines

Changes to level of service (LOS) guidelines can have huge impacts on how winter maintenance operations occur, and the effort put forth by a DOT. This tangentially relates to the application of SWI values, when the SWI is tied with performance management. Changes in LOS should be observable and can be seen as changes in cost, hours of effort, equipment use, materials applied, and more. To observe these changes, a historic data set of performance before the change to LOS would need to be available to compare to current data after changes to LOS – a before/after analysis. This is an exercise MDOT SHA should be able to perform in-house if sufficient data is available.

The MDOT SHA uses the following performance measures to support its LOS guidelines:

- Number of lane miles on the Maryland state highway network.
- Inches of snowfall by district and statewide.
- Pounds of salt used per lane mile per inch of snow.
- Percentage of events when shops reported a time four hours or less to regain bare pavement after a winter storm.
- Number of hours required to regain bare pavement after a winter storm.
- Total winter dollars expended per lane mile per inch of snowfall.

The developed SWI considers inches of snowfall and the four hours after precipitation as the end of a storm, which are shown above. To apply the SWI to all of these performance measures, accurate data on snow fall amount, applied material (liquid and solid), regain time to bare pavement, and costs need to be collected and tied to each storm event.

6.9.3 Relative Humidity Impacts on WMO

Relative humidity is known to have an impact on winter maintenance operations (WMO), specifically deicers. MDOT SHA is interested in looking into the relationship between relative humidity (RH), temperature, and winter maintenance effort. [This is based on very specific issues observed by the MDOT SHA Traffic Operations Center, where deicers (e.g., salt, salt brine, maybe magnesium chloride) functionality appeared to decrease when the RH was around 70% and the temperature was around 31°F.] This tangentially relates to the application of SWI values, when the SWI is tied with performance management and traffic safety. It is recommended that this be included as a future research idea.

7. Recommendations

In addition to the development of the SWI model, a key outcome of this effort is the development of the following recommendations, which were identified through the research process.

General Recommendations

- General Improvements to RWIS include:
    - Data tracking to identify problems, improved consistency in statewide maintenance and calibration of RWIS sensors.
    - Consider a statewide DOT position tasked with reviewing RWIS data, notifying the maintenance contractor when maintenance or calibration is needed, and requiring a response time for work to done by the contractor.
    - Consider requiring all maintenance districts to adhere to statewide RWIS performance guidelines/expectations.
    - Conduct training on how to use the SWI and the benefits of RWIS station data to promote buy-in from the maintenance districts and MDOT SHA Leadership.
    - Replacement of sensors – as RWIS sensors need to be replaced or upgraded, try to do this consistently across the state and record when this was done.
    - Consider adding to the RWIS network – to geographically representative areas, not micro-climates (see Recommended Future RWIS Site and Blowing and Drifting Snow Locations).
    - Consider investigating other methods to collect precipitation data. This may be modifying how each RWIS records precipitation and/or changing to a different precipitation data source to improve accuracy.
    - To better support winter maintenance operations consider adding visibility sensors to key RWIS locations to specifically aid in the detection of blowing and drifting snow.
        - There is potential to use existing cameras in this capacity but the feasibility of this should be further investigated before implementation.
        - Additionally, for RWIS sites with existing visibility sensors, improvements to maintenance and calibration are needed before this data can be successfully incorporated into the SWI model.
- Improvements, changes to EORS reporting:
    - There are times when EORS reports will be critical to report road weather conditions and the associated winter maintenance operations because they are not adequately reflected in the RWIS data. For example, instances when the SWI model does not identify a storm that occurred or a winter event occurred that required maintenance operations should be flagged/noted for future work on the SWI to improve its sensitivity and ability to capture all events that require use of MDOT SHA resources.

    - Changes to EORS reports to support the SWI model.
        - Allow for indication of blowing, drifting snow extent (spatially and temporally) and the effort required to treat it (person/equipment hours, material, etc.).
        - Allow for indication of icing, freezing rain extent (spatially and temporally) and the effort required to treat it (person/equipment hours, material, etc.).
        - Record snow depth in inches accumulated over the storm event.
- Improvements to Data:
    - Develop and implement guidelines for data storage. This includes length of time data is stored, taking into consideration the need for longer-term data sets, and avoiding data being purged in the short term due to limited storage capacity. Five to 10 years of historical should be sufficient for modeling purposes.
    - Create a data dictionary for the developed data sets, spreadsheet tools, etc. (see file [MDSHA_Data_Dictionary.xlsx]). Being aware to clearly link (aka crosswalk) and define station nomenclature. This includes creating a universal or consistent language within the agency and with the weather data provider(s).
    - Have confidence in the data you captured – by ground truthing, calibrating, and conducting routine maintenance on each individual sensor. Apply consistent QA/QC processes to the collected data to ensure it is good, quality data.
    - Track changes in sensors over time, noting sensor units or how changes in the data quality, resolution, or frequency of data captured have changed over time.
    - Data:
        - Rounding consistency for accuracy for each data piece. This may require checking with the weather data vendor to ensure all data pieces are reported as expected.
        - Ensure the units of each data piece are consistent and in the format needed. For example, precipitation recorded as mils versus inches of liquid equivalent or wind recorded as miles per hour versus knots should always be the same.
        - If data is being collected and reported in time intervals (such as 5-, 10-, or 15-minute intervals, which are common for reporting), ensure data is collected over the entire time interval and then reduced to single data point that is reported. In this way, you will have all of the data and a more complete picture. You may need to work with your weather data vendor to ensure all data is captured but then also reported in the time interval that best suits your needs.
    - Support Staff:

        - Some state DOTs have found success in partnering with a university to establish student internship and mentorship programs. Much of the data processing and QA/QC could be done by student interns.
- Improvements to the SWI model:
    - Combining other data sources to improve data resolution. It is recommended that future research investigate methods to combine RWIS station data sources, including invasive and non-invasive sources, and stationary RWIS and mobile road weather data sources. The data would then be available for use in SWI models.
    - The SWI model must be applied carefully, or not at all, for the months of April and October, due to the limited number of storm events that were collected and incorporated into the model for these months. October and April were also outside of the original scope of data collection. A better understanding of the time period over which winter storms occur and require resource allocation should be incorporated into future SWI improvements. To improve the SWI model for April and October, it is recommended that MDOT SHA collect storm data paired with EORS reports for these shoulder months.
    - Consider linking information systems to aid in information integration. Specifically, for MDOT SHA, consider linking the Emergency Operations & Road Conditions (EORS) report to the RWIS data. This will allow for use of EORS reports to provide supplemental information and to ground truth that data.
        - Consider having EORS reports include blowing snow occurrence, duration of blowing snow, drifting snow (location and description), measured precipitation type and depth.
    - Winter maintenance operations variation on different pavement types. For instance, if a large temperature discrepancy is found between pavement types (asphalt versus concrete), future analysis could investigate if it is costlier to provide winter maintenance operations on asphalt or concrete. The same is true if the amount of effort required to treat different pavement types is found. This may be observed as more frequent route timing, higher or more frequent application of deicers, lower friction or quicker reducing in friction values. An assessment of how the varying pavement types are treated differently could also be done.
        - This may be a side project that can be pursued as more data is amassed over time. It may be possible to use a percent multiplier for the percent of asphalt/concrete in an area. Or, it may be a minor difference that is not seen in the amassed data.
        - It may be necessary to use AVL/GPS-based data for each plow, on each route, and detailed mapping of plow routes and pavement types on these routes.

8. Conclusions

An SWI model was developed for MDOT SHA using RWIS data from the 2012 to 2019 winter seasons (defined as October through March). It was then tested using data from the 2019-2020 winter season. The SWI model is based on 3,635 identified storm events from 2012-2019 across the state of Maryland. The state of Maryland was divided into six climate zones (Western Maryland, Northern Tier, Metro, Upper Shore, Southern Maryland, and Lower Shore) so that data from RWIS sites that experience similar weather and climate patterns could be more accurately grouped for analysis. The resolution of the SWI can be statewide or down to the climatic zone.

An SWI value can be calculated for every winter storm event, by month, or for the entire winter season, by climate zone or for the whole state.

The SWI is a living tool, which means it should evolve over time with the addition of new data, refined variables or parameters, improved resolution, and other factors. To allow for this to occur and to realize the full potential of the investment in development of the SWI, numerous recommendations have been made on the RWIS network and data management, use of supplemental information and data, and potential areas to improve the SWI in the future (which can be found in the Recommendations section).

The development of the SWI was done with significant input and guidance from MDOT SHA. This collaboration is reflected in aspects of the SWI development, calculation method, and model output.

Glossary

ACIS - Applied Climate Information System

ASOS – Automated Surface Observing System

AVL – Automatic Vehicle Location system

AWDN - High Plains Regional Climate Centers Automated Weather Data Network

AWOS – Automated Weather Observing Station

CoCoRaHS – Community Collaborative Rain, Hail & Snow Network

COOP – Cooperative Observer Network

EORS – Emergency Operations Reporting System

EC – Environment Canada

FACT - Financial Activity Data Warehouse

GPS – Global Positioning System

IDW - Inverse Distance Weighted

LOS – Level of Service

MADIS - Meteorological Data Assimilation Ingest System

MATS - Maintenance Activity Tracking System

MDOT SHA – Maryland Department of Transportation, State Highway Association

Mph – miles per hour

NASA - National Aeronautics and Space Administration

NCEI - National Centers for Environmental Information

NCDC - National Climatic Data Center

NDFD - National Digital Forecast Database

NIRS – Non-Invasive Road Sensor

NLDAS - North American Land Data Assimilation System (NLDAS)

NOAA – National Oceanic and Atmospheric Association

NSIDC - National Snow and Ice Data Center - Snow Data Assimilation System (SNODAS)

NWS – National Weather Service

PERSIAN-CDR - Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks – Climate Data Record

QA/QC – Quality Assurance/Quality Control

RH – Relative Humidity

RWIS – Road Weather Information Systems

SNOTEL – Snow Telemetry

SWI – Severe Weather Index

UTC –Coordinated Universal Time

WMO – Winter Maintenance Operations

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Appendix A – Full Literature Review

Table 16 provides a more in-depth description of findings within each piece of literature reviewed.

Table 16. Summary table of reviewed documents and relevant findings.

Title (Year), Reference, Web Link	Findings
A Winter Weather Index for Estimating Winter Roadway Maintenance Costs in the Midwest, Carmichael et al. (2004) https://journals.ametsoc.org/doi/abs/10.1175/JAM2167.1	Carmichael et al. made use of an artificial neural network (ANN) to create a winter weather index. They suggested that this was superior to a linear regression technique, citing the ANNs ability to learn by induction. For example, in the project the ANN was able to "reconstruct" snowfall information that had been unavailable. A drawback, however, is that since ANNs have no prior knowledge, they require vastly large datasets. For this project, the National Climatic Data Center (NCDC) and Iowa Climate Summary (IA Climo) data sets were utilized. They noted a challenge to create a good correlation between winter severity and road treatment costs was the fact that urban maintenance garages have more lane miles to maintain than rural ones. The authors compared the results of the ANN to Strategic Highway Research Program (SHRP) index and concluded that the ANN was superior. Not only did it have better correlations with operational variables, it was better able to correctly predict "small-scale spatial variations". When considering which operational variables ANN could predict, it was found that ANN was better able to predict winter index in terms of hours of labor, as compared with the cost of labor.
Indiana Winter Severity Index, McCullough et al. (2004), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.694.8081&rep=rep1&type=pdf#page=176	Predating the energy balance work reviewed above by Baldwin et al. (2015), the work by McCullough et al. (2004) reviews the need for Indiana DOT to develop a weather severity index (WSI) and the methods developed and/or used by various states at this time (Wisconsin, Washington State, the modified Hulme, and the Strategic Highway Research Program Index). Based on the limitation in the identified WSI calculation methods, one was developed for Indiana that incorporated weather data. Using NOAA weather data, the following weather events and data included: • Frost day • Freezing rain • Drifting • Snow • Snow depth

	• Storm intensity • Average temperature Input on important factors and how they were weighted in equation was captured from winter maintenance operators. They validated and modified the WSI using lane-mile snow removal costs. Additional multiple regression analysis (using SAS) was used to refine the weather severity index allowing for WSI equations to be developed for four locations in the state as well as a statewide WSI equation. Identified potential uses of the WSI include: • Verify snow and ice removal expenditures • Determine if new technologies, trainings, etc. are reducing costs • Resource allocation • Cost-benefit analysis for newer equipment, changes in funding regionally, etc.
Development of a roadway weather severity index,*Strong et al. (2005), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.536.9207&rep=rep1&type=pdf	Strong et al. (2005) developed a roadway winter severity index (WSI) for Oregon DOT focused on establishing a relationship between highway crash rates and weather phenomena. The resulting WSI was to be simple, easy to interpret, followed common sense, and relatively easy to compute. From their review of literature published on this topic prior to 2005, Strong et al. found that: • the relationship between winter weather and safety was "relatively unexplored". • a variety of approaches for defining variables were used and there does not appear to be a "universal relationship" between specific weather variables and other factors. • a single model applied over a large geographic area will likely not hold up. • a robust statistical analysis is required to ensure the quality of the output. Strong et al. (2005) used the following data from California, Oregon, and Montana: • weather data from RWIS or NWS • crash counts • annual average daily traffic counts (AADT) • monthly adjusted factors (MAF) to average daily traffic (ADT) counts

	*A full list of data collected from each state is available below in Strong et al. (2005). Assumptions made in the data processing were that weather data can only be extrapolated out 5 miles from each RWIS location, and crash data can only be used if it occurred within the 5-mile radius of the RWIS site. Locations with very high and very low **traffic counts** were removed because crashes in these locations can distort the crash rate (AADT>60,000 vehicles per day and AADT<800 vehicles per day). New variables were calculated to create a consistent data set with the data collected by the state. Weather station locations were classified by climatic zone: 1) mountains, 2) valleys, 3) plains. Sites with **high-crash rates** related to road condition and geometry were removed. In processing the data, a normal distribution was used to model the crash data, and monthly average crash rates were used as crashes per month per 1,000 daily vehicles on the road to account for AADT. The cube root transformation of the response was adopted in the analysis of the data. Missing data presented a problem. For each statewide data set, the models were tailored and run separately each month for each zone (1,2,3) and statewide, and found that crash rates are more attributed to weather in Oregon and Montana than in California. It is also important to note that, for California, NWS data was used, whereas RWIS was used for Oregon and Montana. The use of one set of MAF was a deficiency in the dataset and may have caused significant bias in the models. Different weather variables had different levels of significance in each state, such that black ice was well correlated with crash rates in California but was not the case in Montana. Points from Strong et al. (2005): • The models used between climactic regions within Maryland, even between maintenance shops, may vary. • Key weather variables used in the models may vary between climactic regions and maintenance shops. Method used – test various models on all data sets to define which models works best where and calibrate the weather index to be intuitive.

A Winter Severity Index for the State of Maine, Marquis (2009) https://trid.trb.org/view/1238126	The Maine Department of Transportation changed from a reactive approach to a proactive approach to winter maintenance, recognizing that twenty percent of their operating costs were going to winter maintenance and the costs were increasing annually. They wanted to evaluate the impact of the effectiveness of the change, thus created a winter severity index (WSI) for the season for the five regions within Maine. The authors made use of a Cooperative Observer Program (COOP) weather station. The process is somewhat rudimentary as they suggested "assigning point values to snow events" to generate the WSI. The document does provide an **equation with which to incorporate freezing rain**, the Modified Daily Snowfall formula. They made use of Financial Activity Data Warehouse (FACT) data which provides a summary of labor, equipment, and material costs. Through the Maintenance Activity Tracking System (MATS), the Maine DOT tracks activities and material usage for every maintenance crew. The authors modeled their maintenance zones based on the forecast zones identified by the National Weather Service.
Estimating the relationship between snow and ice maintenance performance and current weather conditions,* Maze et al. (2009), https://trid.trb.org/View/880902	This work estimated the relationship between winter maintenance performance and weather condition data. This project was the first attempt to determine a relationship between weather data and winter maintenance performance in Minnesota. To assign value to performance variables they took road classifications and the time to achieve the prescribed LOS; for example: 3 hours to achieve bare pavement on super-commuter routes. Then, if it took 4 hours to achieve bare pavement (4hr to reach bare pavement divided by 3hr bare pavement goal or 4/3 = 1.33) performance index that can now be used in the severe weather index calculation. The overall calculation method used was a mixed linear retrospective model, e.g., using past data. Weather-related variables used included snow, maximum and minimum temperatures, location of the road segment, and time. Another variable identified by practitioners to be of importance was the direction of the road segment (north-south or east-west), which was built into the equation. Roads N-S trending were assigned a "1" and E-W trending roads were assigned a "0". Average daily traffic was also included. A combination of RWIS and NWS weather sources were used. *A full list of variables is available below in Maze et al. (2009). The report provides details on how the equation/model was derived and tested and provides the equation for the model used. The work found that it is possible to use measurable weather data to estimate differences in winter maintenance performance

	across routes, districts, and sub-districts based on storm severity. They also found that the analysis can be done within a day or two of each storm, so that performance can be modified during the season.
Utah Winter Severity Index Phase 1, Farr and Sturges (2012) https://www.udot.utah.gov/main/uconowner.gf?n=11539601019505676	Farr and Sturges discussed the desire by the Utah DOT to allow them to understand how winter storms impact maintenance operations. In particular, they wanted to quantify the weather impacts into one value, the winter severity index (WSI). They noted that this may be done either season-by-season or storm-by-storm. Many of the authors of documents related to a SWI have noted that the state they are looking at is different than others. Farr and Sturges noted that it was not just the mountainous terrain of Utah that was different. Utah noted that the state rarely, if ever, experiences freezing rain. In contrast, the occurrence of freezing rain was noted to be incorporated by others for Iowa, Indiana, and Maine. The document defined SWI as a single value representing the impact of individual elements of a storm. These elements are those which have the greatest impact. Impact can be to society (i.e. a state's travelers) or to the organization (i.e. a DOT). They suggest that precipitation (i.e. type, rate, quantity, and duration including impact of elevation) and road surface temperature are the most influential storm elements for road conditions. The authors indicate that winter severity index (WSI) may also be called storm severity index (SSI), winter index (WI) or local winter storm scale (LWSS).
A new model for a winter index for estimating and evaluating de-icing salt consumption (Full report in German, abstract only in English), Straβenverkehrstechnik (2012), https://trid.trb.org/View/1142994	The abstract describes the work as developing a better method to estimate and evaluate how much salt will be needed and used in the future by looking at daily weather data from the German National Meteorological Service. The data was used to derive when slippery road conditions occurred from snow, ice, and frost, and to relate these conditions to deicer application rate. The research team will continue to work to get a draft of the full report in English.

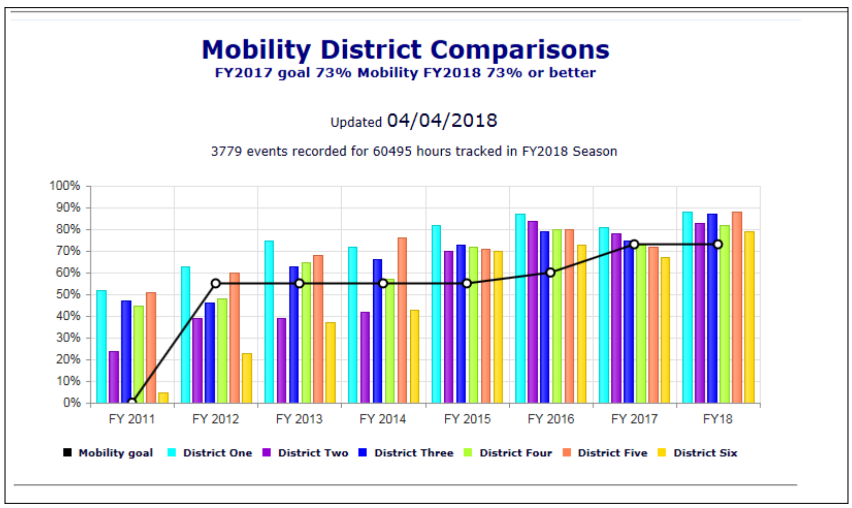
UDOT Weather Operations, Road Weather Index/Performance Metric, Williams (2015), https://transops.s3.amazonaws.com/uploaded_files/UDOT%20Winter%20Maintenance%20Performance%20Metric.pdf	More recently, Utah DOT presented on Road Weather Index/ Performance Metrics and reported on follow-up research of work reviewed above by Farr and Sturges (2012). The goal of developing a road weather index is to provide real-time information to allow for the evaluation of weather, road conditions, and maintenance performance. The road weather index accounts for blowing snow, freezing rain, and wet/dry snowfall, and was developed in-house. Information used in the winter road weather index includes: When the road temperature is below 35°F and the road is not dry; road condition – snow, ice, friction on road when - snow covered, partially snow covered/slushy, wet/dry; road temperature; visibility – used to estimate snowfall rate, precipitation (yes/no; start and end of storm, fog, etc.); wet-bulb temperature (wet/dry snow, rain or snow); and wind gust (great than or equal to 20 mph). The calculation uses a cause and effect approach – atmospheric conditions and road temperature (cause) versus road friction or condition (result). One inch of snow per hour is the benchmark. The following data was reported:
	
	• Temporal
	    o Monthly
	    o Whole season
	• Spatial
	    o Statewide
	    o Region
	    o Maintenance shed
	    o Individual RWIS site
	• Reportable Variables
	    o Winter Maintenance Performance
	    o Winter Weather Index (storm intensity)
	    o Number of storms
	    o Storm duration
	    o Climate normal comparison
	    o Budget comparison
	
	The data is shown as color coded from Performance Metric, where green boxes mean the road condition exceeds what is acceptable, yellow boxes means the road is acceptable for the conditions, and red means there is potential for improvement to road conditions and then working within their recovery time.
	
	They found that **snowfall rate and road temperatures** have the **greatest impacts** on roads. benefits include assessing winter plow performance for specific weather conditions, resource

	assessment tool budgeting and planning, public response to poor road conditions during intense storms, and it improves mobility. Identified limitations include that the information is based on a small sample area, which could be improved with AVL and mobile sensors, as well as modeling using RWIS sites as quality control locations and using plow camera software to assess road condition. Other limitations include when flurries occur in fog, it confuses the algorithm (may need to investigate particle count), and limitation in instrumentation, which could be remedied with investments in newer technology and more frequent calibrations.
Road weather severity based on environmental energy,* Baldwin et al. (2015) https://docs.lib.purdue.edu/jtrp/1575/	Baldwin et al. developed a severity index called the Road Weather Severity Based on Environmental Energy (RWSBEE) index, based on weather and environmental information, e.g., hourly rate of deposition of new snow/ice and the energy required to melt it. This means that road treatment actions (e.g., salt usage) and traffic patterns were *not* incorporated into the severity index. The analysis was done for the Indiana Department of Transportation (INDOT) using MDSS weather variables and an equation included in the MDSS reporting tool. INDOT wanted to be able to better 1) evaluate performance, 2) assist with after-action review, and 3) improve reaction to future weather events. The authors made use of the following data: a) roughness length (friction/grip value for the road segment), b) air temperature at 2 meters, c) wind speed at 10 meters, d) surface temperature, e) net surface shortwave and longwave radiation, f) sensible and latent heat fluxes from North American Land Data Assimilation System (NLDAS), g) vertical temperature profile, h) categorical precipitation type, i) visibility, j) wind gusts from Rapid Refresh (RAP) at 10 meters, k) snow depth from Snow Data Assimilation System (SNODAS), and l) hourly accumulated precipitation from the National Centers for Environmental Prediction (NCEP) Stage IV. **A full list of data collected is available below the summary table in Additional Data Pieces by Author* The following section expands on certain data pieces previously summarized in Table 1. Baldwin et al (2015). Severity indices were computed for each INDOT district, sub-district, and unit for an entire season. They were **displayed in**

	the document randomly, so as not to convey documented criticism of the district, sub-district, or unit. The authors concluded that nearly seventy-five percent of the areas across the state were within plus-or-minus five percent of the value (actual cost that year) when viewing costs in terms of the RWSBEE instead of costs per weather hour. However, they acknowledge that the approach could not account for maintenance costs (i.e. salt application). Points from Baldwin et al. (2015): • Salt usage data down to the local shed/garage is needed. • If blowing snow occurs and affects roadways in Maryland, this variable should be considered in the SWI calculation. • Presents many options for additional data and data process methods.
Idaho Transportation Department (ITD) Winter Maintenance Best Practices, Jensen (2015), ftp://dayweather.com/Road%20Weather%20Services/RWM%20High%20Plains%20(Dec2015)/Idaho+Transportation+Dept+-+Bob+K..pptx	ITD developed a Weather Performance Index (WPI) that incorporated the following data: **WPI#1 = Ice up time (hrs) / Storm Severity Index (WPI#2)** Rates the treatment effectiveness to the storm (recovery time to safe grip). Ice up time is the duration of the event when the grip is below 0.60 for more than ½ hour. **WPI#2 – Storm Severity Index = Wind speed Max (mph) + water equivalent layer Max (mm) + 300/Surface Temp Max (degrees F)** Lower values indicate light storm events. Range of 10-80 equivalent to normal events, severe cold and high winds as high as 500. Required a full RWIS overhaul statewide. ITD has a performance measure called RWIS uptime that reports on the percent of time valid data is provided. Each foreman has at least one RWIS site to use. The Winter Performance Measures are automatically calculated and displayed on the Vaisala Winter Performance Index Reports. A cultural shift at ITD occurred with staff training and improvements in RWIS reliability, which allowed for more

<table>
<tr><td></td><td>structured storm responses driven by RWIS data and WPI calculations. Winter Performance Measures are now used as a rating factor for annual employee performance reviews, with pay increases linked to several factors including Winter Performance Measure results. This used to be a top performer award at ITD but evolved into merit pay increases for metric attainment in winter operations. Every operator has an opportunity to advance three steps in the tech operator program with significant pay increases between each step.

The Mobility metric, calculated using the WPIs, is used to establish statewide goals tracked at the highway segment level. Training and other resources are provided to regions that need to improve. From these efforts steady improvements have been observed over time. Since 2011 a 60% improvement in mobility has been observed (measured as friction better than 0.6) during winter storms. Additionally, they have established more consistency in operations between districts (see chart below). With individual district mobility improvements from 5% in 2011 to 79% in 2018.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<tr><td></td><td></td></tr>
<tr><td>Idaho Transportation Department Winter Performance Measure, Koeberlein (2015), http://www.westernstatesforum.org/Documents/2015/presentations/Idaho_JensenKoe</td><td>ITD has a clear policy to ensure sensor data accuracy, with Vaisala responsible for data hosting and report generation and DTS, Inc. (Digital Traffic Systems) responsible for field support (e.g., when sensor data falls outside of threshold parameters, which uses an automated system). But ITD also requires the District Foreman to be responsible for “owning the data,” meaning they need to review all data and report any suspect data. These measures are paired with annual maintenance and</td></tr>
</table>

berlein_FINAL3_WinterMaintUpdate.pdf	calibration. ITD is also using hybrid RWIS locations to support additional functionality with ITS system. Some weather events are ***exempt*** from the WPI scoring – for ITD this includes ***drifting*** and ***powder snow*** events. Along these lines, the following weather events are ***modified*** in the ***WPI scoring*** – ***hydroplaning***, ***frost*** events leading into storms, ***drifting/powder snow*** events that adhere to the roadway, ***fog*** that affects non-invasive sensor readings, and ***sensor errors***. Unknowns and concerns going into this included: • Would costs increase? • How long would statewide buy-in take? • To what extent would these changes improve winter accident rates? • Would there be a return on investment? The return on investment of the $16 million RWIS network was realized after 3-4 years of savings through reduced material usage along with labor and equipment costs. Winter operational costs were reduced by approximately 30% while providing much better mobility during the winter. Societal costs were not computed in the return-on-investment (ROI). Lessons learned • The system has outgrown the tech support from 47 sites to 130. • Hacking of the digital subscriber line (DSL) landline location was an issue, but they have upgraded to cellular service, where possible, with firewalls inside the modems. • New hires are more receptive to acceptance of the system than veterans. • The system will need to continue to evolve through annual updates. • Crews are very receptive to the sites once effective best management practices (BMPs) were used from the critiques performed. • Demand for new sites surpasses the funding. • Manual quality control is required to validate sensor readings daily. • The system has far exceeded expectations through bonus benefits and is now part of the compensation packages for employees. • System replacement components need to be on hand and life cycles of sensors must be known.

	• Vendors will work together to promote systems. [A presentation by R. Kerr of Utah DOT was given at the PNS conference June 6, 2018 in Spokane, WA, providing updates on Utah DOT Snow Removal Performance Metrics. The presentation will be reviewed and summarized as is relevant to this project. R. Kerr has agreed to be interviewed for this project.]
The Accumulated Winter Season Severity Index (AWSSI), Boustead et al. (2015), https://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-14-0217.1	This research effort worked to develop a method to estimate snowfall by a snow proxy that uses temperature and precipitation, where snow data was unavailable or unreliable. Ultimately the data and calculated values were used to calculate accumulated winter severity index (WSI). Data used include daily maximum, minimum, and average temperature, precipitation, snowfall, and snow-depth data from the Applied Climate Information System (ACIS) database. This paper includes a discussion of how winter was defined which for this effort winter onset occurs when: 1) the daily maximum temperature is ≤ 32°F, 2) daily snowfall ≥ 0.1 in., or 3) it is December 1st. The end of winter was defined as occurring when: 1) the daily maximum temperature ≤ 32°F no longer occurs, 2) daily snowfall ≥ 0.1 in. is no longer observed, or 3) it is March 1st. To calculate the WSI, points were assigned for various parameters (see Table 2 in Boustead et al. (2015)), from which summary categories were created – 1) Mild, 2) Moderate, 3) Average, 4) Severe, and 5) Extreme
Winter Weather Regimes in the Northwest United States, Roller et al. (2016), https://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-15-0274.1	This paper investigates the role of teleconnection and large-scale weather patterns' [i.e., North Atlantic Oscillation (NAO), Arctic Oscillation (AO), Pacific-North American (PNA) pattern, and the El Nino-Southern Oscillation (ENSO)] impact on east coast weather. While not directly applicable to the development of a winter severity index (WSI) calculation method, this paper does provide alternative data sources for consideration. These include National Aeronautics and Space Administration (NASA), Precipitation Estimation from Remotely Sensed

	Information Using Artificial Neural Networks – Climate Data Record (PERSIANN-CDR), National Climatic Data Center (NCDC), and the National Snow and Ice Data Center (NSIDC). There appear to be two scenarios identified that greatly impact east coast weather: 1) WT2, a weather pattern that features a trough along the eastern US and positive precipitation anomalies into southern New England, and 2) WT3, a weather pattern where a trough resides over the western Atlantic and negative precipitation anomalies occur along much of the US East Coast.
Winter Maintenance Performance Measure, Walsh (2016), https://trid.trb.org/view/1396354	The winter performance index (WPI) developed for Colorado DOT shows the total amount of time roads were compromised by winter weather. Walsh (2016) used this method to evaluate Colorado DOT maintenance practices, and suggested this 1) is a "valuable tool" that can be used to perform post-storm analyses, 2) can be used as a training tool for maintenance personnel, and 3) can identify areas for cost savings and improved performance. A Storm Severity Index (SSI) was also developed that rates the severity of a winter storm event based on wind speed, precipitation, and surface temperature. The SSI allows for comparison of performance across geographic areas with unique climactic conditions. The SSI "normalizes the different storm events because it quantifies and compensates for variation in the severity and duration of storms." The goal was to utilize the SWI developed by ITD and Vaisala. SSI = Max Wind Speed (mph) + Max Layer Thickness (mm) + (300 / Min Surface Temperature (°F)) A mobility index (MI) was also calculated: MI = (Grip ≥ 0.60 duration (hours)) / (Combined Event Duration (hours)) % A performance index (PI) was also calculated: PI = Grip < 0.60 duration (hours) / SSI **Winter Performance Index Legend** 0 – Successfully treated 0.00 - 0.30 – Significantly accelerated grip recovery 0.31 - 0.49 – Some success at grip recovery 0.50 - 0.69 – Very little success at deicing 0.70 - – Limited maintenance or no deicer success

	Suggested next steps included an evaluation of the RWIS network in Colorado, training and support for the use of the WPI in CDOT operations, detailed evaluation of Red and Orange rated events (WPI scale shown above), upgrades to CDOT software to support WPI use. [Additional information was sought from T. Agular, CDOT Region 4, but no response has been received.]
Operational winter severity indices in Canada – from concept to practice, Matthews et al. (2017), http://docs.trb.org/prp/17-03338.pdf	A weather severity index (WSI) was developed for use in Canada and assigns a point value to each day. The points can then be aggregated weekly, monthly, and seasonally. These daily and aggregated scores have been found to be easily interpreted because they are directly tied to distinct weather conditions and events. To calculate the WSI, an optimization algorithm was used to determine key weather thresholds and weights for daily scores; these were then correlated with maintenance activities and expenditures. The two data sources used included weather station networks (maintained by Environment Canada (EC)) and RWIS. While the weather station network has good quality data, there are fewer stations in northern Canada, and these stations do not report on road surface conditions. The RWIS data is reported to have a lower level of quality control, with only few RWIS stations having historic rainfall and snow depth data. Both data sources were used to fill in where the other was lacking. Maintenance data is recorded to a Maintenance Management Information System (MMIS), but the quality of the data collected was also found to vary by location and over time. Seven seasons worth of data were used to calibrate and test the model. The following weather data was used: • Snowfall data from EC • RWIS pavement ice warnings • Rain with low temperatures (rainfall data from EC, temperature data from RWIS) • Blowing snow (wind speed data from RWIS, snowfall data from EC) • Series of cold days (temperature data from RWIS) • Warm weather adjustment factor (temperature data from RWIS) For each day, a weather trigger (listed above) is assigned and a 14-day reporting period was used (falling in line with the Maintenance reporting schedule). A WSI score of 0 – 1.5 is

	possible for each of the above listed weather triggers and a summary table developed by Matthews et al. (2017) describes the weather component, component thresholds, score, % of total WSI, and number of days. Overall, the developed WSI model found geographic and temporal trends that can be used to describe, understand, and communicate variations in highway maintenance performance. A strong correlation between high WSI scores and equipment hours was found at the provincial level.
Winter Severity Index: Analysis and Recommendation for Selection, SHA (2017), not available on the web.	Three general weather zones were identified in Maryland: • Western Maryland – snow, blowing snow and snow drifts, freezing rain/icing conditions (Maintenance District 6) • Central Maryland / Upper Eastern Shore – snow, freezing rain/icing conditions (Maintenance Districts 2, 3, 4, and 7) • Southern MD / Lower Eastern Shore – snow (Maintenance Districts 1 & 5) "Two sources of weather data were assessed. RWIS consists of 50 weather stations operated by SHA. They collect several variables at five-minute intervals; <u>however, precipitation amount is not one of them</u>. While there are gaps in the data, the temperature, wind, and type of precipitation records are fairly complete and usable. The other source was data which can be downloaded from National Oceanographic and Atmospheric Administration (NOAA) websites. There are over 500 stations in the NOAA dataset, many of which are not active. Thirty-four active sites were found which could be used to supplement RWIS data. Again, there were significant data gaps, but precipitation, snowfall, and snow depth records were sufficient for WSI analysis. A combined set of RWIS and NOAA stations were found for each SHA maintenance district." "The review of existing indexes showed there is no single WSI that meets all of SHA's requirements off the shelf." The site location data and determination of working and available sensors and data collected at each site is critical information that will be used as a starting point for this project. If new RWIS or NIRS station have been added since this analysis, or stations have been upgraded or repaired, they should be incorporated into this table.

	Note that from this analysis the author suggested that a WSI could only be developed at the SHA District level due to data resolution, but that Maintenance Shops have weather stations in close proximity.
Development of a Novel Road Ice Detection and Road Closure System: Modeling, Observations, and Risk Communication, Toms et al. (2017), https://ams.confex.com/ams/97Annual/webprogram/Paper315187.html	This conference presentation provides a summary of the project in Oklahoma, funded by Oklahoma DOT, to develop a multi-faceted road ice prediction and warning network across the state. The system uses a Road Ice Model (RIM), RWIS data, and a GIS database to access and visualize the data. Data sources used observational data from Oklahoma Mesonet and Automated Surface Observation Station (ASOS), National Weather Service (NWS), and National Digital Forecast Database (NDFD). Using the aforementioned data sources and RWIS data, a stochastic method was developed to determine road ice risk. Additional information including topography, traffic flow, and population were considered and incorporated into the model and GIS visualization tool. A goal of the project was to create a cost-effective and computationally-efficient tool that offers diagnostic and forecasted information. The research team will continue to work to obtain more information and/or a report or journal article on this topic.
Developing a Winter Severity Index to Improve Safety and Mobility, Walker et al. (2017), https://ams.confex.com/ams/97Annual/webprogram/Paper315564.html	This conference presentation provides a summary of the winter weather severity index, called NeWINS, developed for the state of Nebraska. NeWINS is unique in that it calculates varying levels of complexity of atmospheric conditions. NeWINS is also simple and easy to use. The project included a literature review and rigorous data collection to create a ten-year database, including the following storm types – light snow, moderate snow, heavy snow, and air and road surface temperatures, and wind conditions. Data was captured from the High Plains Regional Climate Centers Automated Weather Data Network (AWDN), the National Centers for Environmental Information (NCEI), and the Meteorological Assimilation Data Ingest System (MADIS). The NeWINS is designed to provide data at the district level across the state. Testing of system was conducted in 2016-2017 winter season. [C. Walkers Dissertation on this topic was released at the end of May 2018 and will be reviewed and relevant aspects to this project summarized for use in this project].

Development of a road condition recovery time estimation system for winter snow events,* Kwon (2018), http://www.dot.state.mn.us/research/reports/2018/201801.pdf	Work by Kwon (2018) developed an estimation system for the Normal Condition Regain Time (NCRT) using traffic and weather data (listed below) on a metro-freeway network (i.e., very urban) in Minnesota. The estimation method determined the speed-density of uncongested and congested traffic conditions to determine the stable free-flow-speed pattern as base lines. Then, by collecting after-storm traffic data, they were able to determine a wet-normal condition when post storm traffic data showed a "shifted-down," but similar pattern to the normal-day speed-density, or the NCRT. The NCRT means that after the snow event, traffic behavior returns to normal pre-storm conditions but that speeds are generally slower.
	
	The input data used included:
	
	• Station locations
	• Snow event start and end times
	• Time period for collecting data to calibrate the normal speed-recovery at each station
	• Freeway geometry and traffic detector data
	• Weather data (NOAA, airport, and RWIS)
	    ○ RWIS data used:
	        ▪ Date, time stamp
	        ▪ Surface Condition/Status
	        ▪ Precipitation
	        ▪ Precipitation accumulation (inches)
	        ▪ Surface temperature (degrees F)
	        ▪ Average windspeed, direction
	        ▪ Humidity (%)
	        ▪ Dry or not
	
	*Additional information on RWIS data collected is provided below the summary table in Kwon (2018).
	
	Recommendations for future work include the need to identify the relationship between NCRT estimates and the specific types of snow-management strategies used/applied in each corridor for each event, leading to the development of an optimized snow management strategy.

Additional Data Pieces by Author

The following section expands on certain data pieces previously summarized in Table 1.

Baldwin et al (2015)

Weather data sources identified by Baldwin et al (2015):

- Rapid Refresh (RAP) – an hourly, short-range weather prediction and data assimilation system (National Center for Environmental Prediction [NCEP]) (Benjamin et al., 2006, saved in literature folder in Task 1, not in references). http://rapidrefresh.noaa.gov (version 4 released June 2018)
  - 1 hr temporal resolutions
  - 1/8 degree special resolution
- North American Land Data Assimilation System (NLDAS) – a land-surface model dataset that has built-in quality controls and spatial and temporal consistency (Michell et al., 2004, saved in literature folder in Task 1, not in references).
  - 1 hr temporal resolutions
  - 1/8 degree special resolution
- Snow Data Assimilation System (SNODAS) – (National Operational Hydrologic Remote Sensing Center [NOHRSC]), 2018) provides a framework to integrate snow and ice cover data from satellites and aircraft with surface observations and numerical weather model estimates of snow and ice cover and depth. http://nsidc.org/data/G02158
  - Daily temporal resolution
  - 1 km spatial resolution
- NCEP Stage IV Precipitation Analysis – (From Lin & Mitchell (2005), will be reviewed if needed.) uses NWS data from the 12 River Forecast Centers to create an hourly mosaic of precipitation accumulation from water gauges and radar data. Tied to the RAP analysis method. http://www.emc.ncep.noaa.gov/mmb/ylin/pcpanl/stage4/
  - 1, 6, 24 hr temporal resolution aggregates
  - 4 km spatial resolution
- Local Winter Storm Scale (LWSS) – (From Cerruti and Decker (2011), classifies winter storms on a scale from 0 – 5, and weight various storm elements (e.g., maximum wind gust, snowfall, ice accumulation, and visibility). The goal of 0 – 5 scale was to mimic other scales frequently used to show severity to the public.

Kwon (2018)

RWIS data used:

- Date, time stamp
- Surface Condition/Status – Snow/ice warning, ice warning, snow warning, wet below freezing, ice water, snow/ice watch, snow watch, frost, chemical wet, wet, damp, trace moisture, absorption at dew point, absorption, dew, dry, other, no report, error
- Precipitation type – none, yes, rain snow, mixed, upper, lower, both, light, light freezing, freezing rain, sleet, hail, lens dirty, fault, other, unknown, frozen, no data
- Precipitation accumulation (inches) – every 3, 6, 12, 24 hours, most recent precipitation start and end times, precipitation rates (inches per hour)
- Surface temperature (degrees F)
- Average windspeed, direction – N, NE, E, SE, S, SW, W, NW
- Humidity (%)
- Dry or not

Maze et al. (2009)

A combination of RWIS and NWS weather sources were used. A full list of variables used is provided below:

Index Variable	Variable Definition	Type of Variable	Variable
District	Geographic location	Classification	$District_i$
Storm of season	1,2,….,7	Classification	$Storm_j$
Volume (ADT)	Avg volume on road per 1000	Continuous	$Volume_{ijk}$
Performance relative to goal (LOS)	Actual bare lane time versus goal	Continuous	Y_{ijk}
Route Orientation	E-W or N-S	Integer Variable	EW_{ijk}
Snow quantities	Amount of snow at nearest NWS site	Continuous	$Snow_{ijk}$
Wind speed	Max wind speed at nearest NWS site	Continuous	$Wind_{ijk}$
Max Temp	Max temp record by nearest NWS site	Continuous	$Tmax_{ijk}$
Min Temp	Min temp record by nearest NWS site	Continuous	$Tmin_{ijk}$

Strong et al. (2005)

The data used by Strong et al. included:

<u>California</u>

Weather data (15 NWS stations, 1991-2000)
- Daily precipitation
- Daily snowfall
- Daily min and max temperature
- Temperature at the observation time
- Snow depth at the observation time

Crash data (1991-1999)
- County and route codes
- Ramp milepost
- Roadway classification
- Time of accident
- County code
- Highway group (divided/undivided)
- File type
- Side of the highway

<u>Oregon</u>

Weather Data (32 RWIS sites, 1997-2003)
- Region code
- RWIS station code
- Location description
- Latitude, longitude, elevation
- Air temperature
- Dew Point
- Relative humidity
- Barometric pressure
- Avg. wind speed, wind gust speed
- Min., max., and avg. wind direction
- Precip. type, rate, accumulation, intensity
- Visibility
- Date and time
- Crash data (1997-2003)

- Weather condition (rain, snow, fog, etc.)
- Light condition
- Road surface (slippery, muddy, etc.)
- Type of collision
- Total number of vehicles
- Population group (city, rural, etc.)
- Collision severity
- Number of vehicles involved
- Case number (includes date of crash)
- Traffic counts (from 1991-2000)
- AADT
- MAF (calculated for 2001-2003)

- Date of accident
- Route number
- Description of location
- Milepost
- Pavement condition
- Number of vehicles involved
- Fatalities (yes/no)
- Injuries recorded (yes/no)
- Traffic counts (32 sites, 1997-2003))
- AADT
- MAF

<u>Montana</u>

Weather data (60 RWIS sites, Nov. 1996-Sept. 2003)
- MDT server number, RPU number, and sensor number
- Date and GMT
- Avg. wind speed, gust speed, avg. direction (compass degrees)
- Pavement surface condition
- Pavement surface temperature; back, bottom, freeze, reference temperatures
- Chemical factor
- Chemical percent
- Water depth
- Percent of sensor covered with ice
- System on/off
- Atmospheric temperature
- Dew point
- Precipitation type, intensity, rate, accumulation
- Subsurface temperature

Crash data (Jan. 1996-Sept. 2003, within 5 miles in each direction of each RWIS site)
- Date and time of accident
- Highway route number and milepost
- Weather condition
- Pavement condition
- Number of vehicles involved
- Pedestrians involved (yes/no)
- Number of fatalities
- Number of injuries

Traffic counts (near 60 RWIS sites)
- AADT (1996-2003)
- MAF (1998-2003)

Interviews

Leigh Sturges – The Narwhal Group, formerly of Utah DOT

Utah developed a SWI following the Phase 1 Literature Review by Farr and Sturges. Jeff Williams* has given multiple talks on SWI. There may also be some information on the FHWA website. **There is no formal publication on the Utah SWI**.

Leigh was trying to develop a SWI with Phase 1 but realized if they really wanted to develop a detailed SWI for the road it would require a high level of detail in the data resolution. She commented that to handle this, you end up looking at generalizations. Ideally you would use mobile weather/road data so that you have the most complete picture of what is happening, on the road.

I asked Leigh about the issues with specific data sources used in SWIs. She commented that maybe the issue is the quality of the data between states and the variability in data QA/QC. She commented that there was a downstream affect from the 2008 recession that likely impacted state maintenance budgets, and likely the RWIS network.

Leigh commented that the Utah DOT tool is very helpful, and a SWI makes a lot of sense in terms of performance measurement in winter maintenance operations. She went on to comment, that anytime a state does anything to put the severity of the weather in context they will benefit from analysis of performance, that it will only benefit the program. This way they compare apples to apples.

Points:

- There are very precise and very broad ways to develop and use a SWI; the method depends on what outcomes you want.
- The level of details can in part be determined by the level of investment.

*The research team spoke with Jeff Williams of Utah DOT in the proposal development stage of this project.

John Mewes – Clear Roads National SWI

John Mewes works for the private sector and the company is a partner in the MDSS pooled fund. Over time, working with MDSS, and as each winter goes on, they aggregate the weather data and simulate/forecast the winter weather on routes. There are merits to collecting the data and calculating a SWI, making treatment recommendations, or both. Over time, they found what works and does not work. As well as getting feedback from partnering DOT meteorologists, letting them know what works and does not.

Q1. You discuss a bias in weather sensor data that can affect calculations specifically when spatially normalizing data. Can you explain this in more detail?

Response: This was specifically with respect to wintertime precipitation, which is much harder to measure accurately than rainfall. What we found was that a combination of different sensors (with differing sensitivities) between different weather observing networks, and likely issues related to sensor calibration and maintenance, would make any type of spatial analysis based off their data pretty much useless. One way this issue becomes very apparent is when you mix data from different observing networks that have stations in close proximity to one another. When doing this, **we would find differences in winter severity across a single town to be as large as differences across an entire state**, at which point all confidence in the severity indicator at any one location relative to other locations is lost. My recollection is that when doing this analysis, we found:

- "Manned" Automated Surface Observation Station (ASOS) weather stations reported more severe conditions than unmanned ASOS stations, as the person manning the site will occasionally provide supplemental precipitation information that the sensor(s) are not picking up on. Further exacerbating this issue is that it is not easy to know which stations are manned, or during which hours of the day, or whether a particular precipitation report came from a sensor vs. a human observation.

- National Weather Service (NWS) does manual daily snowfall data collection, but they are few and far between. They are ground truthed and only have a daily reading. You can supplement using the Cooperative Observer Network (CON), but they did not have good success because of too much variability between each observer. They ended up the first hour of each forecast (that was verified after it occurred) and ran parallel systems of each state, some weather stations along with radar information, and other short-term forecasts (states like the forecast approach). But you can use the secondary parallel analysis to verify the data. They run an observation based and forecast based SWI and use both to build confidence.

- There were substantial differences in sensitivity between ASOS and AWOS stations, with AWOS stations picking up more light precipitation than ASOS stations. Further, though the AWOS stations were more sensitive, they also seemed to exhibit less consistency with other nearby AWOS sites.

- **There is so much variability in how you can observe precipitation**, and so many different ways to pick up precipitation. They started out counting the number of hours with snowfall, which seems to have a good correlation, but only after you look at stations across the state, and sensors on a common framework. Generally speaking, ASOS are somewhat reliable and comparable between stations. Some of them are manned and it is hard to figure out when someone is supplementing the station, which stations are manned and how aggressively they are manning the station (attention to detail). With the AWOS there is less consistency between stations, one reason is they have more sensitivity, which allows them to pick up more light snowfall (1/100 in). (They use present weather observation and use an algorithm, and wind to assess snowfall, but for freezing rain use gauges.) AWOS are more variable but pick up more snowfall because they are more sensitive. Whereas ASOS stations are more consistent but do not pick up as much of the lighter snow falls.

- RWIS data are kind of a disaster for this type of exercise. There is generally too much variability in the sensor packages, and too many issues relating to lack of calibration and/or maintenance for them to provide useful information regarding winter severity. If you are looking at a location over time, the weather sensors can provide good data over time. But if you are trying to compare data spatially, e.g., comparing data from a station in District 1 to another station in District 7 then you will likely have issues. They found they could not do spatial analysis using RWIS data.

Q2. You mention that this issue seems to be less of a concern when comparing historical data to the data collected from the same weather station.

Response: Relative to the inconsistencies between observing stations, inconsistencies over time at a single station seemed to be less problematic. So long as the sensors are maintained, and they are not changing the sensors out at a given station, they would be apt to produce a consistent response to similar conditions over time. That said, it is also true that it can be really hard to pick out a problem with a particular station's data if it develops over time. As an example, from one study we did, we happened to be looking at data from two nearby stations and noted that one seemed to be getting more severe over time relative to the other one. Digging deeper, it appeared that the station that was showing more severe conditions over time was likely the one that was incorrect, but we would never have even noticed there was a problem if we were not looking at data from other stations that were in reasonably close proximity to it at the same time. If we had not noticed it, the conclusion would have been that the later winters in the dataset were more severe than the early ones, which would have been erroneous.

Q3. Have you noticed any issues with comparing historical data to the data collected from the same weather station that has had newer equipment/sensors added over time?

Response: I cannot say that we explicitly looked into this problem. The first obstacle would be finding such cases. It is not really easy to find information as to when [sensors are replaced, upgraded, maintained] this occurs. But, given everything mentioned above, I would expect this to create additional issues when it does occur.

Recommendation – if you are going to deploy sensors to support SWI, have a maintenance plan and deploy the **same** package across the state. RWIS data can be a disaster because of the slow deployment over time, lack of maintenance, various sensors and versions of sensors used over time.

Q4. From the composite US WSI map, could we somehow get more information about how it was done for the states with the green band, particularly those near the Atlantic Ocean? Virginia, Massachusetts?

Response: I do not think I understand the question here. We followed the exact same process everywhere, and I believe that process was all spelled out in the final report? I am also not really sure what you are referring to with respect to a "green band"?

Ultimately, they did not handle green zone, or maritime areas, any different, they applied the same model using national data.

Q5. Thoughts on mobile sensors for data collection?

Response: They are starting to look at using mobile sensors in the MDSS pooled fund, but for weather severity calculations, mobile sensors may just exacerbate the problem of highly variable data. From John's perspective mobile sensors could be used to make maps of trouble spots. Feedback that John has heard from DOT users of mobile sensors, is that the data quality is improving with time.

Dennis Jensen – Idaho Transportation Dept.

Winter Performance Index (WPI) – Idaho Transportation Department (ITD) engineers developed an empirical formula that reports a numerical value. The ITD engineers quickly came up with this simple calculation method.

Storm Severity Index = Wind speed Max (mph) + water equivalent layer Max (mm) + 300 / Surface Temp Max (degrees F)

Ice up time = when friction below 0.6 is reported on the RWIS surface state condition

WPI (Mobility) indicator value = Ice up time / storm severity

Winter Performance Index Legend	(Advanced scale)
0.0	Successfully treated
0.00 - 0.20	Significantly accelerated grip recovery
0.21 - 0.40	Some success at grip recovery
0.41 - 0.69	Very little success at deicing
0.70 -	Limited maintenance or no deicer success
	Observation data / parameter missing or temp is below threshold

The goal is to have a seasonal WPI index average value below 0.15, with many events 0.00 indicating no ice or snow bonded to the roadway.

With the calculation of the WPI, they thought, start simple and it will become more complex over time as it matures. ITD ended up sticking with the original equation. As they considered adding more variables, the calculation method seemed to get very complicated. The original thought was that precipitation intensity should be included, but they could not come up with a good way to do this.

The next step after the WPI was developed, involved Dennis applying the WPI values in the field to see what the numbers mean. Once the system was "calibrated" (see box above) they were able use it.

Initially using a WPI was foreign to everyone, as well as using the information for performance management. They started piloting it in the districts, then a new director came on with a goal of building consistency in the state across each district, so they implemented it across the state to measure performance.

An example of the limitations and workarounds they came up with - The RWIS can only report/show if there is snow on the roadway, but you don't know if it is stuck to the road or not.

Precipitation must be adhering to the road surface to be scored in the WPI, this is done with camera images and field reporting. They decided that in the case of drifting snow, if snow is shown as presented from the RWIS data, that they would not treat it, instead allow it to blow off, in effect exempting these conditions from the WPI related treatment plan.

For their RWIS network, they started with Vaisala maintaining the site, but the system outgrew the Vaisala support going from 47 to 130 sites. ITD rebid the contract and currently DTS is the RWIS maintenance contractor.

The goal of the program is to focus efforts on winter response they can control.

Initially the RWIS sites were located in the worst areas with the highest traffic volume, but then realized they needed at least one RWIS in each foreman location. Idaho is plagued with microclimates, so locating RWIS sites needs to be strategic.

The return on investment of the $16 million RWIS network was realized after 3-4 years of savings through reduced material usage along with labor and equipment costs. Winter operational costs were reduced by approximately 30% while providing much better Mobility (mobility defined as improved friction, with values 0.6 or higher) during the winter. Societal costs were not computed in the return-on-investment (ROI).

Vaisala has intellectual property on the developed WPI so anyone working with Vaisala can use this as a starting point, it is already built into and automated within the system.

ITD quickly moved beyond focusing on the WPI; staff were using the data so quickly and efficiently, now they use a mobility index. WPI is still used as an indicator instead of performance metric. As crew proficiency improved using the WPI metric, many events never developed a WPI index score greater than 0.00 (because they were treated so well/quickly) resulting in the need for a second metric. **Mobility is the time the grip is above a 0.60 grip coefficient or safer driving conditions** which is metric used now (Figure 22).

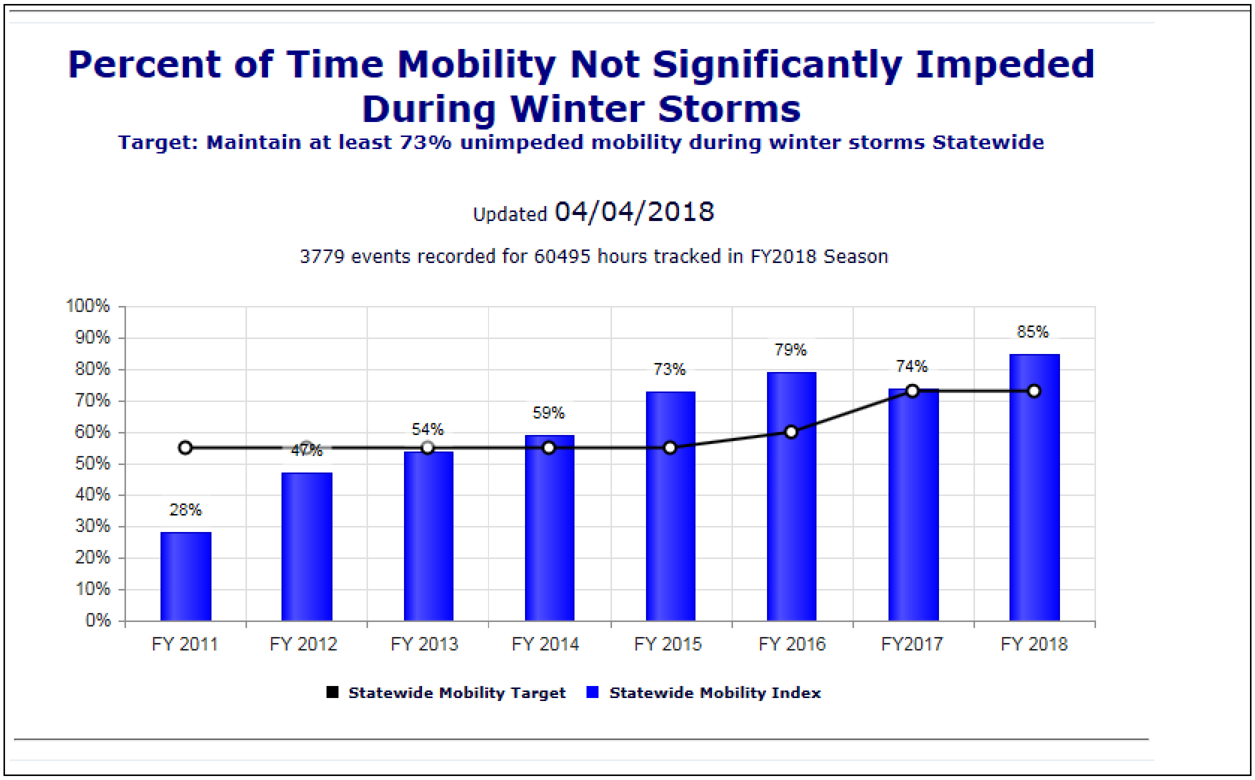


Figure 22. Mobility figure provided by ITD to accompany the discussion above.

The **RWIS system is tied into the 511 system**; all drivers can use their smart phone and look at RWIS data through the 511 system. Now they have tablets in the trucks, along with the treatment application matrix, to allow real time, in the field, decisions to be made. Automatic vehicle location (AVL) data is also collected from the trucks, and the data is transferred to the RWIS data system. ITD used to manually report materials and equipment, but now it is automated and much more accurate.

Using the AVL data they have been able to see:

1) A reduction in materials and operations costs ($30 million to $20 million)
2) A reduction in the workforce (FTE positions eliminated; salary savings were returned to employees as full-time raises).

<u>Lesson Learned</u>

When ITD started, they approached this from the technical side assuming staff would pick it up quickly, but this was not the case. The staff had trouble using the technology (developed SWI, tablets/ipads, etc.). So, in the past two years, ITD have been doing staff development and have built a customized training. Now that they are doing the training, the staff are doing much better.

Consider explaining to staff beforehand the "Why?" and provide training from the beginning.

Tony McClellan – Indiana DOT

Indiana DOT has been a part of two weather severity indices (WSI). Tony was involved with the development of the first one (McCullough et al., 2004). They are not using this one, though it was fully developed. Somehow it got lost in the implementation, maybe in part be due to **loss of personnel** leading to it not being adopted. Indiana DOT is now working with (Baldwin et al., 2015) on the development of a new WSI that uses energy balance.

Tony suggests that you should clearly define what you want to accomplish with the weather severity index. Indiana DOT was trying to measure costs to see if they were hitting their targets, looking at historical cost data per winter and comparing it to the calculated weather severity index. Tony cautions that you need to have a good understanding of key factors, for example - **cloud cover**, but that you also need to then have good data to support using these factors in the weather severity index. You need the current data, but also the historical data to verify the weather severity index.

Tony advises to **keep it as simple as possible**. The original weather severity index was very complex, and he is not sure if it was worth the extra effort.

Tony also suggested that we should work to clearly define severity. **What is considered severe, versus normal?** There are a lot of different ways to measure this. For Indiana DOT they wanted to know why did one winter cost more than the next?

Tony felt going through the process of helping to develop the weather severity index was beneficial; specifically Tony helped to determine the factors used in the calculation. But he is not sure if they gained a lot with coming up with all of those factors.

The current weather severity index being developed is in the initial phase of testing. Indiana DOT's goal is to use it as a cost justification tool.

The biggest difference between the two weather severity indices developed for Indiana DOT, is that the current one is simpler. We discussed this, and he felt that simplicity may be of the greatest benefit to the end user – the DOT.

Data sources used in the Indiana DOT weather severity index – AWOS/ASOS, RWIS, NWS.

They wanted to use historical data to verify the weather severity index and ended up using NWS data to do this. What they found is that there were not as many observation stations in Indiana as they originally thought.

Indiana currently has about 32 RWIS stations, and 6 districts, but the RWIS stations are not evenly distributed between districts. Indiana DOT is looking to improve and add to the RWIS network, and will likely do this once they have some confidence in the newer weather severity index/model; using the data to justify the need and offset the cost.

I asked Tony if they have observed or discussed how to deal with how changes in sensor type overtime and **upgrading to new technology** can potentially affect the data. Tony said they have discussed this, but nothing beyond that.

An observation from Indiana DOT, they use the *winter weather hour* to track costs. Winter weather hours are tracked as occurring when there is precipitation and temperatures are below 32°F, so they will likely have trucks out to combat the weather. Indiana DOT has 1100 trucks, which they can tell the drivers what to do (application rate, etc.), but **the drivers end up doing what they want**. In terms of costs and material use, it ends up being a wash in the end. If they are out, they are doing the same thing each time. So, averaging recommendations ends up being what they are seeing.

Indiana DOT used to use AVL and will likely move back to it in the future. Until then, tracking material use is done by what is reported.

Tony suggests that **ice is a major challenge** that can be very expensive to treat and can occur in a relatively moderate winter.

Appendix B – MDOT SHA District and Maintenance Shop Survey Results

Survey Findings

Surveys were distributed by MDOT SHA staff to each of the seven districts in order to obtain information on key variables and data used by the twenty-eight maintenance shops to make decisions about their winter maintenance operations. Surveys were completed between May 14, 2019 and June 10, 2019. Thirty-nine survey responses were collected via Qualtrics, representing all seven maintenance districts and the central office, as well as eleven maintenance shops.

Maintenance Shop and District

Respondents were asked to provide their maintenance shop and district number. At a minimum, two responses were received from maintenance personnel in each district and a few responses were received from MDOT SHA Central Office (Figure 23). Five responses could not be matched to any maintenance shop or district. Districts 3 and 5 have a slightly higher response rate when compared to the other districts. A summary of responding districts is provided in Figure 23.

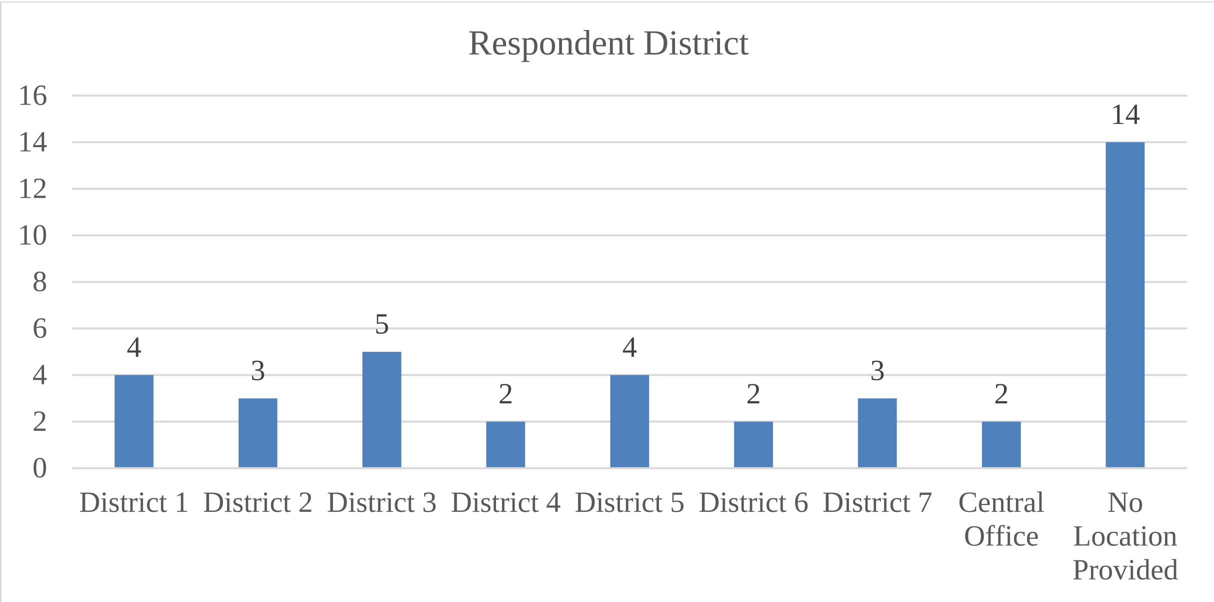


Figure 23. Survey Responses from Each Maintenance District

Fifteen respondents representing eleven maintenance shops provided information on behalf of their shop. An overview of the specific shops that responded is provided in Table 17.

Table 17. Text Responses

Please provide your Shed/Garage name and District.	District
District 1 Princess Anne	1
Princess Anne Shop	1
Salisbury - District One	1
Salisbury Shop------ District One	1
Denton shop Caroline county	2
District 2 Office	2
Elkton D2	2
District 3 Office	3
District-3	3
Gaithersburg Md State Highway Administration	3
Gaithersburg Shop Dist-3	3
Laurel, District 3	3
District 4	4
Owings Mills Shop	4
D5	5
District Five Office	5
Glen Burnie District 5	5
Keyser's Ridge Shop, District 6	6
Keyser's Ridge, District Six	6
Dayton 7	7
District 7	7
Westminster Shop, District 7	7
Sandi Sauter OOM	Central Office
Scott Simons Central Office	Central Office
Asbury Jones (included in "No Location Provided")	Unknown
Mapped Location	5

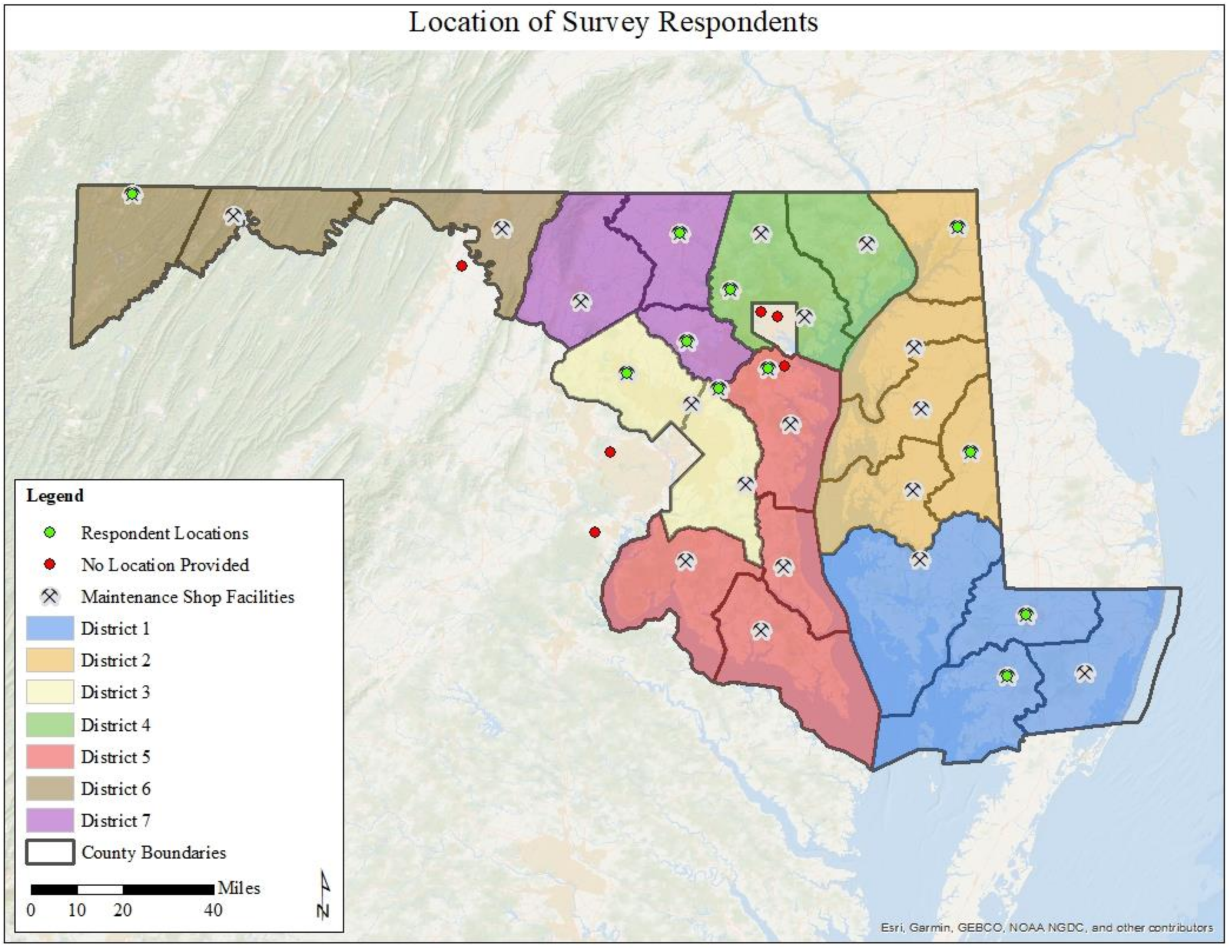


Figure 24. Location of Survey Respondents

To identify the location of survey responses that did not provide their name, District, or maintenance shop, their response location was mapped using the location information provided by survey tool, Qualtrics, as latitude and longitude coordinates of the computer log in address, and is shown in Figure 24. One respondent was matched to District 5, Glen Burnie Maintenance Shop. These responses were added to Figure 23 and Table 17.

Storm Variables

Respondents were asked to rank the variables they use when considering winter road conditions from most important (1) to least important (8). Thirty-seven respondents (out of 39) answered this question. Pavement temperature had the largest number of respondents (n=12) ranked as "1" or most important, followed by air temperature and precipitation type, which both had 8 respondents rank it as most important (see Figure 26 for user ratings). "Other" had the most respondents rank it as least important (n=10), followed by wind speed – max or min, gust (n=8).

Responses related to storm variable rankings are summarized in Table 18. Taking the average rank for each storm variable, air temperature is rated as the most important variable with an average of 3.00. Pavement temperature and precipitation type were also ranked as being important, which are circled in red in Figure 25.

Table 18. Storm Variable Rankings with 1 being most important and 8 being least important. (The lower the average score the more important the variable.)

Category	Number of Responses	Min	Max	Average
Air Temperature	35	1	7	3.0
Pavement Temperature	37	1	8	3.2
Precipitation Type	34	1	8	3.2
Total Precipitation	35	1	8	4.5
Wind Speed	34	2	7	5.1
Wind Direction	35	1	8	5.3
Wind Speed (Max or Min, Gust)	36	1	8	5.7
Other	23	1	8	6.0

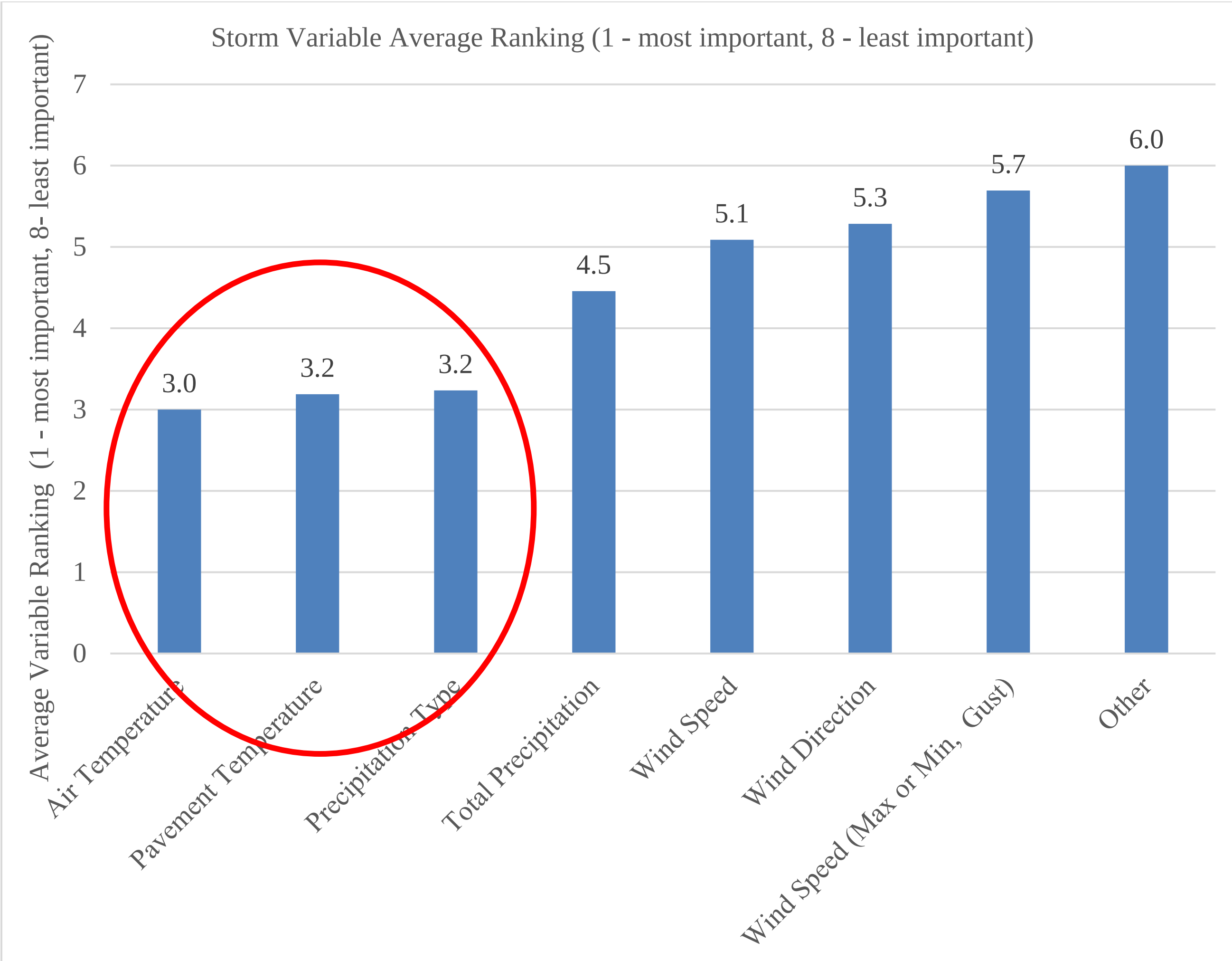


Figure 25. Storm Variable Average Ranking

Seventeen respondents provided comments or text for other storm variables that they use or consider important. Other variables considered include amount of traffic, precipitation intensity, previous salt usage, and time of storm event. Responses are summarized in Table 19.

Table 19

Table 19. Text Responses for Other Storm Variables Considered

District	Maintenance Shed	Other (please explain) - Text
1	Princess Anne	Timing and severity of all of the variables mentioned
2	Denton	Ice/Snow mix

3		Humidity
3	Gaithersburg	Time of event
3	Gaithersburg	Prior salt usage
3	Laurel	Precipitation Changes
4		traffic
5		Residual salt left on road from prior storm
5		Precip intensity
6	Keysers Ridge	Precip. Intensity
6	Keysers Ridge	Precipitation Intensity
		Time of event
		time of day
		amount of traffic
		Route priority
		Bridges/ overpasses
		cold spots

Figure 26 shows the total number of responses for each storm variable category and ranks their importance.

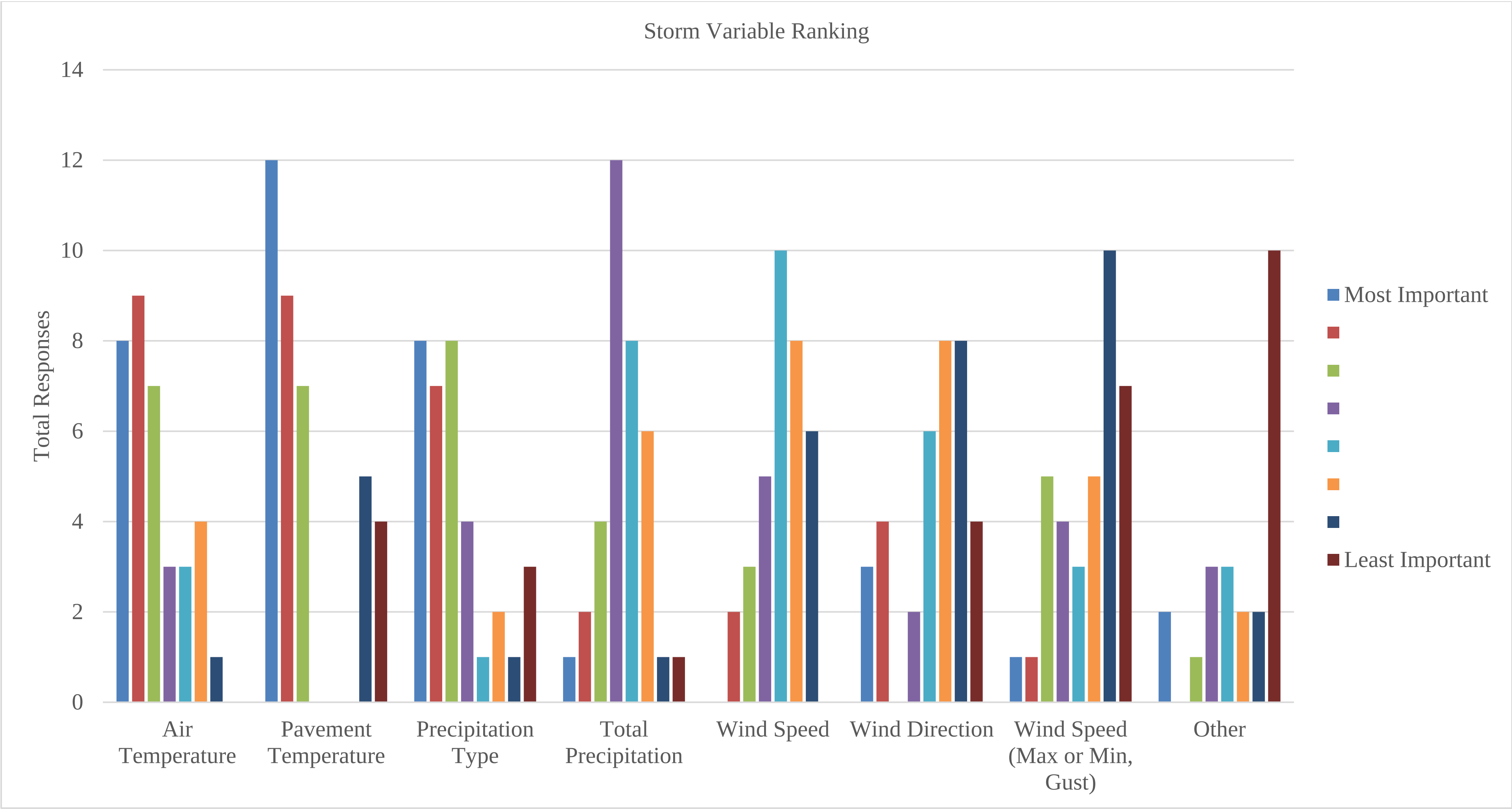


Figure 26. Storm Variable Ranking

Storm Variables by District

District 1

Respondents in District 1 (n=4), ranked air temperature as most important (1.3), followed by pavement temperature (2.5). There was one respondent that ranked “Other” as most important, stating that the time and severity of all variables were important. Total precipitation and wind speed were ranked around the middle, with wind speed ranked as least important. District 1 responses are summarized in Figure 27.

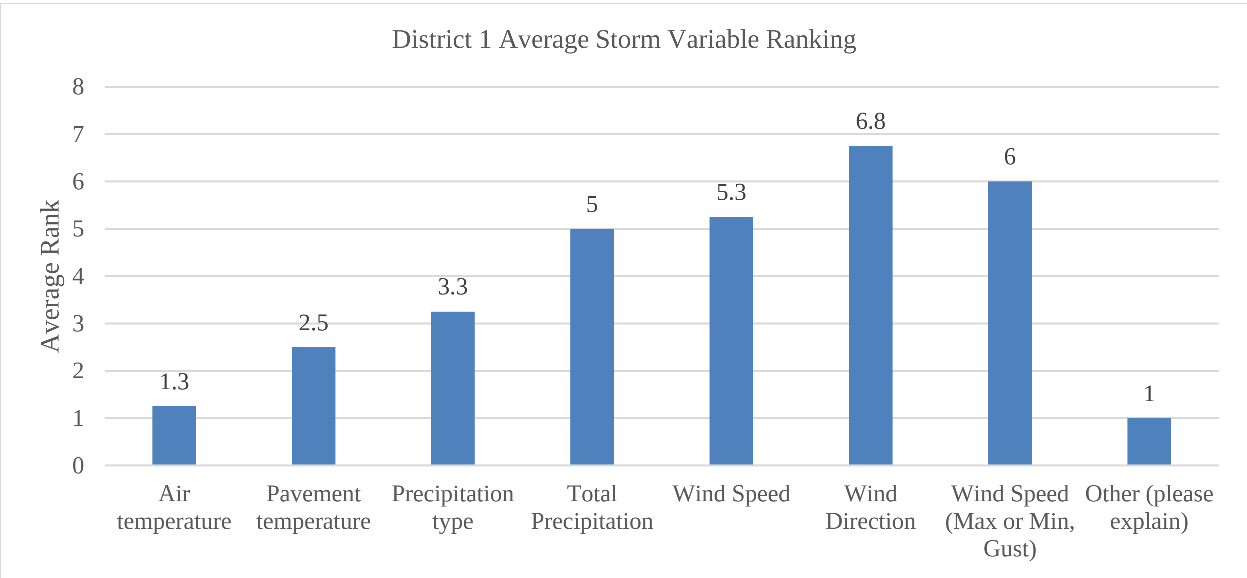


Figure 27. District 1 Average Storm Variable Ranking

District 2

Respondents in District 2 (n=3) ranked pavement temperature as most important (1), followed by air temperature (2.5), and precipitation type (2.7). Wind speed was ranked as least important. District 2 responses are summarized in Figure 28.

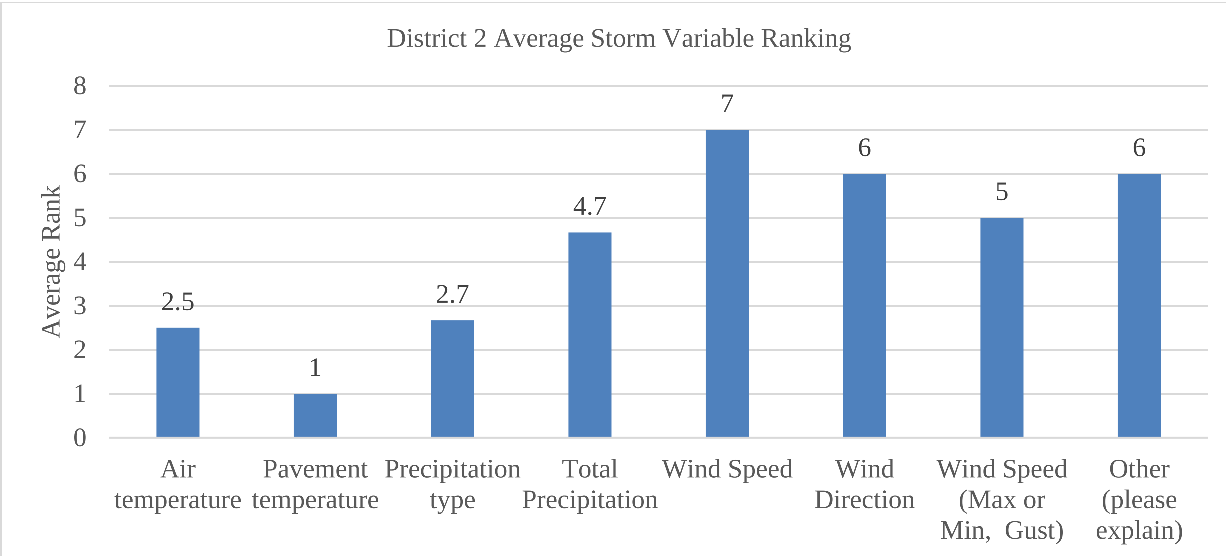


Figure 28. District 2 Average Storm Variable Ranking

District 3
District 3 respondents (n=5) ranked precipitation type as most important (1.8), followed by pavement temperature (3.2), and air temperature (3.6). Wind speed (max or min, gust) and Other were ranked as least important. Other variables reported included time of event, prior salt usage, and precipitation changes. District 3 responses are summarized in Figure 29.

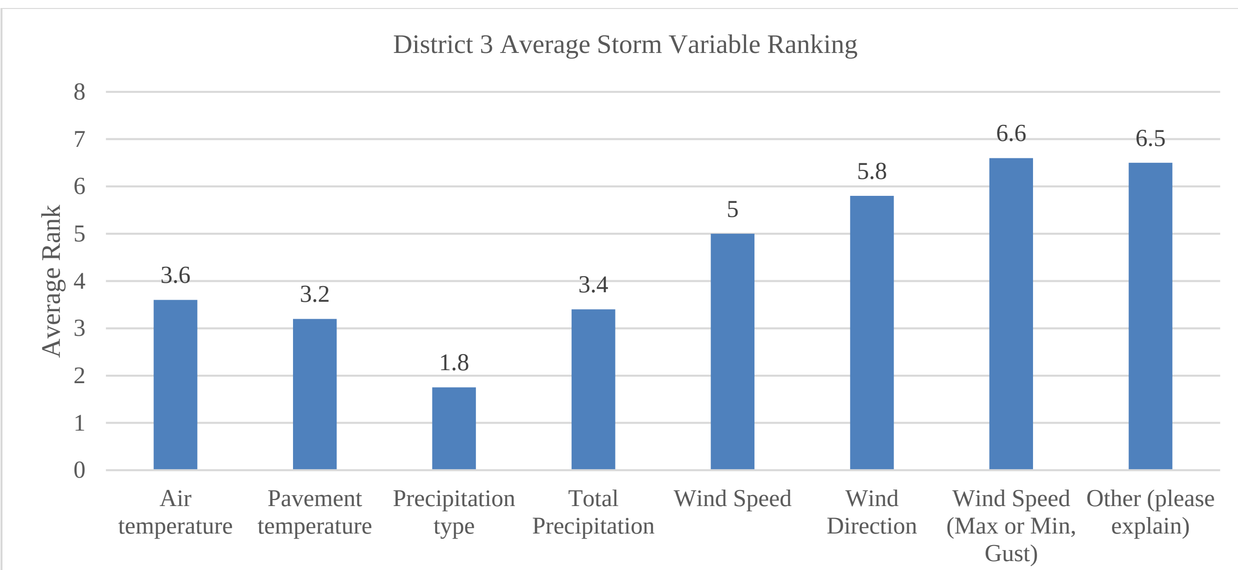


Figure 29. District 3 Average Storm Variable Ranking

District 4
District 4 respondents (n=2) ranked all variables at the mid-range of importance around 4. Precipitation was ranked as the least important at 5.5. District 4 responses are summarized in Figure 30.

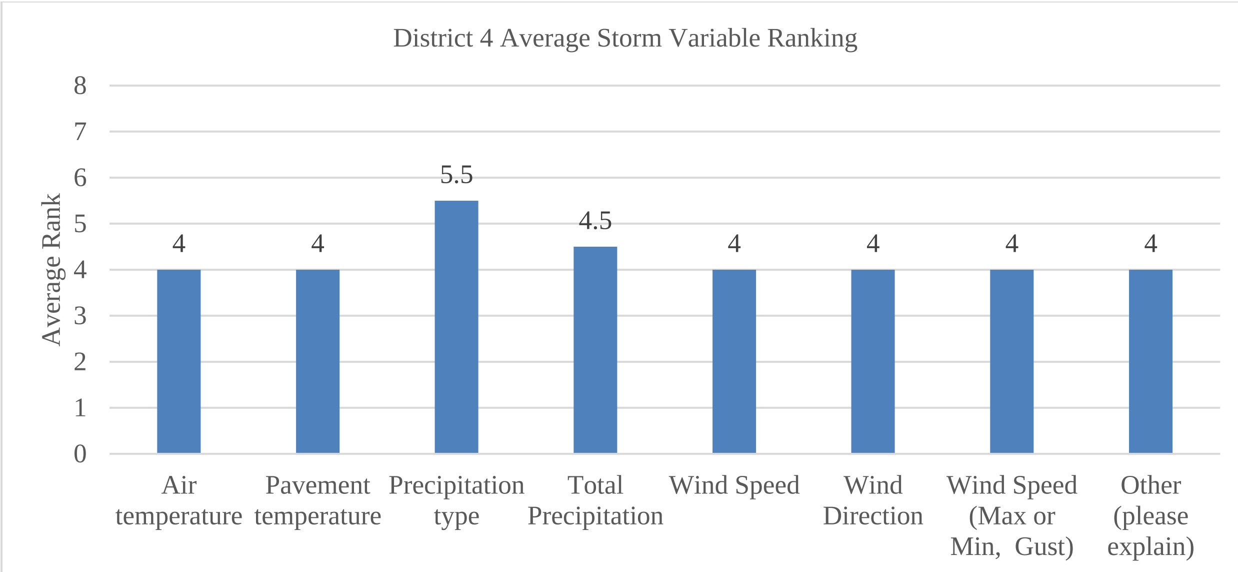


Figure 30. District 4 Average Storm Variable Ranking

District 5

Respondents from District 5 (n=4) ranked precipitation type, wind speed, and wind direction as their most important variables (3.5). Most variables were ranked around the middle of the scale for importance, with total precipitation and other being ranked as least important at 6.5 and 7.3 respectively. Other variables included precipitation intensity and prior salt on the roadway from previous events. District 5 responses are summarized in Figure 31.

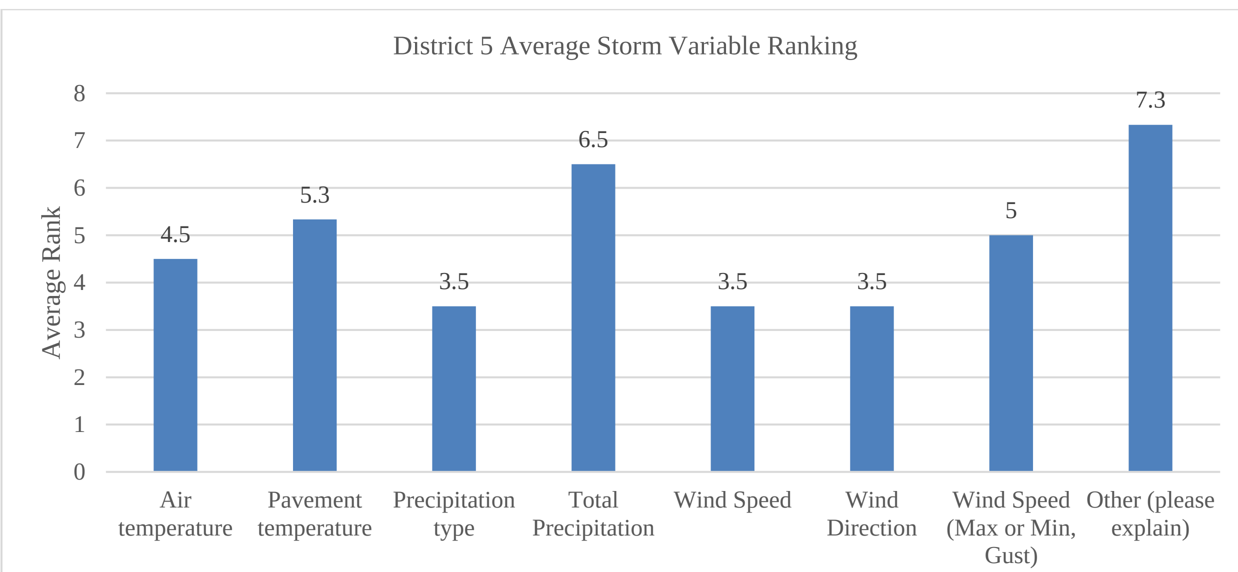


Figure 31. District 5 Average Storm Variable Ranking

District 6

District 6 respondents (n=2) ranked precipitation type as most important (1). Pavement temperature and air temperature were ranked highly for importance, whereas wind speed and wind speed (max or min, gust) were ranked low. Other storm variables were ranked around the middle (4), respondents reported the other variable was precipitation intensity. District 6 responses are summarized in Figure 32.

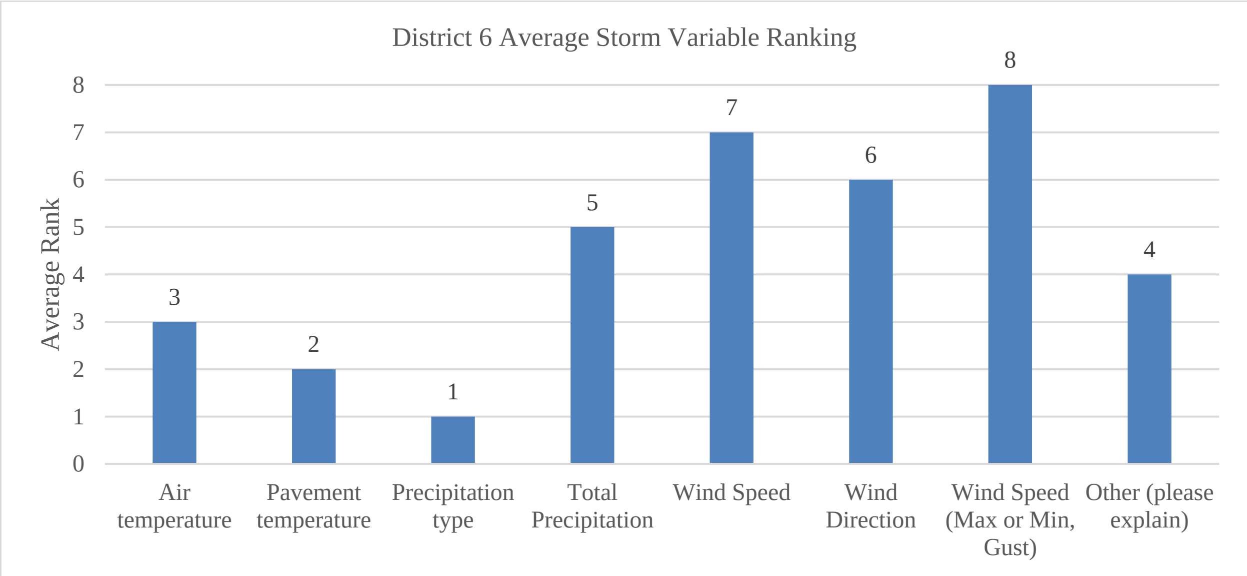


Figure 32. District 6 Average Storm Variable Ranking

District 7

Respondents from District 7 (n=3) ranked air temperature, precipitation type, and pavement temperature as most important storm variable. Other was ranked at as the least important, though the respondents did not provide information on what other conditions they experienced. District 7 responses are summarized in Figure 33.

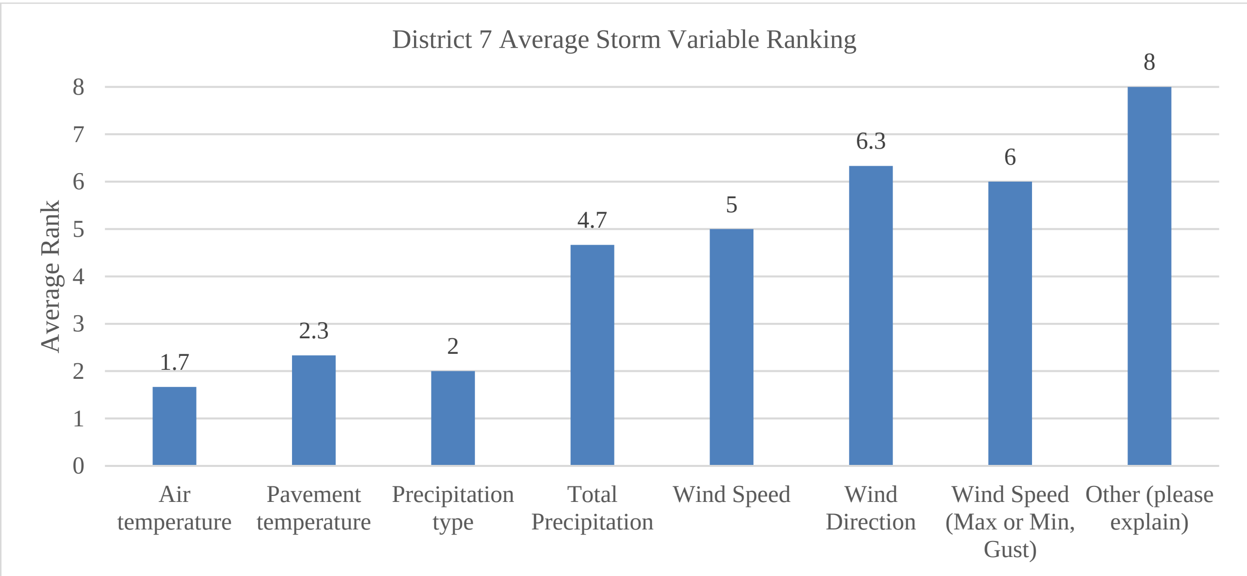


Figure 33. District 7 Average Storm Variable Ranking

Storm Conditions

Respondents were asked to describe what sorts of winter storm conditions they experience within their maintenance district. Thirty-six (out of 39) respondents answered this question. Freezing rain was the most commonly reported condition (97% of respondents), followed by drifting snow (86%) and heavy snow accumulation (86%). As Figure 34 indicates, all weather conditions that affect maintenance operations received a high number of responses to this question.

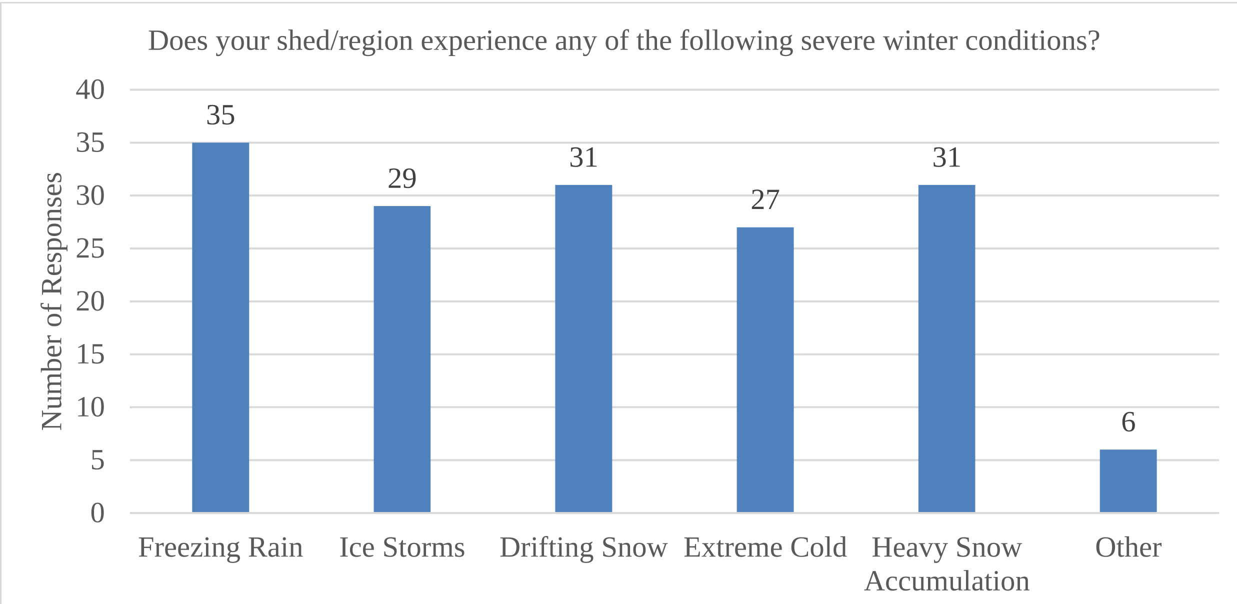


Figure 34. Winter Storm Conditions Experienced

Six respondents replied with Other storm conditions of concern, and five of those respondents provided text to describe those conditions, which are detailed in Table 20. Other conditions identified included sleet, hard pack snow, high winds, and borderline freezing temperatures.

Table 20. Other Winter Storm Conditions

District	Maintenance Shed	Other (please explain) - Text
1	Princess Anne	sleet freezing rain often, borderline freezing temps geographically
2	Denton	Wind chill dip down cold
5		traffic
Central Office		Sleet and hard pack
		High wind

Respondents were next asked to describe the winter storm conditions that their maintenance shop experienced. Sixteen respondents provided comments on freezing rain conditions, which are provided in Table 21. The feedback provided described issues with bridges and overpasses during freezing rain events, high accident [crash] rates, traffic volumes in District 3, and increases in salt usage.

Table 21. Freezing Rain Comments

District	Maintenance Shed	Freezing Rain - Text
1	Princess Anne	contributing to ice on roadway
1	Princess Anne	often a mixture
1	Salisbury	not often
2	Denton	Low temp – 9
2	Elkton	Yes
3	Gaithersburg	Concerns because of high volume of traffic, staying ahead of this is tricky
3	Gaithersburg	traffic still moving at posted speed, High accident results
3	Laurel	Precip. Line generally falls in our area.
4		uses lots of salt
6	Keysers Ridge	Ground temperature less than 28 degrees F
6	Keysers Ridge	Intense freezing rain with temps below 28 degrees
7	Dayton	slight movement of the rain freeze line along the I95 corridor
7	Westminster	Air and surface temp, freeze line
		Elevation changes
		Surrounding rivers and bays
		We have problems with our high elevated bridges and overpasses, especially during a freezing rain event, when it is cold and foggy

Thirteen respondents provided comments on ice storm conditions as shown in Table 22. Comments mentioned issues with ice storms causing tree limbs and power lines to come down and issues with bridges and overpasses freezing quickly.

Table 22. Ice Storm Comments

District	Maintenance Shed	Ice Storms - Text
1	Princess Anne	contributing to ice on roadways
1	Princess Anne	occasional
1	Salisbury	one in a winter
2	Denton	Yes we are
3	Gaithersburg	tree coming down

4		uses lots of salt
6	Keysers Ridge	1" or greater bringing down limbs and power lines
6	Keysers Ridge	1/2 inch or greater of ice that brings down limbs and power lines
7	Dayton	being in an area where conditions are rain in the southern end of the county and ice/snow in the northern area
7	Westminster	Air and surface temp, freeze line
		Elevation changes
		Ice storms, cause our bridges and overpasses to freeze quickly especially the ones near the bay.
		surrounding rivers and bays

Fifteen respondents provided comments on drifting snow conditions as shown in Table 23. Six comments specifically mentioned wind speeds or wind gusts as being concerns leading to impacts on maintenance operations. Additionally, multiple comments mention that their district had issues with drifting snow in areas with open fields or farmlands.

Table 23. Drifting Snow Comments

District	Maintenance Shed	Drifting Snow - Text
1	Princess Anne	isolated areas
1	Salisbury	a few times
2	Denton	Yes, lots of open fields
2	Elkton	Yes, we have many flat drifting areas in the northern and southern ends of the county
2		Light snow and winds above 15 MPH
3	Gaithersburg	open field areas bring increased patrol
3	Gaithersburg	We have farms in our area with wide open spaces in our right of way
6	Keysers Ridge	25 mph plus can create severe conditions. Snow sifts out at 10 mph or greater.
6	Keysers Ridge	Winds greater than 20 mph
7	Dayton	very little drifting
7	Westminster	Winds over 15 sustained and gusts over 25
		Certain areas experience isolated drifting
		High winds in field areas
		We have Problems areas that we don't have living snow fence, such open farm land.
		Yes over 25 mph

Nine respondents provided comments on extreme cold conditions as shown in Table 24. A few of those comments mention temperatures of -10 degrees Fahrenheit as being a point of extreme temperature. One comment specifically mentioned that extreme cold conditions caused the pavement to deteriorate due to freeze/thaw cycles.

Table 24. Extreme Cold Comments

District	Maintenance Shed	Extreme Cold - Text
1	Princess Anne	occasional
1	Salisbury	most storms are moderate
2	Denton	Yes we had -13 for a week last year
2	Elkton	Yes
6	Keysers Ridge	-10 F or below
6	Keysers Ridge	Temperatures less than -10 F
		extreme cold, causes the pavement to deteriorate due to the freezing and thawing, which causes pot holes on older road surfaces.
		How long temps remain low>
		surrounding rivers and bays

Twelve respondents provided comments on heavy snow accumulation events as shown in Table 25. One respondent in District 2 mentioned storm events dropping 6 to 10 inches of snow at a time. Two respondents from District 6 mentioned receiving over 3 feet of snow in a day.

Table 25. Heavy Snow Accumulation Comments

District	Maintenance Shed	Heavy Snow Accumulation - Text
1	Princess Anne	Occasional
1	Salisbury	one a winter
2	Denton	Around 6/10 inch more at a time
2	Elkton	Yes, our northern end of the county tends to receive more accumulation than central or southern
3	Gaithersburg	damage to infrastructure
5	Glen Burnie	Glen Burnie due to its location is more likely to experience this type.
6	Keysers Ridge	36 inches per day or greater
6	Keysers Ridge	Greater than 3 feet per day

7	Dayton	path of the storm when it follows the 95 corridor
		Heavy snow accumulations in our area causes problems for us with blowing and drifting snow.
		Length of storm
		Surrounding rivers and bays

Storm Conditions by Maintenance District

District 1

Four responses came from Maintenance staff in District 1, two from the Salisbury Maintenance Shop and two from the Princess Anne Maintenance Shop. According to respondents, District 1 experiences all of the mentioned storm conditions with freezing rain being the most commonly reported condition. One respondent from the Princess Anne Maintenance Shop responded with Other and stated that they often see sleet and freezing rain and borderline freezing temperatures geographically. District 1 responses related to storm conditions are summarized in Figure 35.

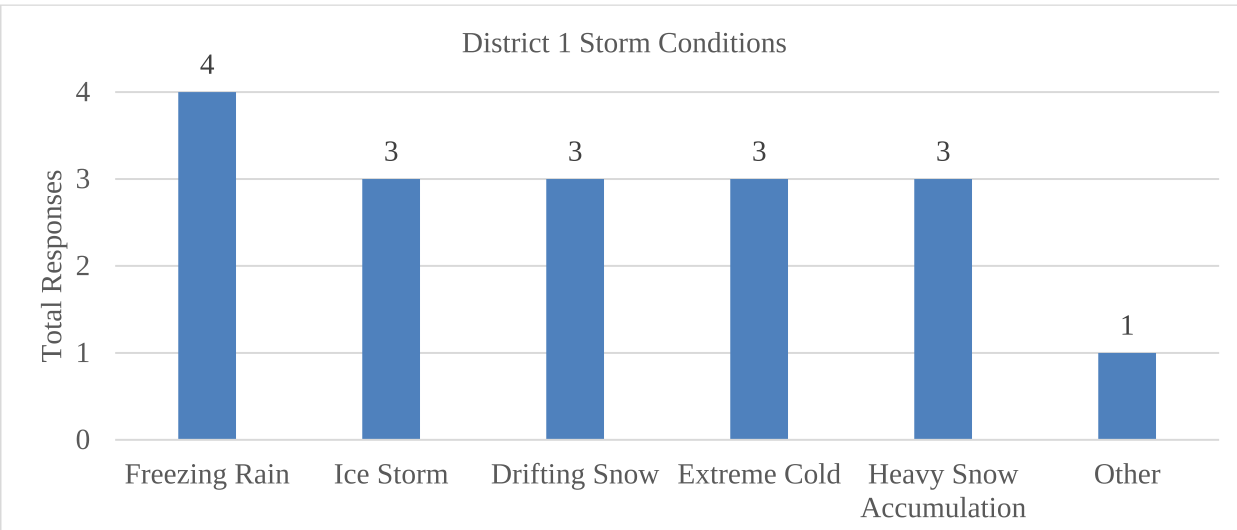


Figure 35. District 1 Storm Conditions

District 2

Three respondents were from District 2, one from the Denton Maintenance Shop, one from Elkton, and one unknown. Freezing rain, drifting snow, extreme cold, and heavy snow accumulation were reported by all three see Figure 36. Ice storms and “other” were reported by the Denton Maintenance Shop and this respondent also reported that they experienced “wind chill dip[s] down cold.” District 2 responses related to storm conditions are summarized in Figure 36.

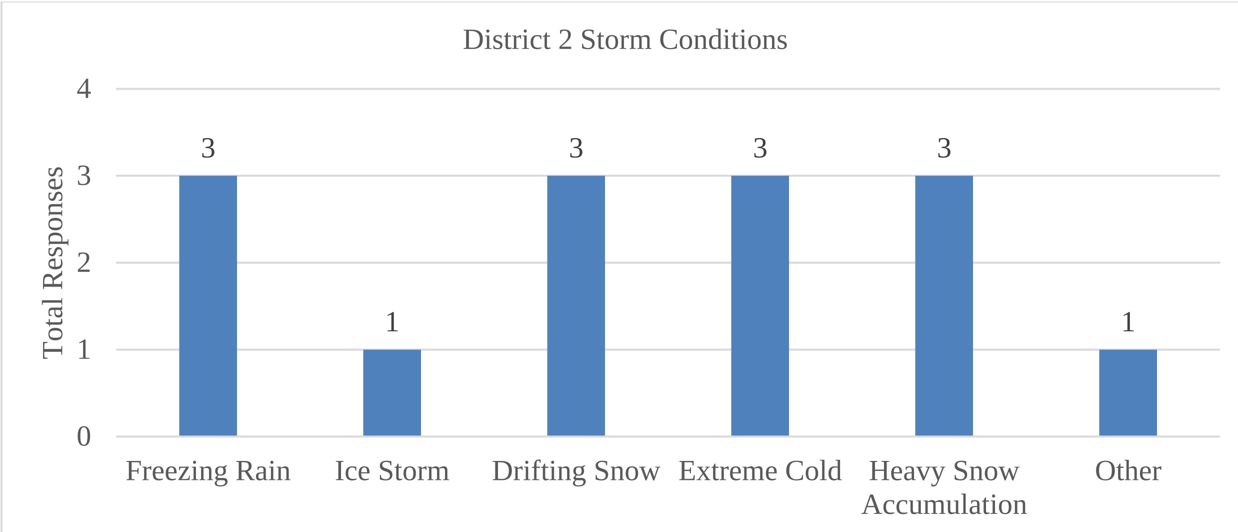


Figure 36. District 2 Storm Conditions

District 3

Five respondents were from District 3, two from the Gaithersburg Maintenance Shop, one from Laurel Maintenance Shop, and two did not provide their further information. Freezing rain was the most commonly reported storm condition (80%), see Figure 37. Both respondents from the Gaithersburg Maintenance Shop reported issues with freezing rain and traffic, heavy volumes of traffic, and that the public still travels at the posted speed limit. District 3 responses related to storm conditions are summarized in Figure 37.

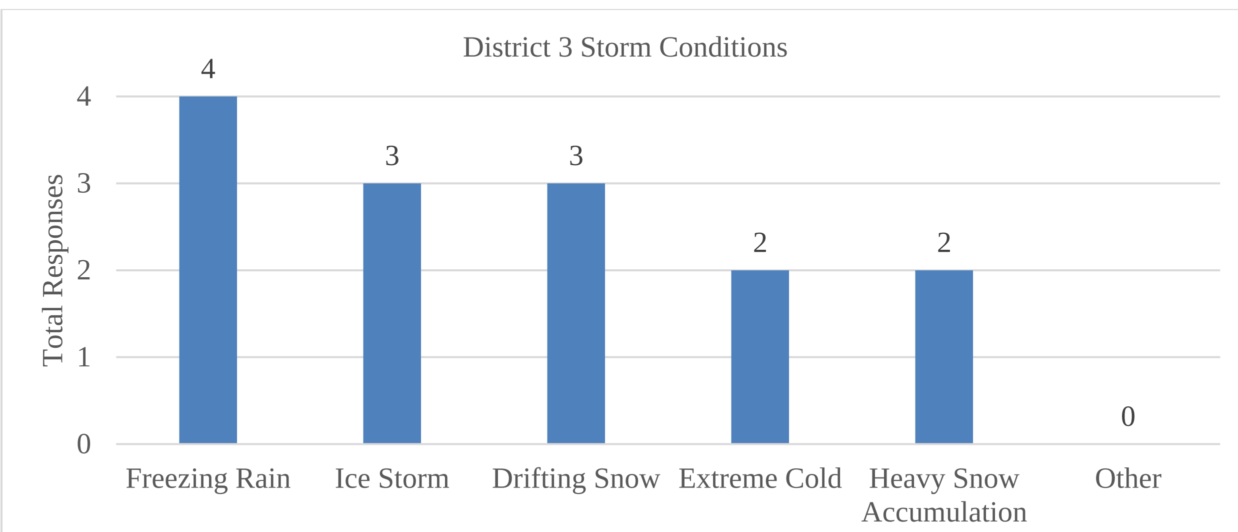


Figure 37. District 3 Storm Conditions

District 4

Only two respondents from District 4 answered this question, one from Owings Mills Maintenance Shop and the other did not provide further information on their location. Both respondents reported experiencing freezing rain, ice storms, drifting snow, extreme cold, and heavy snow accumulation. The one respondent that did not provide their maintenance shop responded with "other," but did not provide further information on the further storm conditions that they experienced. District 4 responses related to storm conditions are summarized in Figure 38.

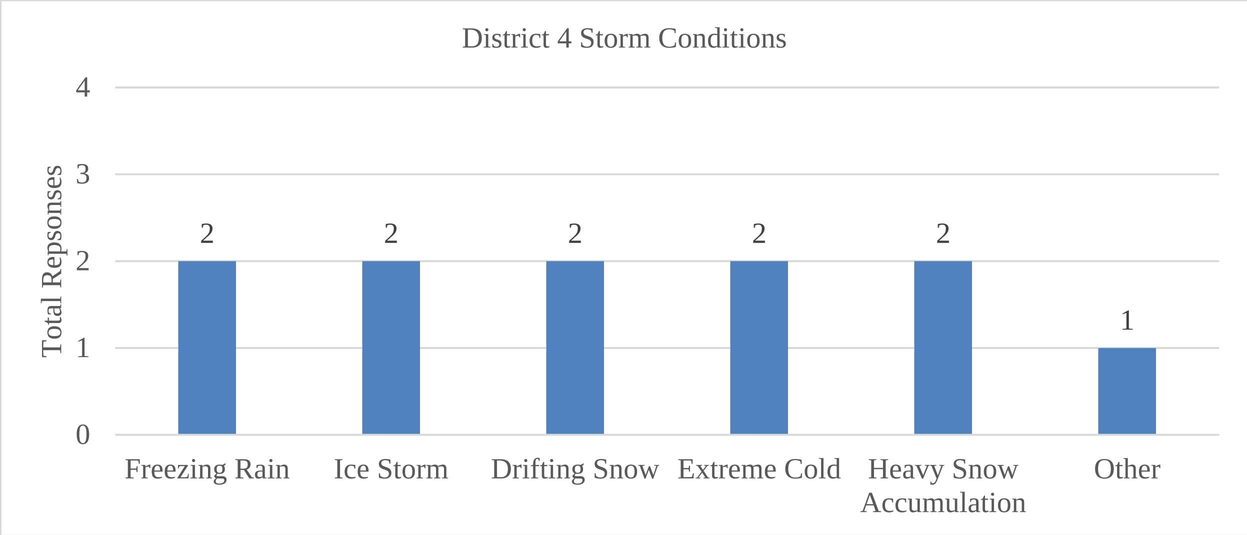


Figure 38. District 4 Storm Conditions

District 5

Four respondents from District 5 answered this question; only one provided their maintenance shop (Glen Burnie). Heavy snow accumulation was reported by all of these respondents. One respondent responded with "other" and reported "traffic." District 5 responses related to storm conditions are summarized in Figure 39.

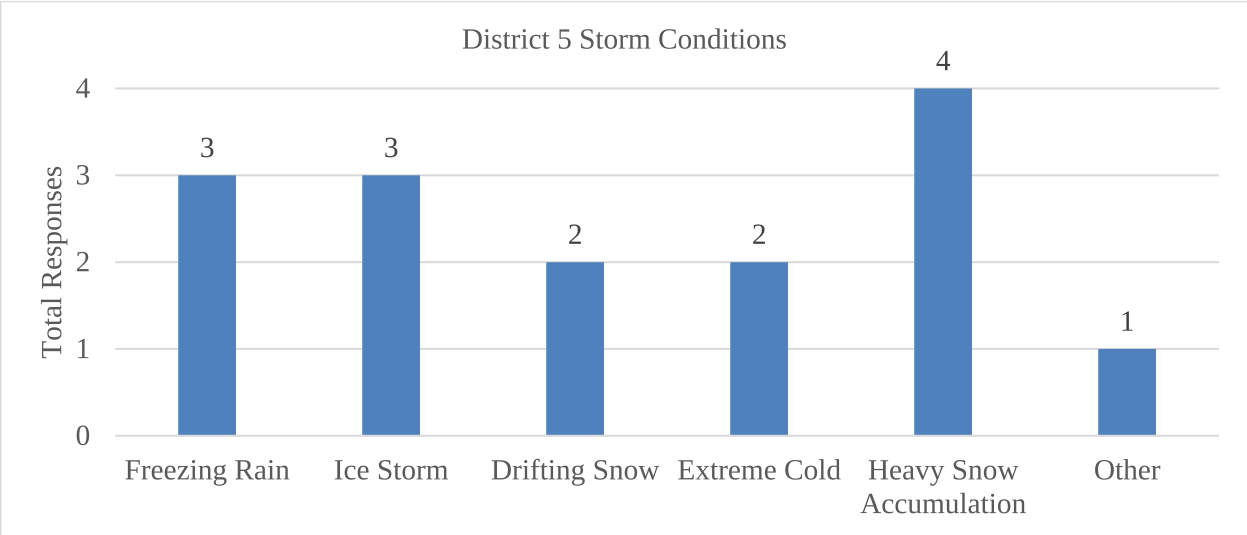


Figure 39. District 5 Storm Conditions

District 6

Two respondents from District 6 responded to this question; both were from the Keysers Ridge Maintenance Shop. Both respondents reported experiencing freezing rain, ice storms, drifting snow, extreme cold, and heavy snow accumulation. Both respondents reported they experienced intense freezing rain where ground temperatures went below 28 degrees Fahrenheit. For ice storm conditions, both respondents mentioned experiencing over half an inch of ice resulting in tree limbs and power lines coming down. District 6 responses related to storm conditions are summarized in Figure 40.

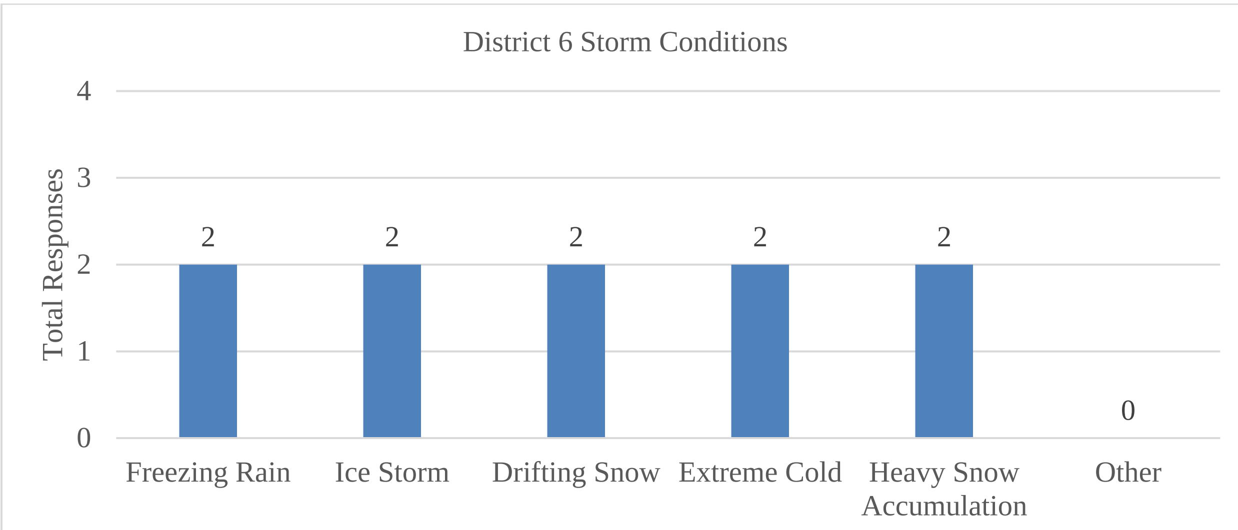


Figure 40. District 6 Storm Conditions

District 7

Three respondents from District 7 answered this question; one reported being from the Westminster Maintenance Shop, one from Dayton, and the other did not provide further information on their location. All three respondents reported experiencing freezing rain, ice storms, drifting snow, and heavy snow accumulation. The one respondent who did not provide information on their maintenance shop reported experiencing extreme cold conditions. District 7 responses related to storm conditions are summarized in Figure 41.

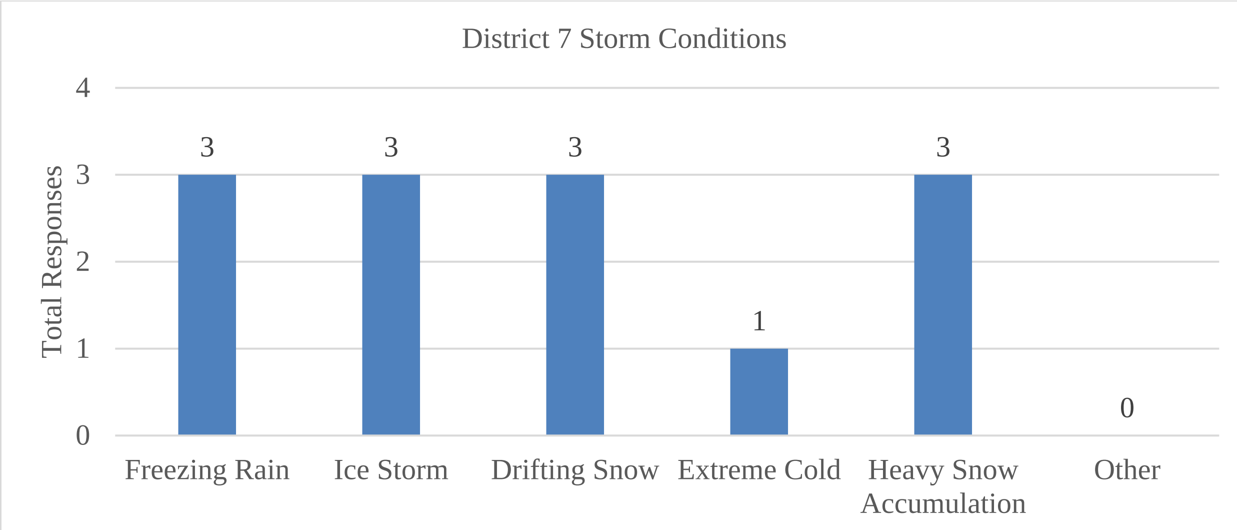


Figure 41. District 7 Storm Conditions

Precipitation of Various Storm Types

Respondents were asked to indicate the amount of precipitation that their maintenance shop experiences based on differing storm events for both a "normal" and "severe" event. Twenty-nine (out of 39) respondents answered this question. On average, reported precipitation varied from 0.4 inches for freezing rain (normal) to 21 inches for heavy snow accumulation (severe). In general, freezing rain (both normal and severe) and ice storms (both normal and severe) tended to have the lowest amounts of precipitation. Drifting snow (severe) and heavy snow accumulation (severe) had the most precipitation. Responses related to precipitation of various storm types are summarized in Table 26 and Figure 42.

Table 26. Summary of Responses - Precipitation of Various Storm Types

Category	Number of Responses	Min (Inches)	Max (Inches)	Average (Inches)
Freezing Rain - Normal Precipitation	28	0.01	2	0.4
Freezing Rain - Severe Precipitation	18	0.2	3	1.1
Ice Storms - Normal Precipitation	20	0	2	0.3
Ice Storms - Severe Precipitation	18	0.25	2	0.8
Drifting Snow - Normal Precipitation	24	0	12	3.8
Drifting Snow - Severe Precipitation	18	0	36	13.8
Extreme Cold - Normal Precipitation	8	0	10	4.1
Extreme Cold - Severe Precipitation	9	0	24	12.0
Heavy Snow Accumulation - Normal Precipitation	25	1	24	8.9
Heavy Snow Accumulation - Severe Precipitation	17	6	42	20.9

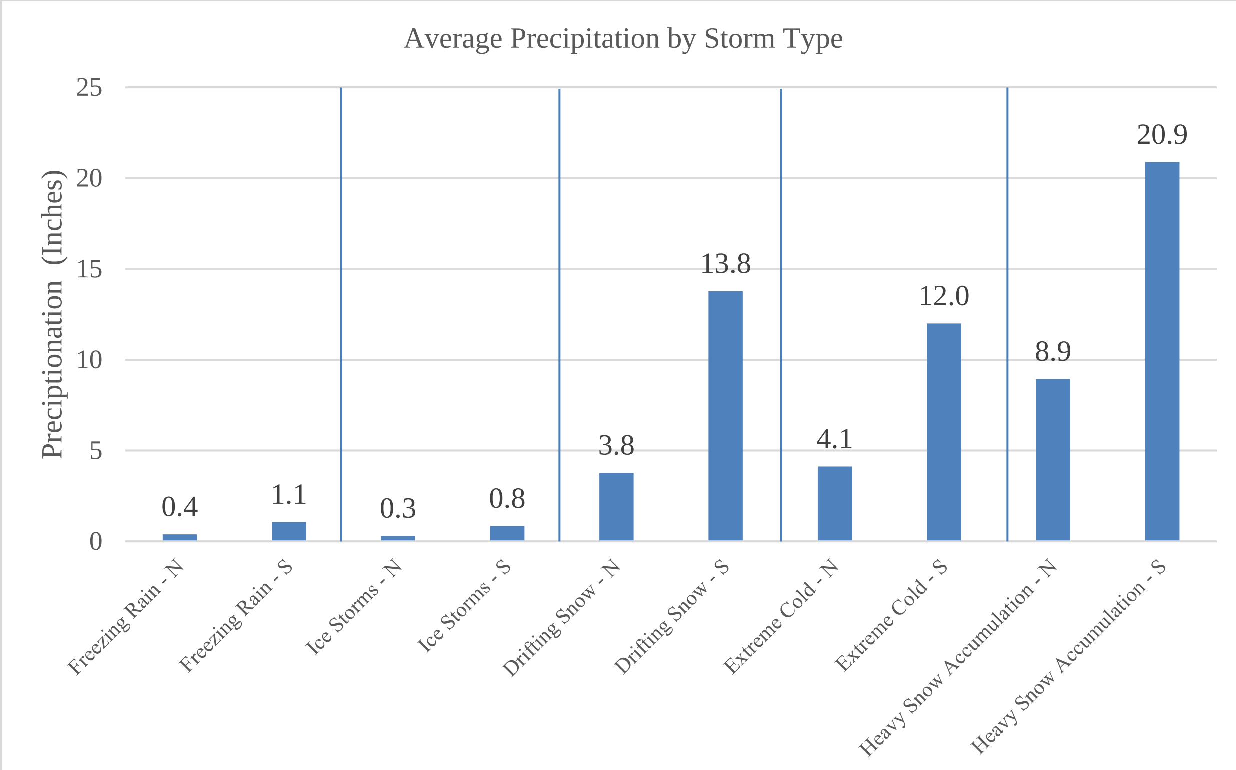


Figure 42. Average Precipitation (N – Normal Precipitation, S – Severe Precipitation)

A few respondents answered zero for precipitation. It is unclear if this is because their maintenance district did not experience this storm type. If the "zero" responses are removed, the average precipitation amounts increase minimally except for extreme cold (severe), which increases from 12 inches to 13.5 inches. Responses related to precipitation of various storm types, with the zeroes removed, are summarized in Table 27 and Figure 43.

Table 27. Summary of Responses - Precipitation of Various Storm Types - Zeros Removed

Category	Number of Responses	Min (Inches)	Max (Inches)	Average (Inches)
Freezing Rain - Normal Precipitation	28	0.01	2	0.4
Freezing Rain - Severe Precipitation	18	0.2	3	1.1
Ice Storms - Normal Precipitation	18	0.01	2	0.3
Ice Storms - Severe Precipitation	18	0.25	2	0.8
Drifting Snow - Normal Precipitation	22	1	12	4.2
Drifting Snow - Severe Precipitation	17	3.5	36	14.6
Extreme Cold - Normal Precipitation	7	2	10	4.7
Extreme Cold - Severe Precipitation	8	5	24	13.5
Heavy Snow Accumulation - Normal Precipitation	25	1	24	8.9

Category	Number of Responses	Min (Inches)	Max (Inches)	Average (Inches)
Heavy Snow Accumulation - Severe Precipitation	17	6	42	20.9

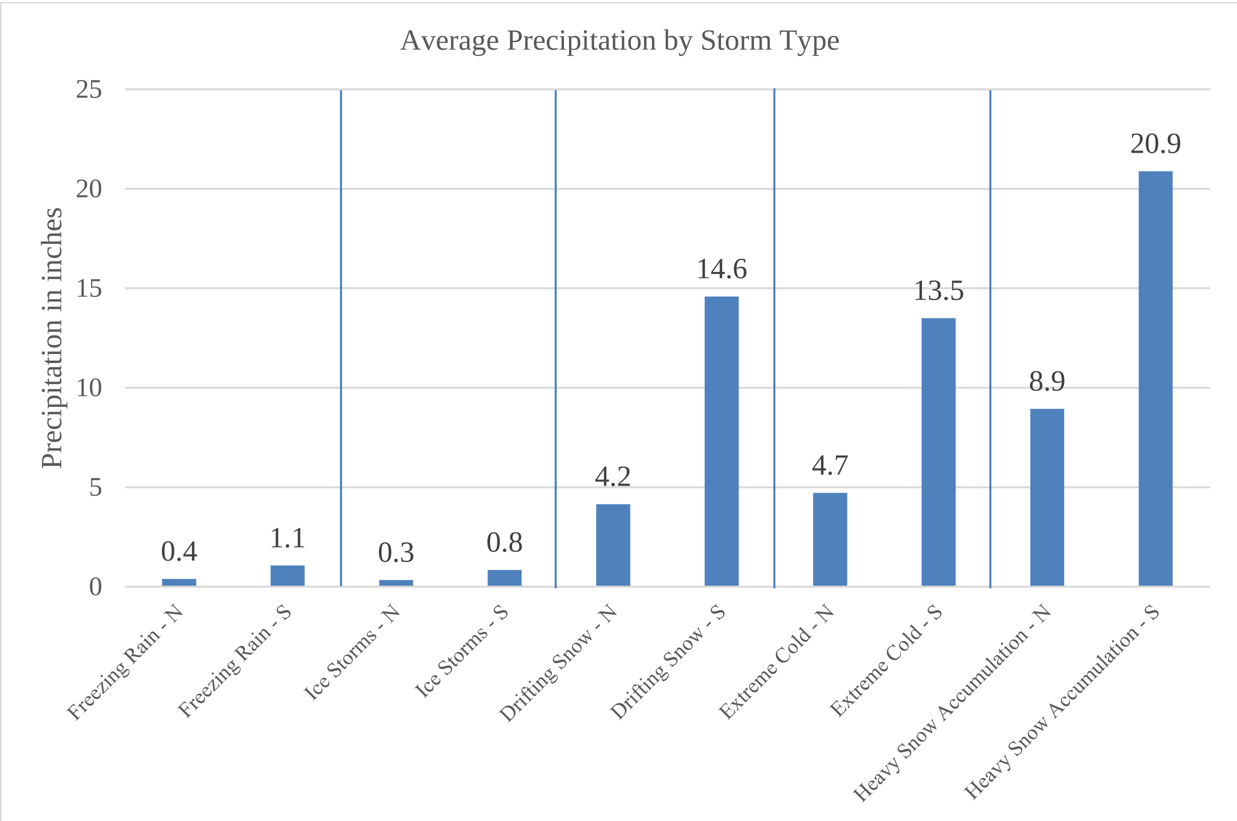


Figure 43. Average Precipitation - Zeros Removed (N – Normal Precipitation, S – Severe Precipitation)

Precipitation of Various Storm Types by Maintenance District

Average precipitation by storm type varied by district, but on average, freezing rain and ice storms were reported most to have the lowest amount of precipitation and heavy snow accumulation. District 6 reported higher amounts of precipitation for drifting snow events compared to all other maintenance districts. Out of all districts, District 5 and District 6 reported the higher amounts of precipitation for extreme cold events. Districts 3 and 4 reported higher average precipitation for heavy snow accumulation (severe) events than any other district. Responses related to precipitation of various storm types by maintenance district are summarized in Figure 44.

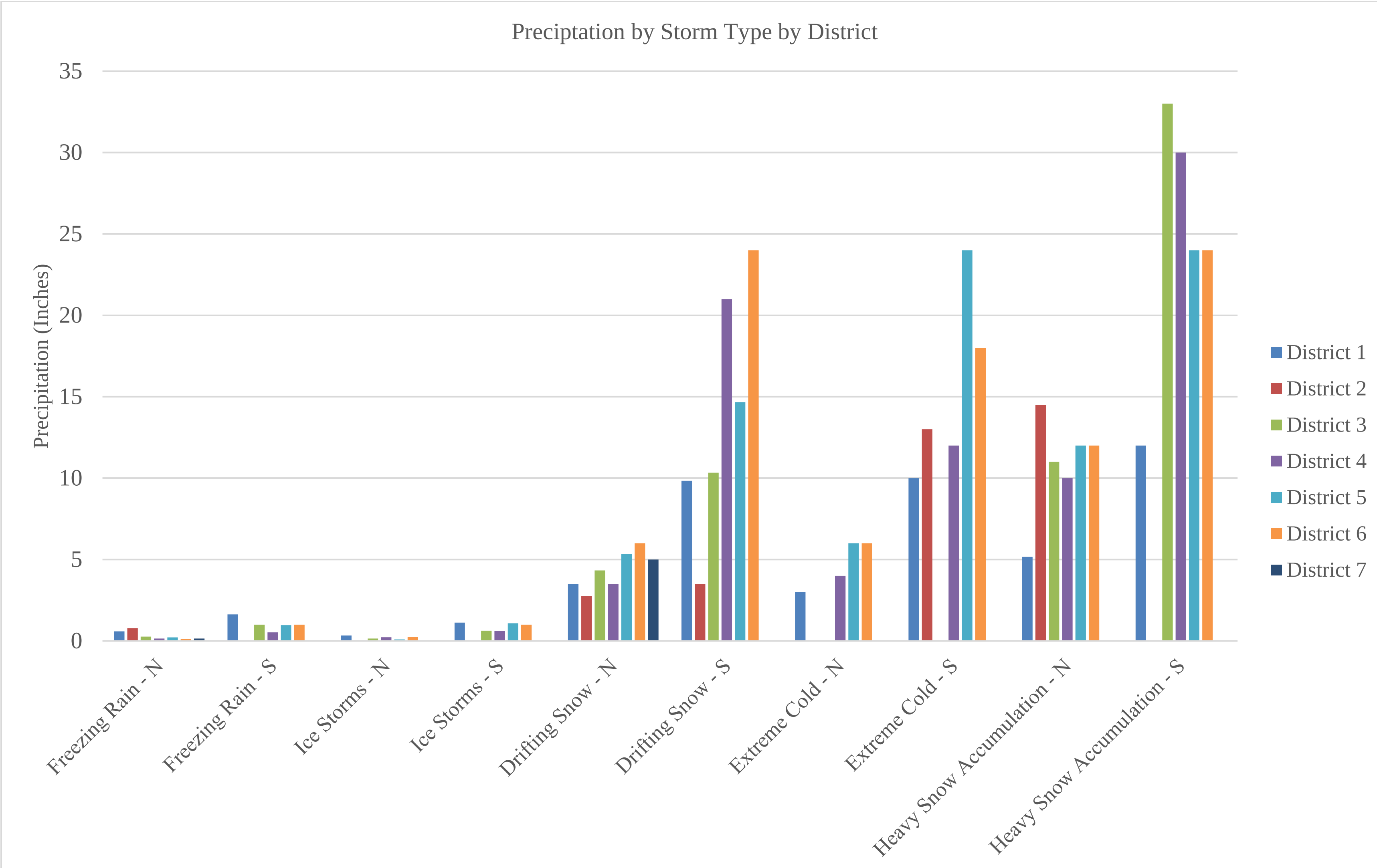


Figure 44. Average Precipitation by Storm Type for Each Maintenance District

District 1

Respondents from District 1 (n=4) reported total precipitation ranging from 0.3 inches for ice storms (normal) to 12 inches for heavy snow accumulation (severe). Severe events including drifting snow, extreme cold, and snow accumulation have the largest amount of precipitation while freezing rain (normal) and ice storms (normal) result in less than an inch of precipitation. Responses related to average precipitation by storm type in District 1 are summarized in Figure 45.

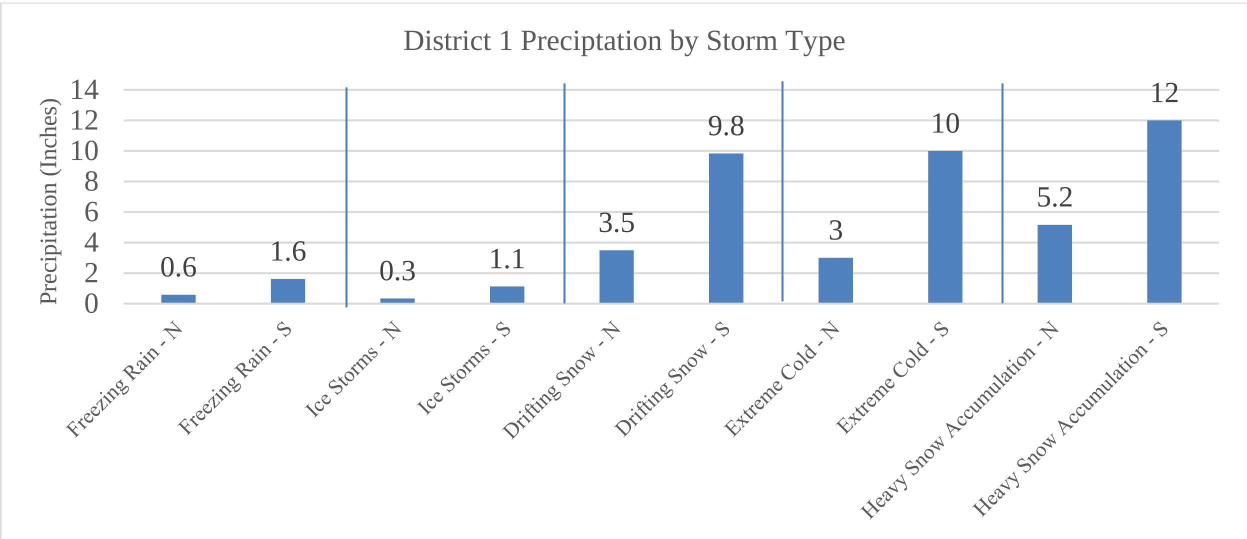


Figure 45. District 1 Average Precipitation by Storm Type

District 2

Three respondents provided information on storm precipitation; none of the respondents provided precipitation numbers for freezing rain (severe), ice storms (both normal and severe), extreme cold (normal), or heavy snow accumulation (severe). It is unclear if this is because District 2 does not experience these storm types or if the respondents chose not to answer. Considering the answer to the previous question, District 2 does experience ice storms so it would seem to indicate that that the respondents chose to skip answering parts of these questions. Heavy snow accumulation (normal) and extreme cold (severe) experience the largest amounts of precipitation at 14.5 inches and 13 inches respectively. Drifting snow was reported to result in 2.8 to 3.5 inches of precipitation depending on the storm severity. Freezing rain (normal) results in less than an inch of precipitation. Responses related to average precipitation by storm type in District 2 are summarized in Figure 46.

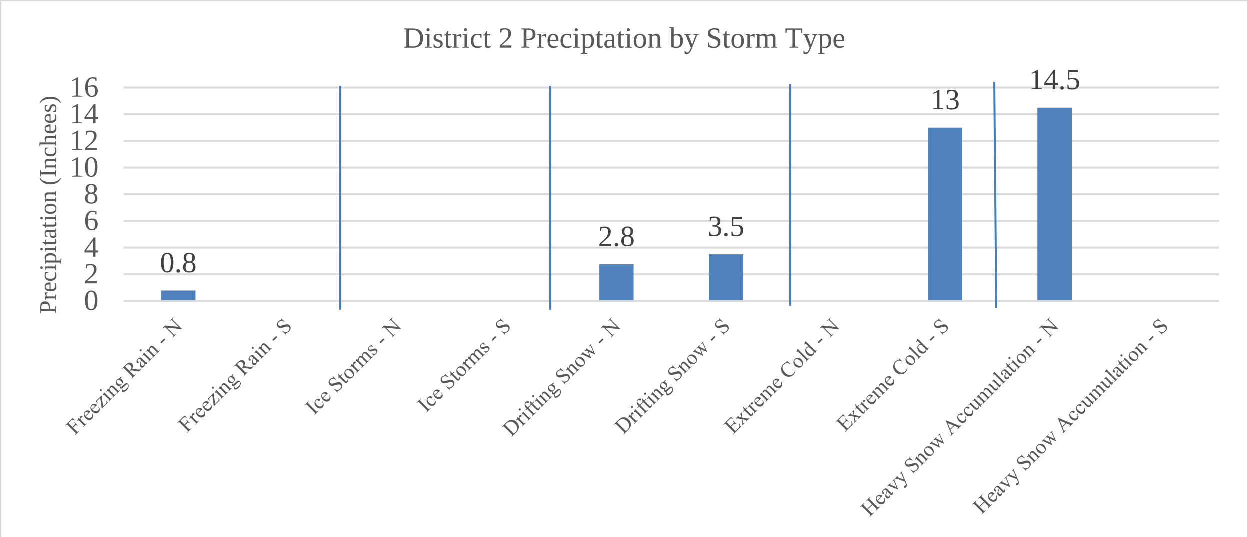


Figure 46. District 2 Average Precipitation by Storm Type

District 3
District 3 (n=3) reported fairly low precipitation (less than 10 inches) for most storm events with the exception of heavy snow accumulation which saw 11 inches to 33 inches depending on the severity of the storm. Freezing rain and ice storms both result in an inch or less of precipitation. Responses related to average precipitation by storm type in District 3 are summarized in Figure 47.

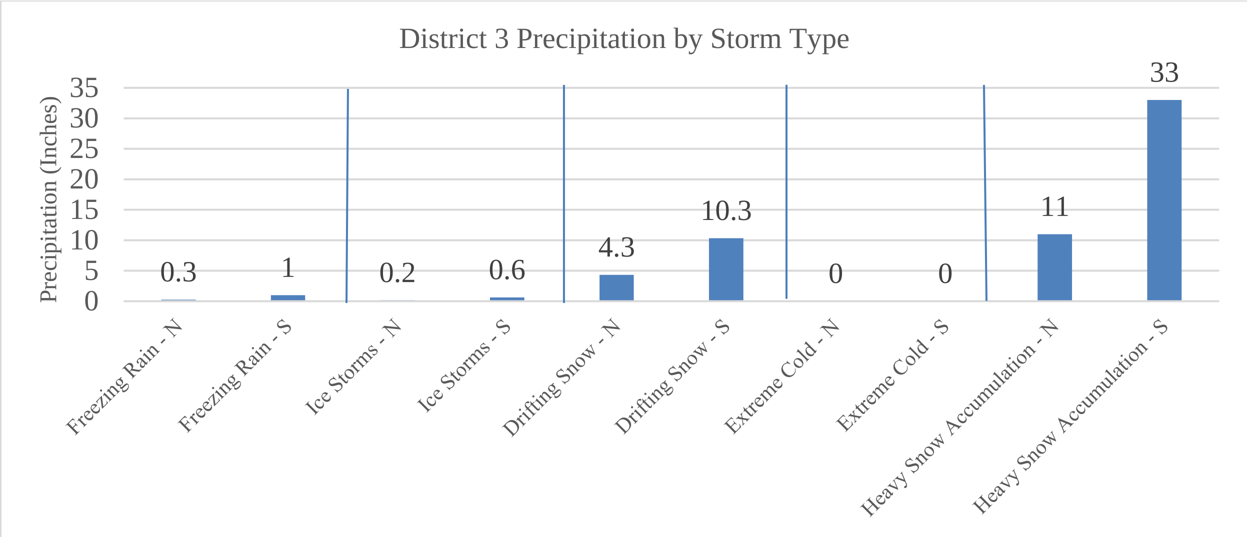


Figure 47. District 3 Average Precipitation by Storm Type

District 4
District 4 (n=2) reported similar precipitation numbers to that of District 3. Respondents reported heavy snow accumulation resulting in 10 inches to 30 inches of precipitation depending

on storm severity. Drifting snow (severe) also say larger amounts of precipitation (21 inches). Both freezing rain and ice storms result in less than an inch of precipitation. Responses related to average precipitation by storm type in District 4 are summarized in Figure 48.

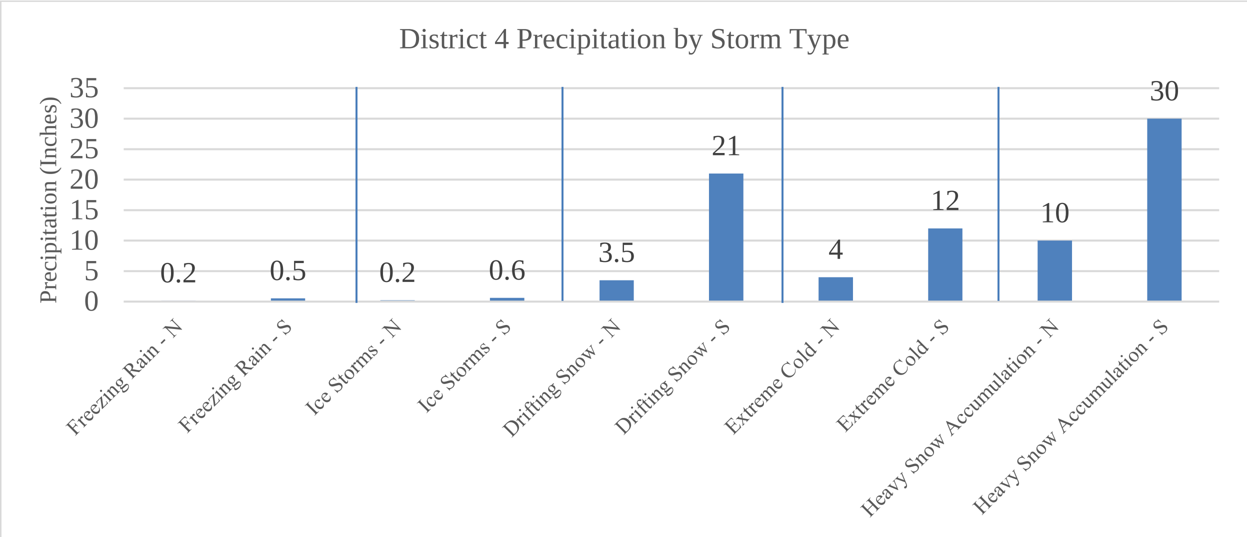


Figure 48. District 4 Average Precipitation by Storm Type

District 5

Respondents from District 5 (n=4) reported seeing upwards of 24 inches of precipitation with extreme cold (severe) and heavy snow accumulation (severe) events. Similar to Districts 3 and 4, District 5 sees an inch or less of precipitation with freezing rain and ice storm events. Responses related to average precipitation by storm type in District 5 are summarized in Figure 49.

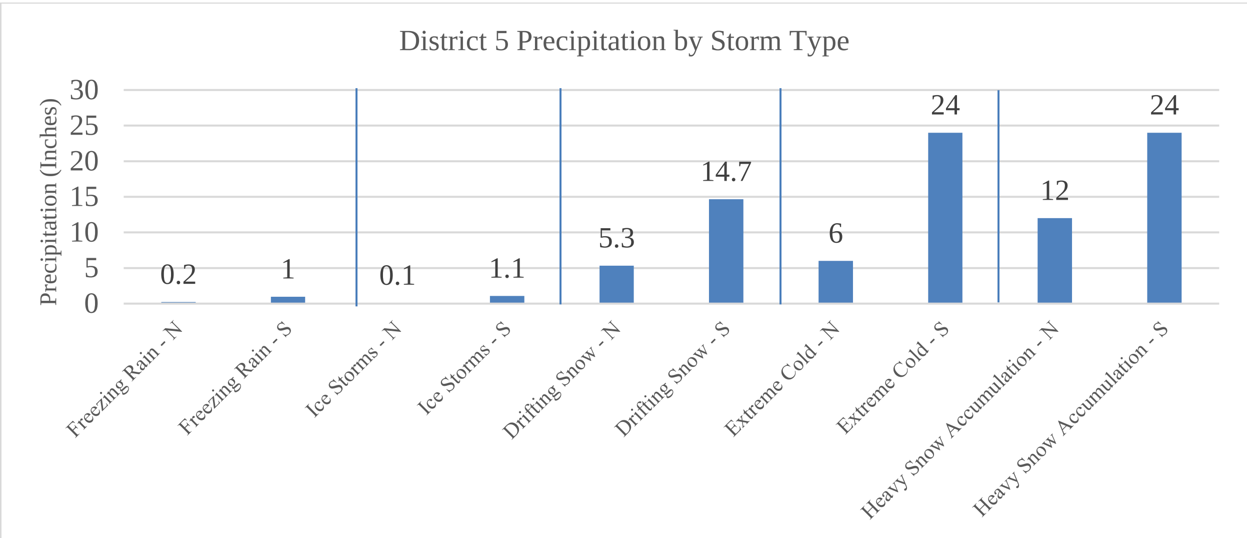


Figure 49. District 5 Average Precipitation by Storm Type

District 6
Respondents from District 6 (n=2) reported similar amounts of precipitation for each storm type to the amounts reported by District 5. Both drifting snow (severe) and heavy snow accumulation (severe) were reported to result in up to two feet of snow. Again, freezing rain and ice storms see an inch or less of precipitation. Responses related to average precipitation by storm type in District 6 are summarized in Figure 50.

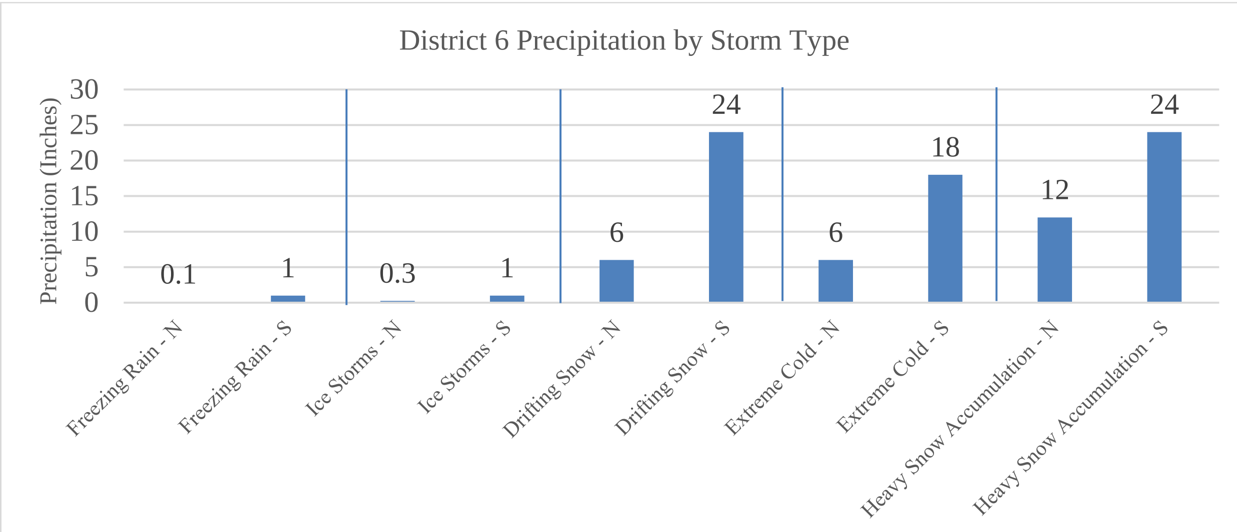


Figure 50. District 6 Average Precipitation by Storm Type

District 7
Only one respondent provided precipitation amounts for District 7. Precipitation amounts were only given for freezing rain (normal), which sees around 0.2 inches and drifting snow (normal) which sees 5 inches of precipitation. The respondent did not provide further information on any of the other storm types. Again, it is unclear if this is because the respondent chose to skip parts of the question or if they do not experience these events in District 7. Responses related to average precipitation by storm type in District 7 are summarized in Figure 51.

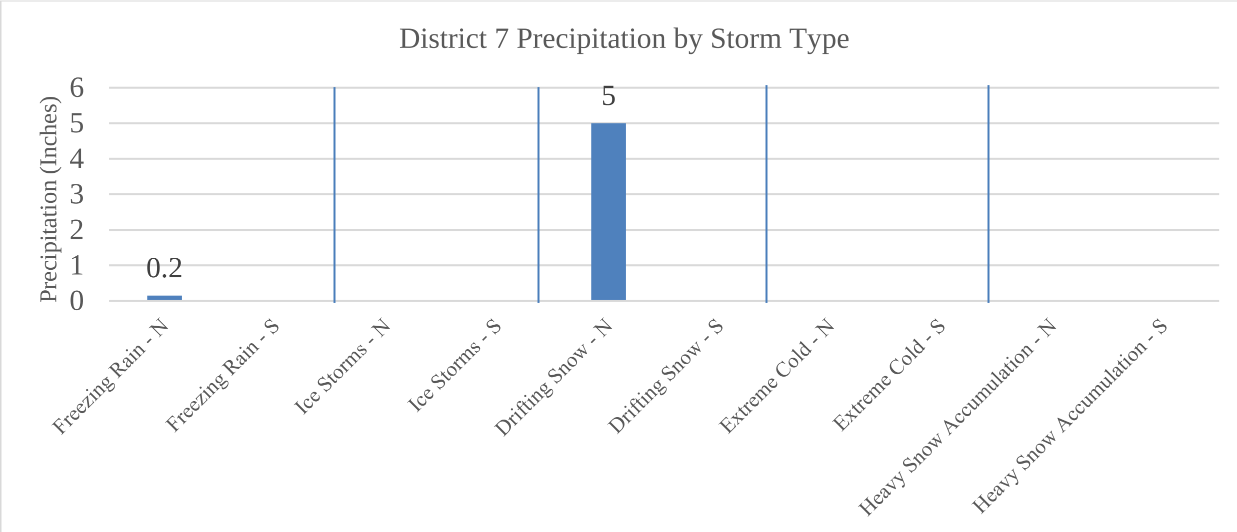


Figure 51. District 7 Average Precipitation by Storm Type

Duration of Various Storm Types

Respondents were asked to indicate the duration of various storm events that their maintenance shop experienced for both a "normal" and "severe" event. Twenty-nine (out of 39) respondents answered this question. Storm duration ranged from 0 hours to 120 hours (see Table 28 and Figure 52). On average, extreme cold (severe) events had the longest duration at 49 hours. Some respondents stated extreme cold events could last up to 120 hours. On average, ice storms (normal) had the shortest duration at 6 hours. Freezing rain (both normal and severe) and ice storms (both normal and severe) tended to be shortest duration events, whereas extreme cold and heavy snow accumulation had the longest durations.

Table 28. Summary of Responses - Duration of Various Storm Types

Category	Number of Responses	Min (Hours)	Max (Hours)	Average (Hours)
Freezing Rain - Normal Duration	19	0.2	48.0	8
Freezing Rain - Severe Duration	16	0.4	72.0	15
Ice Storms - Normal Duration	16	0.0	24.0	6
Ice Storms - Severe Duration	16	0.4	72.0	18
Drifting Snow - Normal Duration	16	0.0	48.0	14
Drifting Snow - Severe Duration	16	0.0	120.0	33
Extreme Cold - Normal Duration	8	0.0	120.0	26
Extreme Cold - Severe Duration	10	0.0	120.0	49
Heavy Snow Accumulation - Normal Duration	16	0.6	83.3	23
Heavy Snow Accumulation - Severe Duration	15	1.0	120.0	37

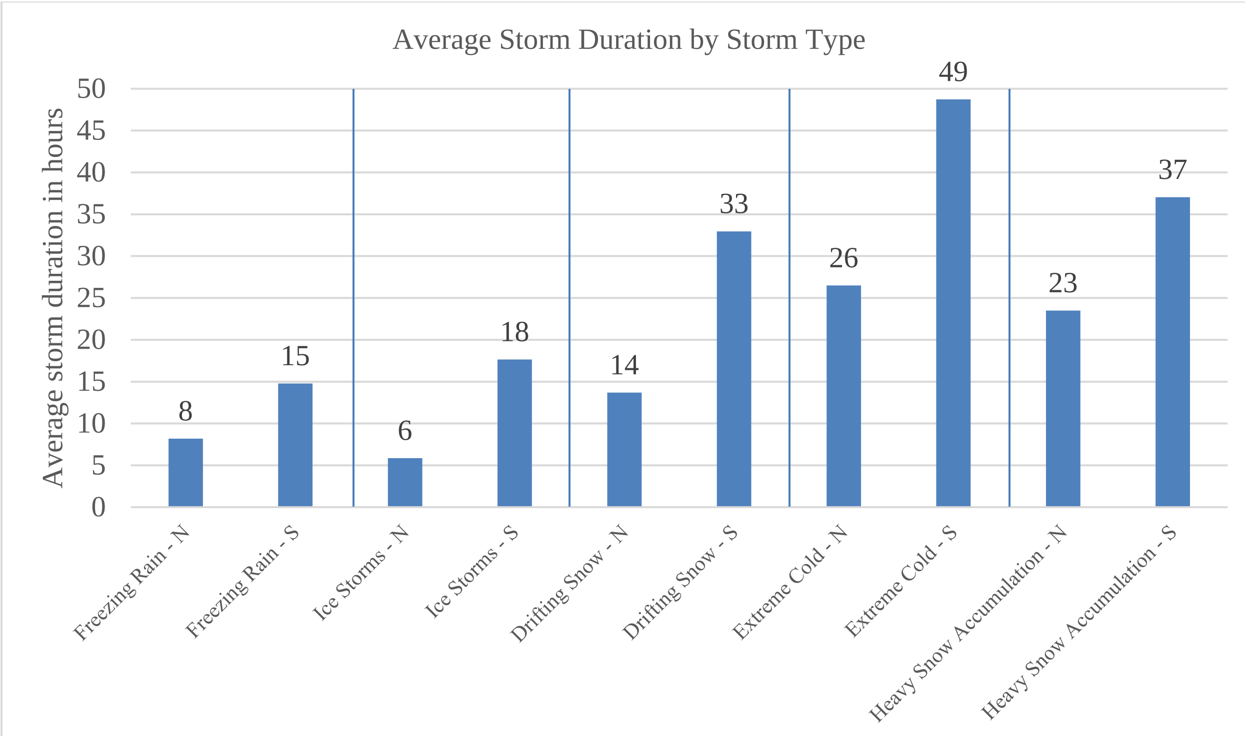


Figure 52. Average Duration of Various Storm Types (N – Normal Duration, S – Severe Duration)

A few respondents provided an answer of zero for duration. It is unclear if this is because their maintenance district did not experience this type of event, or whether there was another reason for providing that response. If these responses are removed, the average storm duration increases by approximately 3 hours for drifting snow, extreme cold, and heavy snow accumulation events (Figure 53 and Table 29). One item to notes is that average duration for a normal extreme cold event and severe cold event are the same. The average duration of various storm types with zeros removed is summarized in Table 29 and Figure 53.

Table 29. Summary of Responses - Duration of Various Storm Types - Zeros Removed

Category	Number of Responses	Min (Hours)	Max (Hours)	Average (Hours)
Freezing Rain - Normal Duration	19	0.2	48.0	8
Freezing Rain - Severe Duration	16	0.4	72.0	15
Ice Storms - Normal Duration	16	0.2	24.0	6
Ice Storms - Severe Duration	16	0.4	72.0	18
Drifting Snow - Normal Duration	16	1.0	48.0	15
Drifting Snow - Severe Duration	16	2.0	120.0	35
Extreme Cold - Normal Duration	8	8.0	120.0	29
Extreme Cold - Severe Duration	10	8.0	120.0	54
Heavy Snow Accumulation - Normal Duration	16	0.6	83.3	23

Heavy Snow Accumulation - Severe Duration	15	1.0	120.0	37

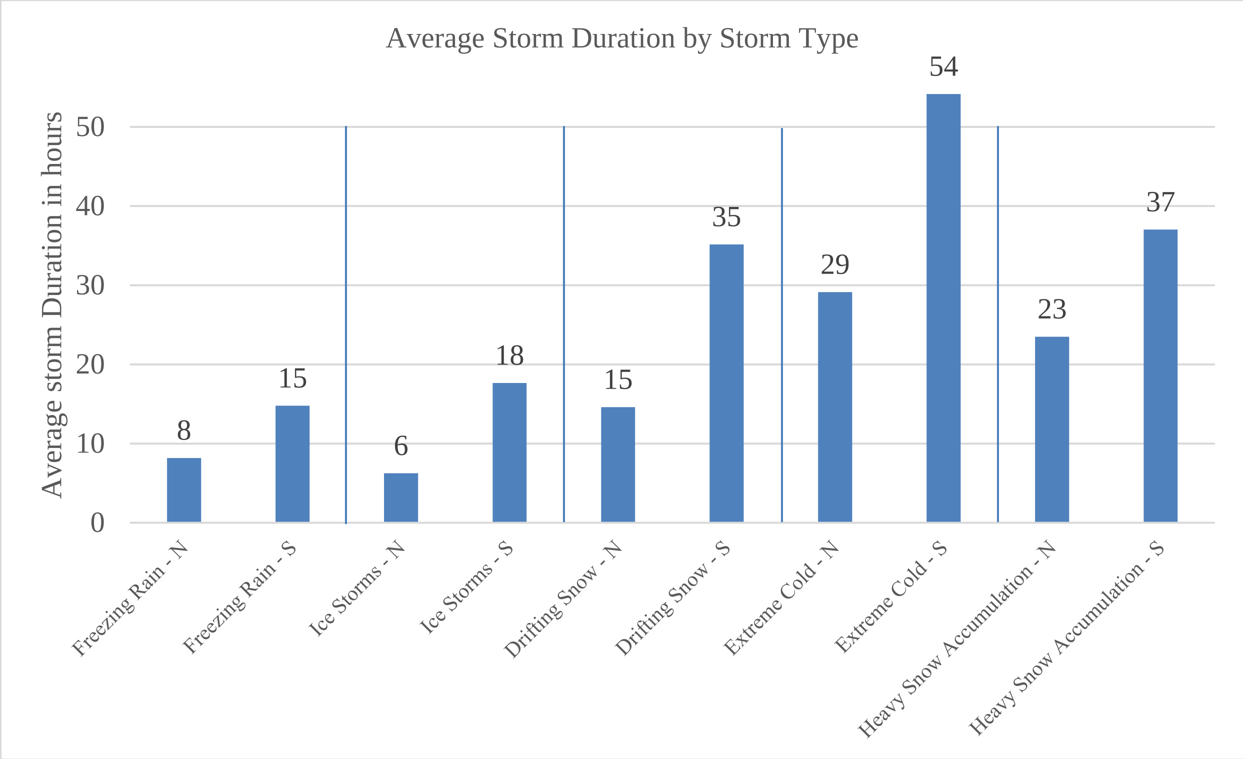


Figure 53. Average Duration - Zeros Removed (N – Normal Duration, S – Severe Duration)

Storm Duration by Storm Type by Maintenance District

Strom durations varied by Maintenance District but on average freezing rain and ice storms were reported to be the shortest events. Drifting snow (severe) and extreme cold (severe) on average lasted the longest. District 4 reported longer average storm durations for many storm event types including freezing rain (severe), ice storms (both normal and severe), drifting snow (severe), extreme cold (severe), and heavy snow accumulation (severe). Districts 3, 5, and 6 reported shorter average storm durations. The average storm duration by storm type for each maintenance district is summarized in Figure 54.

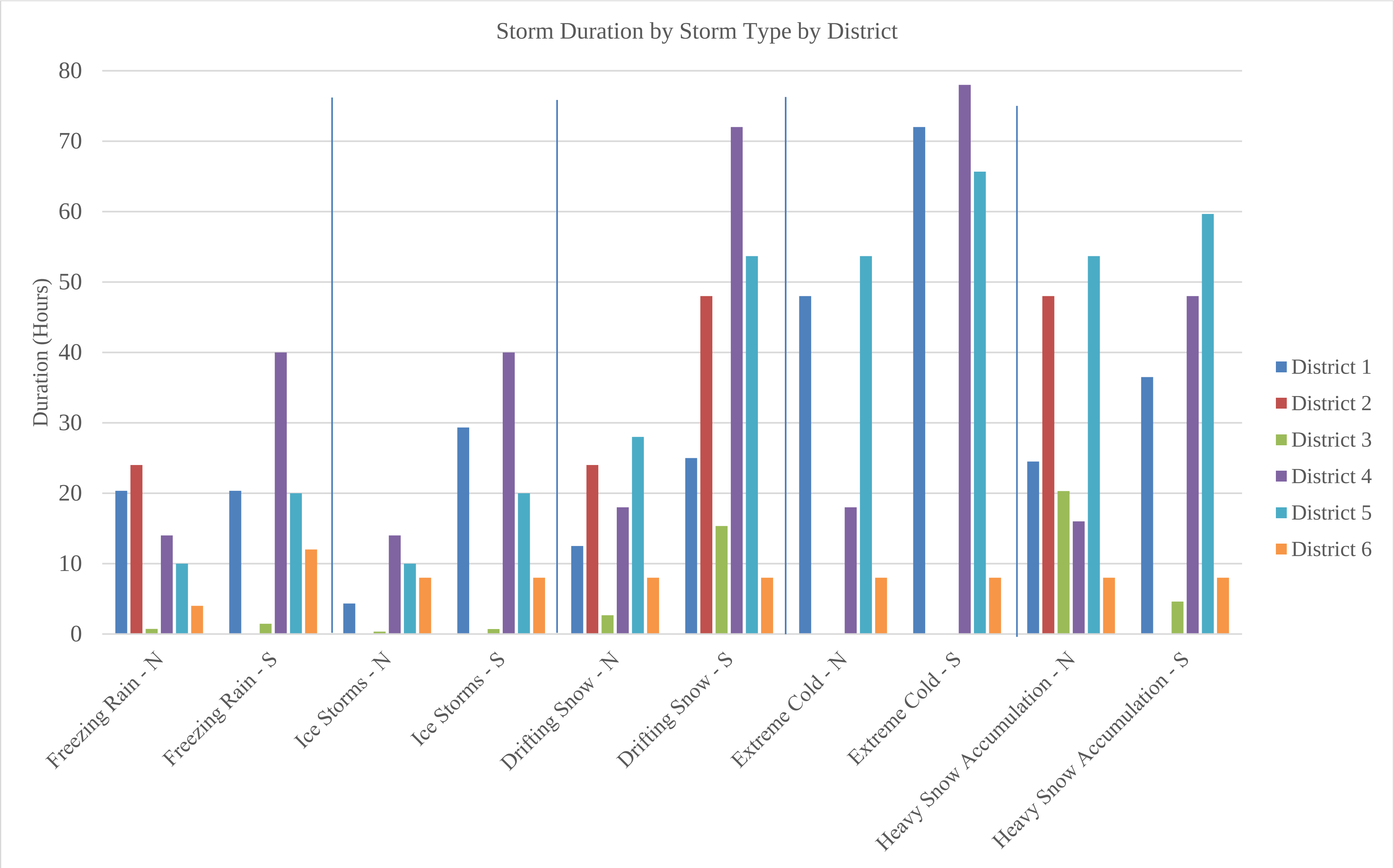


Figure 54. Average Storm Duration by Storm Type for Each Maintenance District

District 1

Respondents from District 1 (n=3) reported extreme cold events (both normal and severe) lasting the longest at 48 hours to 72 hours respectively. Ice storms (normal) are reported to be the shortest events in District 1 at 4 hours. A summary of District 1's responses on average storm duration by storm type is provided in Figure 55.

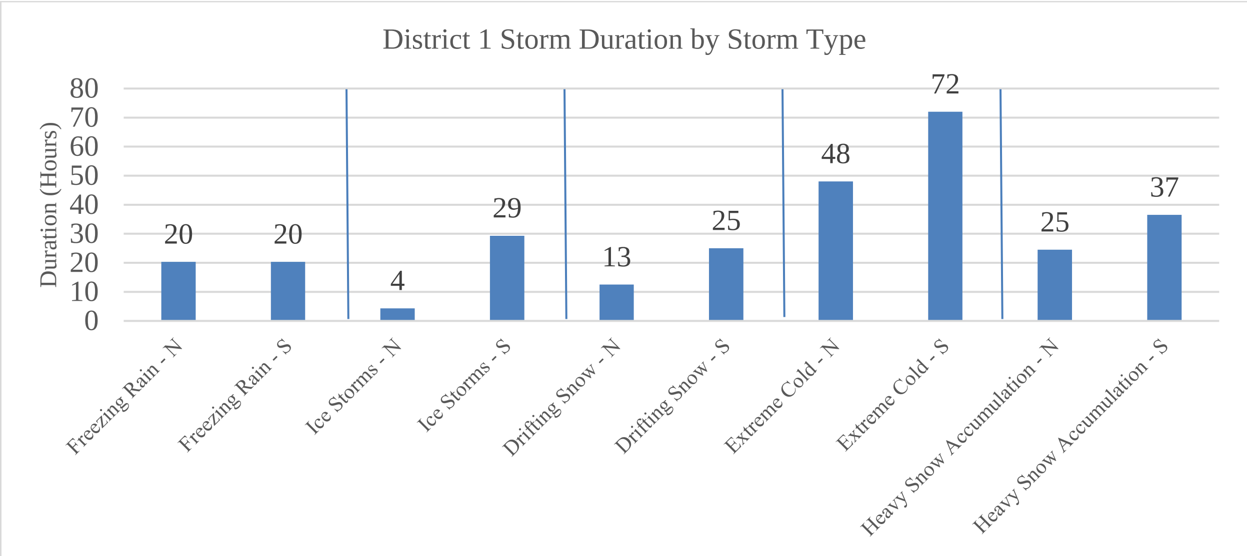


Figure 55. District 1 Average Storm Duration by Storm Type

District 2

Only one respondent provided information on storm duration, they did not provide responses for many storm event types including freezing rain (severe), ice storms (both normal and severe), and extreme cold (both normal and severe). Both drifting snow (severe) and heavy snow accumulation (normal) result storm events lasting up to 48 hours. Freezing rain (normal) and drifting snow (normal) can last up to 24 hours. The respondent entered 0 for heavy snow accumulation (severe), this might have been in error since heavy snow accumulation (normal) was reported to last 48 hours and one would expect a severe event to last longer. A summary of District 2's responses on average storm duration by storm type is provided in Figure 56.

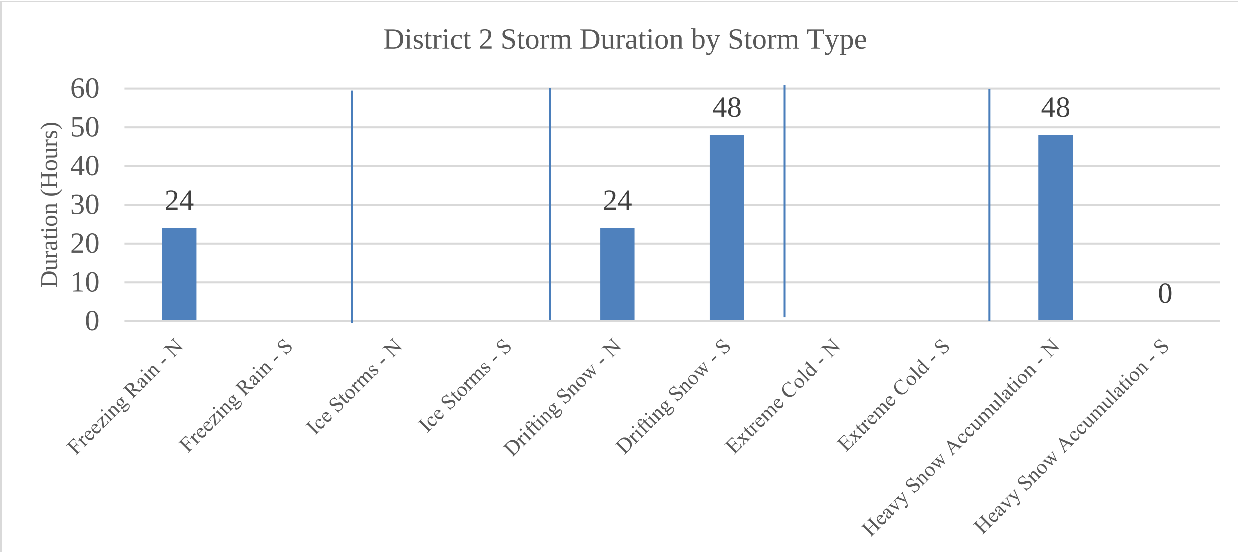


Figure 56. District 2 Average Storm Duration by Storm Type

District 3

Most respondents in District 3 (n=3) reported freezing rain (normal and severe) and ice storms (normal and severe) were likely to last an hour or less. Drifting snow and heavy snow accumulation were reported to last the longest at 15 hours and 20 hours respectively. Heavy snow accumulation (severe) was reported as lasting 5 hours, which is less than heavy snow accumulation (normal), and is likely an error in the response, as one would expect a severe event to last longer than a normal event. Additional input will be sought on this from the Technical Panel. A summary of District 3's responses on average storm duration by storm type is provided in Figure 57.

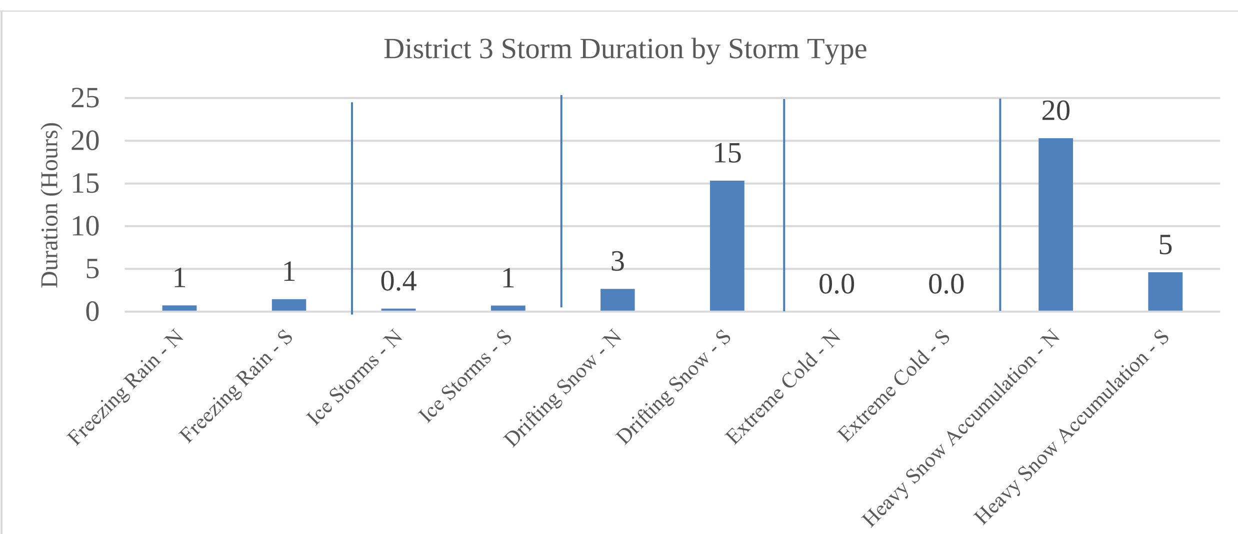


Figure 57. District 3 Average Storm Duration by Storm Type

District 4

Respondents from District 4 (n=2) reported all storm types lasting at least 14 hours. Both drifting snow (severe) and extreme cold (severe) were reported to last the longest at 72 hours and 78 hours respectively. Heavy snow accumulation events were reported to last an average of 48 hours. A summary of District 4's responses on average storm duration by storm type is provided in Figure 58.

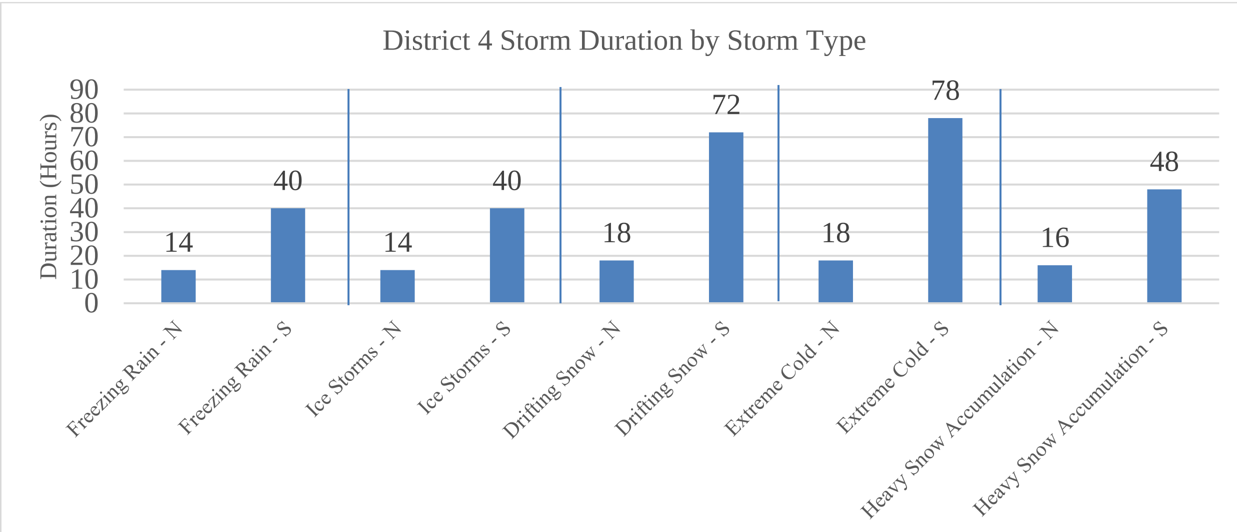


Figure 58. District 4 Average Storm Duration by Storm Type

District 5

Respondents from District 5 (n=2) reported drifting snow (severe), extreme cold (both normal and severe), and heavy snow accumulation (both normal and severe) all lasting at least 54 hours. Freezing rain and ice storms were shorter events in District 5, lasting an average of 10 to 20 hours depending on storm severity. A summary of District 5's responses on average storm duration by storm type is provided in Figure 59.

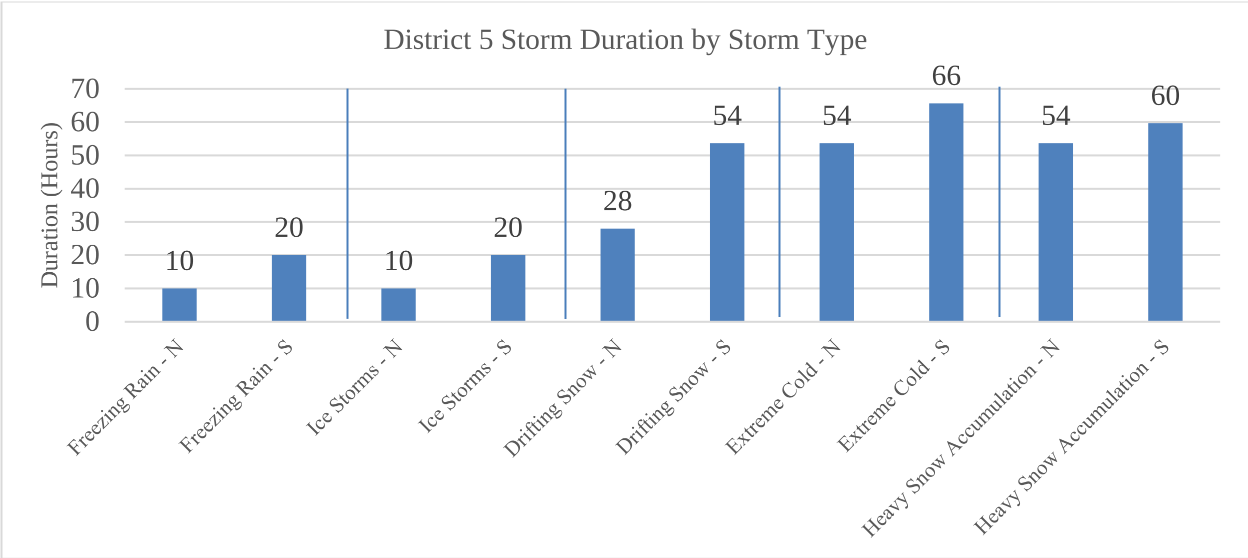


Figure 59. District 5 Average Storm Duration by Storm Type

District 6

Only two respondents from District 6 provided information on storm duration. These respondents reported most events lasting an average of 8 hours, with the exception of freezing rain events which were reported to last 4 to 12 hours depending on the storm severity. A summary of District 6's responses on average storm duration by storm type is provided in Figure 60.

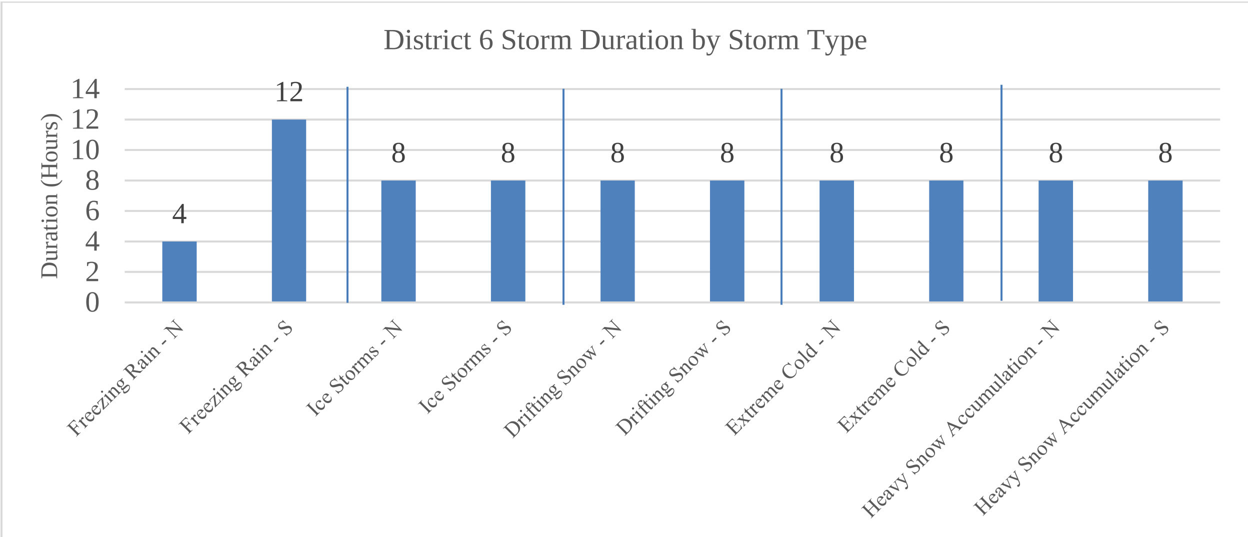


Figure 60. District 6 Average Storm Duration by Storm Type

District 7

No respondents provided information on average storm duration from District 7.

Additional Data Used for Winter Maintenance Decisions

Respondents were asked to provide any additional information on data used to make winter maintenance decisions. Nineteen (out of 39) respondents provided comments for this question. Many comments mentioned time of event, traffic, and weather forecasts. Additional data used included an ice accumulation formula, road condition visuals, historic data, and resource availability. One comment mentions that each storm is unique and is treated differently. Respondents comments on additional data are provided in Table 30.

Table 30. Additional Data Comments

District	Maintenance Shed	Is there any additional information you would like to share about data used to make winter maintenance decisions in your area?
1	Princess Anne	variables which are associated with each storm usually are not the same, each storm is treated differently
2	Elkton	Ice accumulation formula
2		Timing of the event, Accumulation, Rate of accumulation, wind and Temps
2	Denton	We see a lot of ice/snow because of the ocean/bay
3	Gaithersburg	What my operators are seeing firsthand on the roadways.
3	Laurel	There needs to be a better way to capture accurate quantities of freezing rain/sleet. We are currently using ice totals for this purpose; however, ice totals do not accurately portray our operations to mitigate the precipitation.
4		rush hour/traffic
4	Owings Mills	The ability to get the proper salt usage numbers for sleet events
5		Forecasting our weather I am told is difficult in Maryland. If we could improve that some would help
5		traffic, time of day, day of week
6	Keysers Ridge	We consider salt usage and human factors. If drivers see bare wheel tracks, they'll try to drive the speed limit or greater.
Central Office		Timing of event (day of week, time of day), resource availability, expected duration of event (one day, extended event).
		Historical records, Employee experience, Multiple forecasts. Roadway monitors (mechanical and personnel)

		National weather forecasts, Iteris weather, road temps, air temps, travel volumes on holidays and time of storm impact. I -68 gets high traffic volume on Fridays and Sundays due to tourism (ski resorts in the area). We also look at the type of precipitation that is coming and how it will affect those travelers. For instance, we will call crews in before an ice storm hits to insure safe travel on all occasions. But if we are expecting heavier snow on a high-volume traffic day, we will have crews out earlier as well. Also, Doppler Radar does not work great at times in this area.
		Please take into consideration the time of the event.
		time of day, traffic, what the storm is doing. how long the storm is going to last
		When fronts come from west to east, sometimes hits ocean air humidity/temp and intensifies accumulations, and causes storm to stall

Additional Information

Finally, respondents were asked to provide any additional information on normal or severe winter weather events in their area. Thirteen respondents provided comments on this question. These comments discuss timing of the storm event and when to respond, including having as much as possible prepped prior to a storm event. Many comments demonstrate the respondent's depth of knowledge and understanding of how a winter storm will affect their maintenance district depending on the geography of the area, which direction the storm is traveling, and even how various subsoils will affect snow accumulation. Additional information on normal or severe winter weather events provided by respondents is presented in Table 31.

Table 31. Additional Comments

District	Maintenance Shed	Is there any additional information about normal or severe winter weather in your area that you would like to share?
1	Salisbury	I think the biggest thing about any storm is getting the jump on the storm. You have got to be ready by that everything in place and have what area that you brine already done hire trucks in place. You have got to be ready before the storm not getting ready [during] the storm
1	Princess Anne	The subsoils in this county are sand and/or red clay which transfer solar heat better than areas with bedrock or granite. Things melt faster Shaded areas tend to refreeze due to lack of sunlight or wind to dry out pavement We watch for frost forming in rumble strips, usually the first sign the roadway is starting to freeze
2	Elkton	A lot of times our numbers look out of sync with everyone else's, but our county is a different animal
2	Denton	At time we have 24 inches of snow in two days
3	Gaithersburg	Because of the heavy traffic, timing is everything. We focus on before and after rush hour, we are immobile during these times
4	Owings Mills	I have roads (same road) that are part concrete and part asphalt that have to be treated differently due to surface temps
5		we get sleet
6	Keysers Ridge	Our area is mountainous and is higher than the surrounding counties. Motorists are often not prepared to go from dry roads to totally snow covered roads and back to dry roads as they pass through our area.
		Allegany County Maryland is diverse in its elevations and Temps across those ranges. The farther west you go the higher up you get in elevation. With that said, we experience more snow in our western portions. We also have three high mountain ranges across the whole County that can receive snow just on the tops of those mountains. This is critical to know because it is also common in this area to receive Alberta Clippers that will dump 5 inches of snow within an hours' time. We could get heavy snow on those ridge tops and far western portion and maybe a dusting to 2 inches in the valleys.
		no two storms are the same and you have to adapt

		Our area has drastic geographical changes, causing different types of precipitation and weather conditions within a short distance.
		When storms come from the south (heading up the coast) Southern and eastern Maryland get heavy accumulation and a wet snow. Where central and western Maryland get little or no accumulation.

Conclusions

Air temperature, pavement temperature, and precipitation type were identified as the most important variables used in winter maintenance operations in almost all of the districts. Wind speed was identified as least important in almost all districts, with the exception of Districts 4 and 5 who uniquely ranked storm variables as most and least important.

It is interesting to note that comments include considering the timing of the storm event, i.e., whether or not it occurs overnight or during peak travel times like rush hour, weekend traffic to ski resorts, or whether or not they would expect for the precipitation to adhere to the pavement.

Key storm types and winter weather related issues identified by respondents is provided below by District:

- District 1 – freezing rain, ice storms with longest duration during severe events, drifting snow, extreme cold with longest duration during normal and severe events, heavy snow accumulation with longest duration during severe events, soil type = varying freeze/thaw patterns of roads.
- District 2 – wind/drifting snow with longest duration during severe events, freezing rain, extreme cold (-10°F), heavy snow accumulation with longest duration during normal events, feel they have high numbers because of conditions they deal with, and less so ice storms.
- District 3 – Freezing rain, traffic during icing events, ice storms, wind/drifting snow, heavy snow accumulation which has resulted in upwards of 33 inches of snow and damage to infrastructure (respondents mentioned that timing of the storm event is everything and that during rush hour they struggle with maintenance operations.).
- District 4 – freezing rain with longest duration during severe events, ice storms with longest duration during severe events, drifting snow with high accumulation of snow during severe events and with longest duration during severe events, extreme cold with longest duration during severe events, heavy snow accumulation with very high accumulation during severe events and with longest duration during severe events.
- District 5 – heavy snow accumulation with longest duration during normal and severe events, freezing rain, ice storms, drifting snow with longest duration during severe events, extreme cold with high accumulation of snow during normal and severe events and with longest duration during severe events, traffic, and forecast accuracy issues.
- District 6 - wind/drifting snow causing high accumulation of snow in severe events, freezing rain, ice storms, drifting snow, extreme cold (-10°F) with high accumulation of

now during severe events, heavy snow accumulation – including conditions that have resulted in tree limb and powerline damage.

- District 7 – freezing rain, ice storms, heavy snow accumulation, drifting snow, extreme cold.

As would be expected, freezing rain and ice storms had the lowest overall precipitation rates for normal and severe events, where heavy snow accumulation and drifting snow had the overall highest precipitation rates for severe events. It is interesting to note that most districts felt like they were impacted by all of the suggested "severe" winter weather - freezing rain, ice storms, drifting snow, extreme cold, heavy snow accumulation, but to varying degrees between districts. The research team will work with the project Technical Panel to differentiate which "severe" weather occur more often in each district.

Reported accumulation for normal versus severe amount of precipitation for freezing rain, ice storms, drifting snow, extreme cold, and heavy snow accumulation can be folded into the SWI calculation method.

Issues related to Doppler radar in some parts of the state were reported.

A survey respondent noted that variation in pavement between concrete and asphalt can have varying temperature profiles and may need to be treated differently. If a large temperature discrepancy is found between pavement types, future analysis could investigate if it is costlier to provide winter maintenance operations on concrete or asphalt? Assess how the varying pavement types are treated differently? This may be a side project Scott can work on as more data is amassed over time. It may be possible to use a percent multiplier for the percent of asphalt/concrete in an area. Or maybe it is so minor that it is not seen in the amassed data.

Appendix C – Maintenance District Interview Summary

Summary Notes from District RWIS data discussion

District 1

Overall okay with current climate zones.

Avg. Precipitation Figure – Overall the precipitation amounts look reasonable. RWIS site #46 is on a bridge.

RWIS site #53 was damaged and is being repaired now. It will be up soon but will be wireless.

Avg. Wind Speed Figure – overall looks okay. RWIS site #52 is sheltered and may be underreporting wind speed. Drifting was reported to occur with sustained winds from 5-9 mph.

District 2

Overall, the D2 folks agree with climate zones.

Overall, the folks in District 2 seem unhappy/untrusting of the RWIS pavement temperature data (and this has led to general mistrust and lack of use of RWIS station data). For example, RWIS site #60 the pavement temperature reading is consistently off by 7 degrees F. They have sent it back to Germany to be fixed, and it was reinstalled in Sept. 2019, but it is still not accurate. They have put in a call already for maintenance of it. [Consider validating the pavement temperature with a different method than the temperature gun (not designed for this)]. [The lack of trust in the RWIS data could be a longer-term issue, consider creating more buy-in locally on RWIS status, data use, etc.]

Avg. Precipitation Figure – RWIS site #99 is not really used. The avg. precipitation seems too high. Instead of discussing the precipitation figure we ended up talking about RWIS sites that they don't trust: #60, #59.

RWIS sites they use to mobilize and plan for storms: #3, #40, #20, #19, #24 (they feel the data is good enough for pre-storm planning), but the overall sentiment is the they need to go out check the conditions because the RWIS data is wrong.

RWIS site #24 is located on a bridge. Are bridge RWIS sites are registering more storm events due to colder temperatures.

During the call they reported that the Cambridge RWIS site was not working, but Scott checked it on the Lufft site and it was up and running. There may be an issue in CHART or maybe more training is needed on how to access the data from Lufft?

Avg. Wind Speed Figure – Site #99 is sheltered and so may not accurately report what they experience, they would expect to see higher avg. wind speed. Site #20 may also be sheltered.

District 3

Overall, the Climate Zones are well defined.

Avg. Precipitation Figure – RWIS site #2 stands out as reading to high, but it is located in a low area that tends to accumulate more snow so this is likely accurate. RWIS sites #4 and #5 look low, maybe in part due to the urban heat island effect, are these values to see if they are on the cusp of being in the green.

RWIS sites they use: #43, #2, sometimes #16, #15, #6.

Note that RWIS sites #7 and #15 are on bridges.

Avg. Wind Figure – They generally agree with the wind being moderate in their District and that when winds come in from the west, they are stronger.

District 4

Overall, they feel the RWIS data available to them is good and reliable. They use this information for forecasting and mobilizing operations, and throughout events.

Overall agree with the Climate Zone for District 4. (Golden Ring has the most snow in the area).

Avg. Precipitation Figure – They feel that RWIS sites #9 and #14 could be more consistent, closer together. [This is likely a function of more storms that occurred at RWIS site #9 than #14.]

Avg. Wind Figure - Overall this figure looks more accurate than the Avg. Precipitation figure. RWIS sites #9 and #14 should maybe have higher Avg. Wind (green instead of blue). Some of the wind readings in the metro areas may be higher due to wind tunneling on the highways.

Key RWIS sites used by D4 - #81, #14, #9, #44, #23.

Drifting snow does occur in open fields, when there is crosswind blowing to W/NW.

District 5

Philip only has NIRS station in his county. Overall limited RWIS in the southern part of D5.

Overall, they are happy with how the District is split between two climate zones.

RWIS site #105 gets hit the hardest.

Avg. Precipitation Figure - RWIS sites #105 and #26 should be more consistent. NOTE that almost all of the southern D5 RWIS stations are located on bridges (RWIS sites #26, #13, #76). How would location on a bridge versus on land impact the data? [For example, the southern part of D5 is generally warmer, there are storm events occurring overall up north in D5, but higher precipitation values in lower part of D5 may be due to proximity to water or location on a bridge.] Most of the data the Districts are using comes from NIRS stations, which are not incorporated into the SWI model. RWIS site #6 can used as non-bridge RWIS for comparison.

Avg. Wind Figure – wind speed should be higher for RWIS site #27, comparable to RWIS sites #76 or #13.

RWIS site #102 is shield by its location so lower avg. wind speed makes sense. RWIS site #105?

Overall, the RWIS locations in southern D5 are not ideal for this project; consider adding in more RWIS stations to locations with weather more typical of the region.

District 6

Overall, they agree with how the climate zones are broken out.

Avg. Precipitation Figure – RWIS sites #34 and #10 should be similar [We looked into this previously and RWIS site #34 looks more severe because we only a few years of data for this site that can be used and the years of data we do have were more severe winters. Future data will need to be added to the model to bring this average in line with similar RWIS sites like #10.]. RWIS site #11 should be comparable to RWIS site #55; precipitation seem low, check if it is on the cusp of being green. RWIS site #11 could be sheltered causing the lower avg. Precipitation values. It is located in the rest area and weather is partially blocked by the mountain. RWIS sites #54, #35, #31, #55 values seem low, see if they are on the cusp of being yellow.

Future RWIS location: on the west side of the pass from Site #11. At Flintstone (?), Martins (?), Cumberland Bridge/West of Site #31.

RWIS sites they use: #12, #106, #11, #51. RWIS sites that don't always well represented the area, and or get less weather #34, #54, #31, #55.

Avg. Wind Figure – RWIS site #31 does not accurately show wind in that area because of its location on the east side of the mountains; the winds are lower than what most of the District experiences. RWIS site #35 is also low but may be due to sheltering by trees. RWIS site #11 should be higher.

District 7

Overall okay with how the climate zones are broken out. Consider looking into revising in the future if needed and data supports this.

Avg. Precipitation Figure – Would expect to see more precipitation at the Pennsylvania line at RWIS site #21, compared to RWIS site #38. RWIS sites #12, #106, #17 look accurate. They feel RWIS sites #16 and #39 should be higher (yellow SWI rating); how close are these are to yellow? Normally RWIS site #81 would see less snow than at the top of the county. [I am guessing it is based on limited data and is skewed by having data from storms with higher precipitation.]

How close is RWIS site #37 is to yellow?

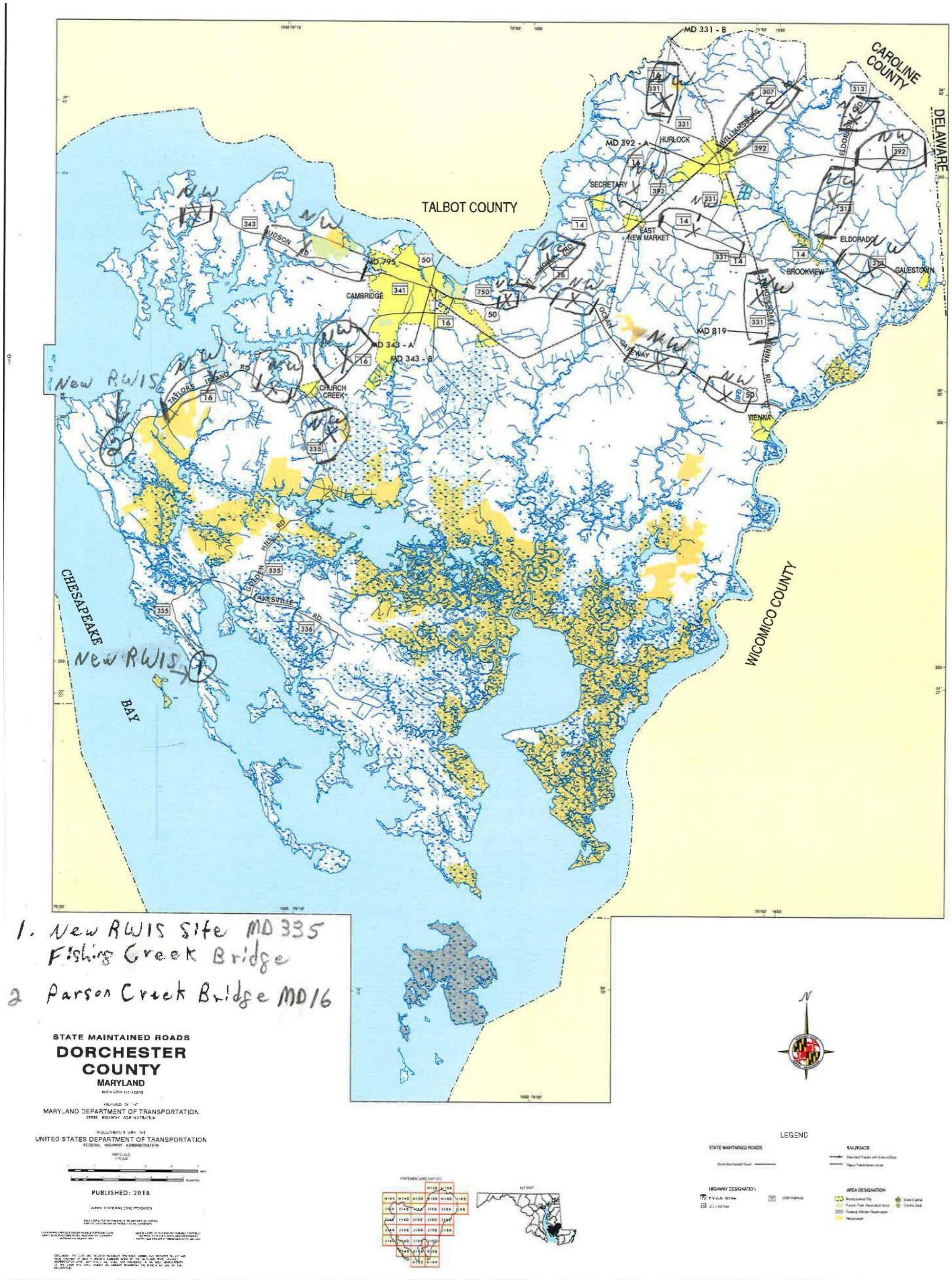
Avg. Wind Speed Figure – Overall looks good. In some locations they can have sustained wind with speeds as low as 8mph and get drifting.

Recommended Future RWIS Site and Blowing and Drifting Snow Locations

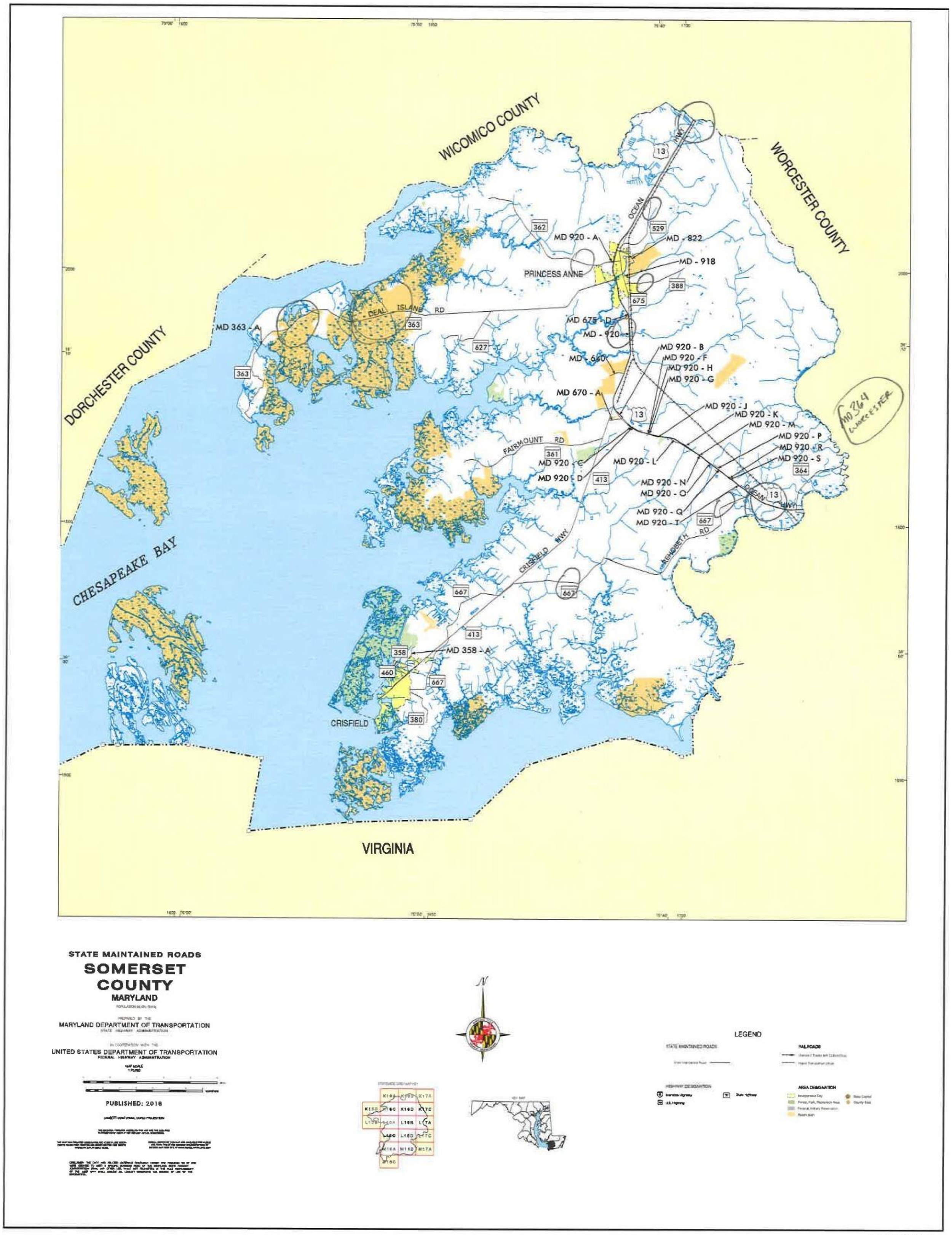
As a part of this research effort, the Maintenance Districts were interviewed to collect information on trustworthy RWIS sites, RWIS sites that routinely have issues or seem off, or RWIS sites do not seem to provide accurate data. A part of the interviews involved asking Maintenance District staff for locations for RWIS sites that would greatly benefit their operations and that could provide data that generally representative of that climate zone, maintenance district, etc. Note that MDOT SHA indicated they will use this list of suggested RWIS location for future planning. In the interviews, information was also collected from Maintenance Districts on the locations where blowing and drifting snow frequently occurs. Note MDOT SHA indicated they will use this information to create a GIS layer of blowing and drifting snow locations that can be updated over time.

The following locations for information on future RWIS locations and locations where blowing and drifting now occur were identified:

District 1, Salisbury Shop

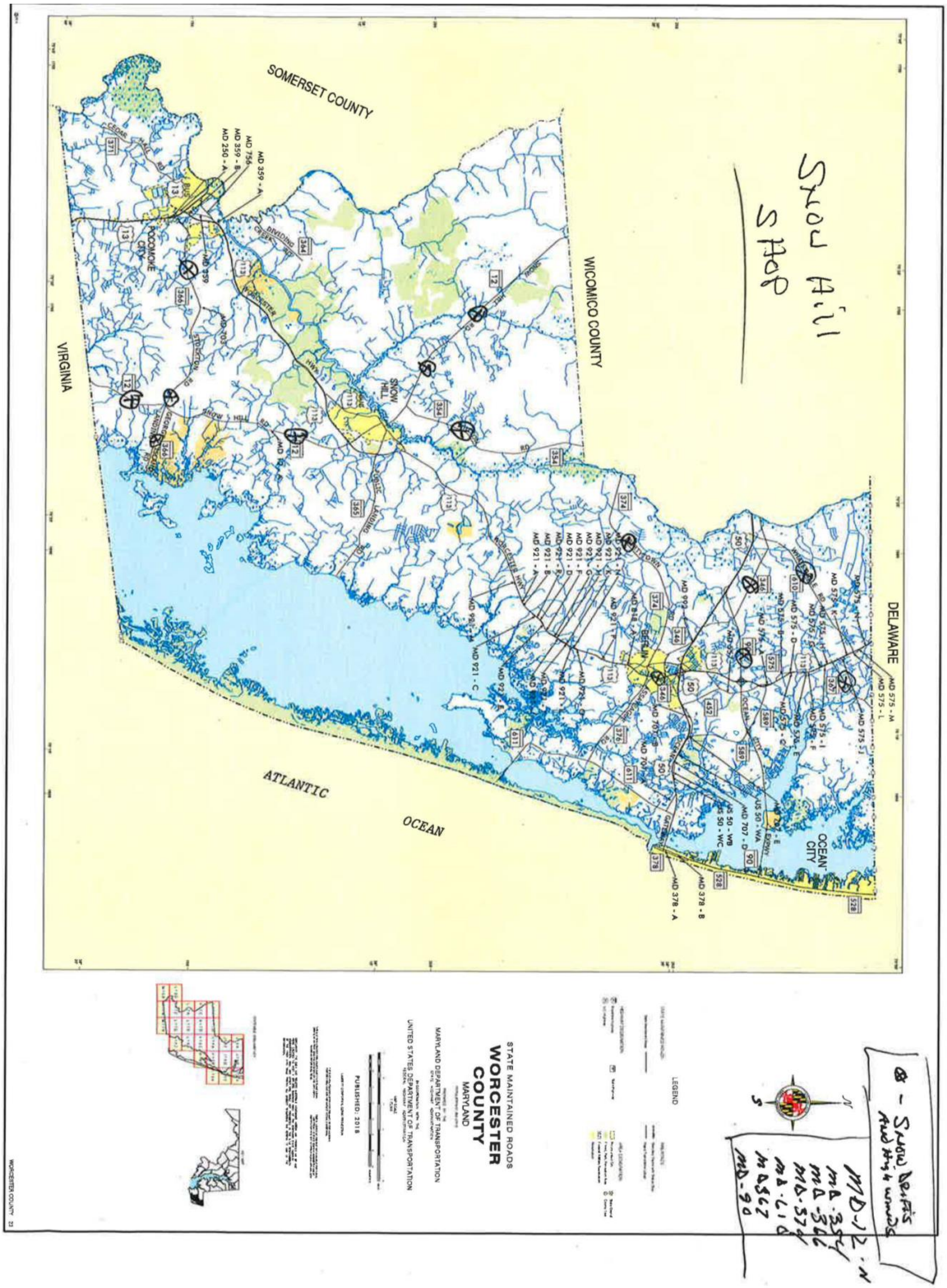


TALBOT COUNTY
CAROLINE COUNTY
DELAWARE
WICOMICO COUNTY
CHESAPEAKE
BAY
MD 331 - B
MD 392 - A
HURLOCK
SECRETARY
EAST NEW MARKET
ELDORADO
BROOKVIEW
GALESTOWN
CAMBRIDGE
MD 795
MD 819
MD 343 - A
MD 343 - B
CHURCH CREEK
VIENNA
New RWIS
New RWIS
1. New RWIS Site MD 335
Fishing Creek Bridge
2 Parson Creek Bridge MD16
STATE MAINTAINED ROADS
DORCHESTER
COUNTY
MARYLAND
MARYLAND DEPARTMENT OF TRANSPORTATION
UNITED STATES DEPARTMENT OF TRANSPORTATION
PUBLISHED: 2018
LEGEND


WICOMICO COUNTY
WORCESTER COUNTY
DORCHESTER COUNTY
CHESAPEAKE BAY
VIRGINIA
PRINCESS ANNE
CRISFIELD
DEAL ISLAND RD
FAIRMOUNT RD
CRISFIELD HWY
OCEAN HWY
MD 920 - A
MD - 822
MD - 918
MD 363 - A
MD 675 - D
MD - 920
MD 920 - B
MD 920 - F
MD - 660
MD 920 - H
MD 920 - G
MD 670 - A
MD 920 - J
MD 920 - K
MD 920 - M
MD 920 - P
MD 920 - R
MD 920 - S
MD 920 - C
MD 920 - D
MD 920 - L
MD 920 - N
MD 920 - O
MD 920 - Q
MD 920 - T
MD 358 - A
13
362
529
388
675
363
627
361
413
364
667
358
460
380
STATE MAINTAINED ROADS
SOMERSET COUNTY
MARYLAND
MARYLAND DEPARTMENT OF TRANSPORTATION
UNITED STATES DEPARTMENT OF TRANSPORTATION
PUBLISHED: 2018
LEGEND

DRIFTING/BLOWING SNOW
SHA SOMERSET

ROUTE	MILE POINT	DIRECTION
US13	20.17 – 20.28	west to east
	0.92 – 2.10	east to west
MD358	no issues	--
MD361	no issues	--
MD358	no issues	--
MD362	2.01 – 4.16	south to north
MD363	7.28 – 9.27	south to north
	4.90 – 6.54	south to north
MD364	Worcester county areas	west to east
MD380	no issues	--
MD388	0.11 – 0.59	north to south
MD413	12.01 – 13.44	south to north
MD460	no issues	--
MD529	2.34 – 2.57	south to north
MD627	no issues	--
MD640	no issues	--
MD667	15.96 – 16.77	south to north
	8.61 – 9.04	south to north
MD673A	no issues	--
MD675	no issues	--
MD822	no issues	--
MD918	no issues	--
MD920	0.02 – 0.97	west to east


Snow Hill Shop
SOMERSET COUNTY
WICOMICO COUNTY
VIRGINIA
DELAWARE
ATLANTIC
OCEAN
POCOMOKE CITY
SNOW HILL
BERLIN
OCEAN CITY
STATE MAINTAINED ROADS
WORCESTER COUNTY
MARYLAND
LEGEND
MARYLAND DEPARTMENT OF TRANSPORTATION
UNITED STATES DEPARTMENT OF TRANSPORTATION
PUBLISHED: 2018
WORCESTER COUNTY
⊗ - Snow Drifts And High winds
MD-12
MD-354
MD-366
MD-376
MD-610
MD-367
MD-90

RWIS for Snow Hill Shop:

1. US 113 Delaware line.
2. MD 12 North @ South.
3. US 13 Pocomoke Virginia line

RWIS Locations Salisbury Shop:

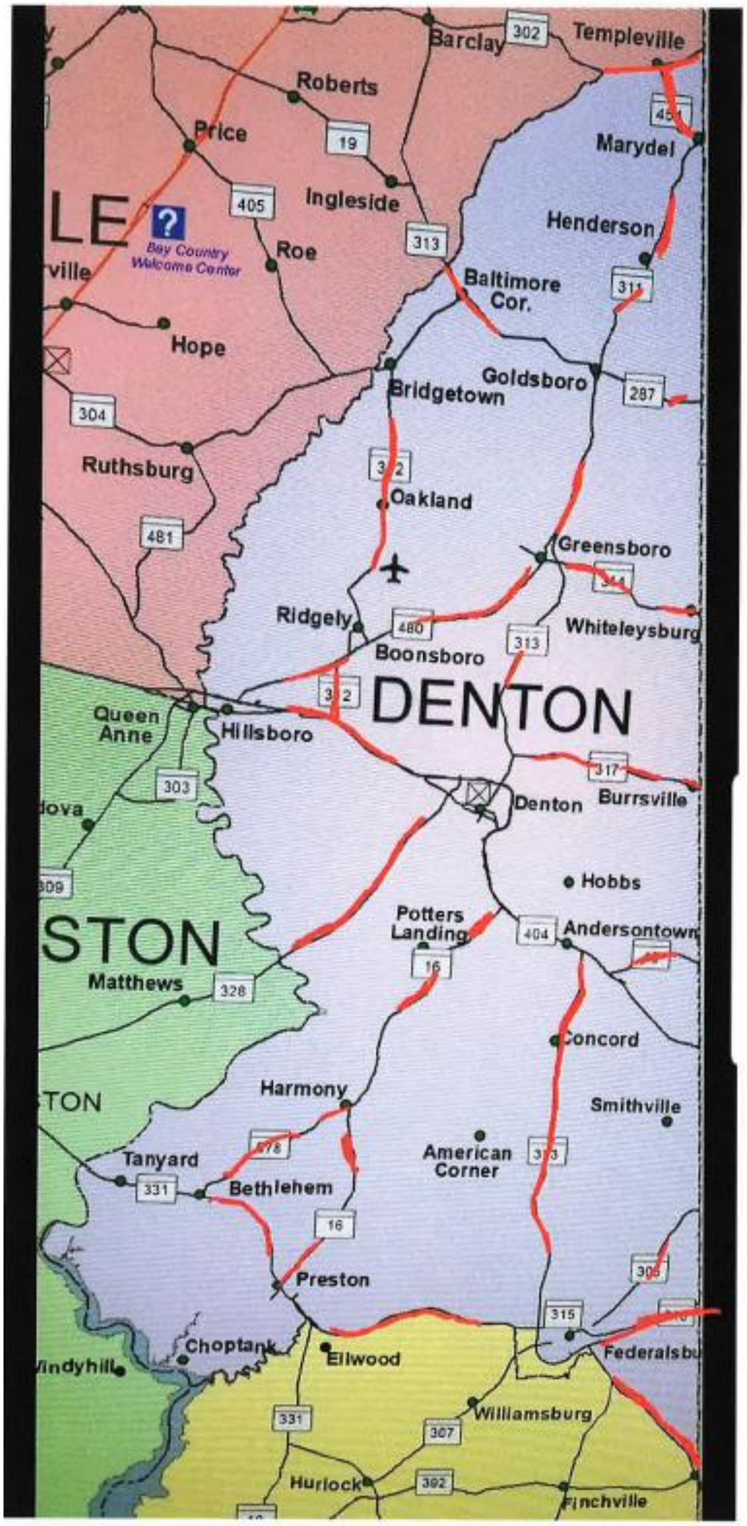
1. US 50 Bypass MP 13.186 US 50 UA on the Naylor Mill Rd overpass.

2. US 13 Bypass MP 07.870 at MD 350 MT Hermon RD overpass.

3. US 13 BU at MP 01.050 northbound on the US 13 Bypass southbound where US 13 crosses over S Fruitland Boulevard.

District 2, Caroline County Snow Drifting locations

North, North-West, and South, South-West winds cause the most drifting snow conditions in Caroline County. The red lines indicated drifting snow areas. RWIS sites - Templeville in Caroline County and one at Reliance Road in Caroline County.



District 2, Cecil County Drifting Snow Locations

1. MD 273 in the area of little Egypt Road, with wind coming from the north and south.

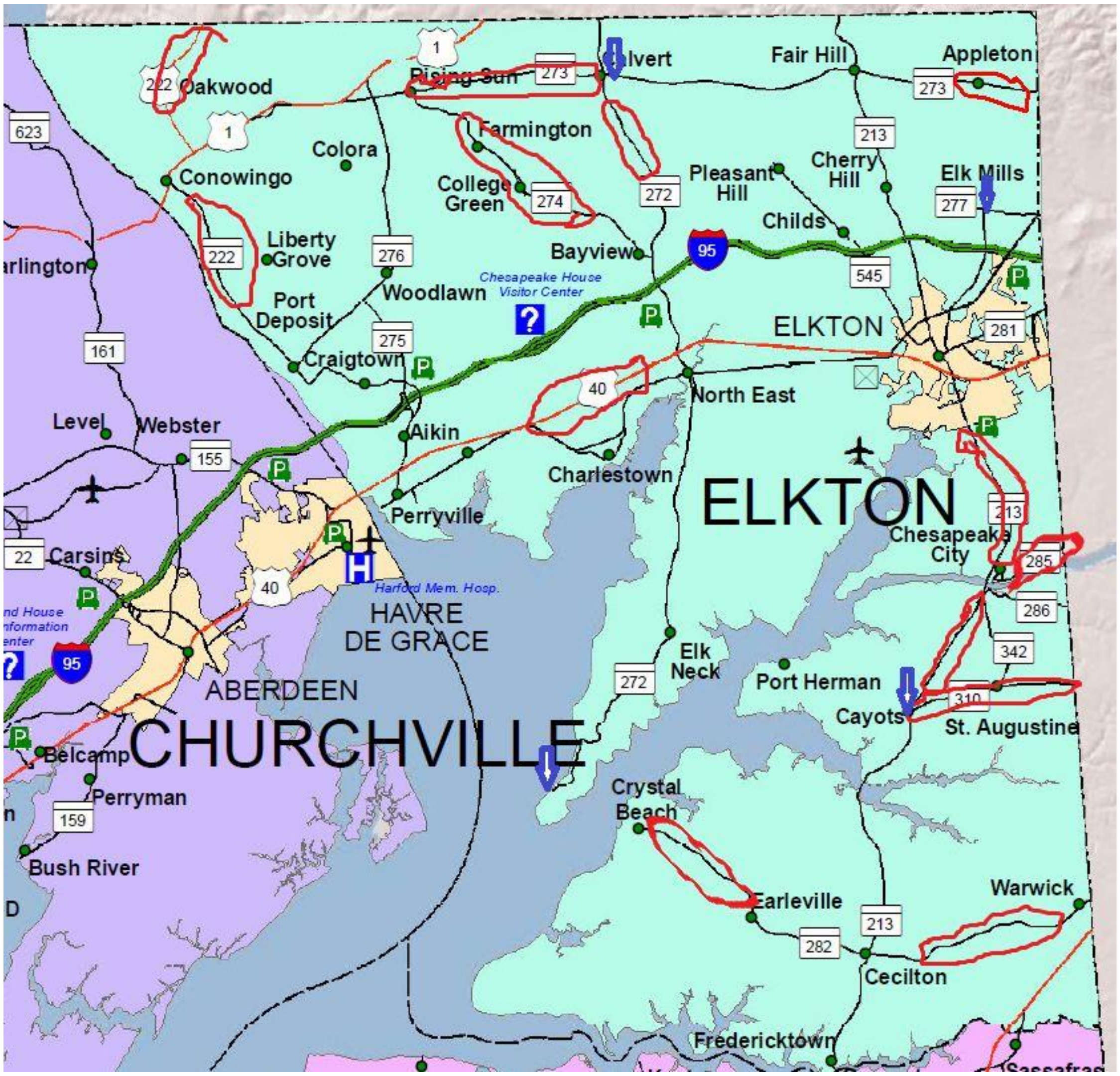
2. MD 273 @ Thankless Lane, with wind coming from the north and south
3. U.S. 222 @ Pennsylvania line, with wind coming from the east and west
4. MD 272 @ Fairfield Drive, with wind coming from the east and west
5. MD 222 @ Mount Ararat Farms with wind coming from the north and south
6. U.S. 40 @ Belvidere Road with wind coming from the north and south
7. MD 213 @ Between the Courthouse Point Road and MD 310 with wind coming from the east and west
8. MD 7B Between Mill Creek and Coudon Blvd with wind coming from the east and west
9. MD 310, along all of road with wind coming from the east and west
10. MD 213 @ Mill Lane with wind coming from the east and west
11. MD 282 between Rogue Neck and Cabin John Road with wind coming from the north and south
12. MD 282 @ Wards Hill Road with wind coming from the north and south
13. MD 282 @ Sassafras Road with wind coming from the north and south
14. MD 285 Town limits to Delaware line with wind coming from the north and south
15. MD 274 Between Washington School house to Crothers Road with wind coming from the east and west

District 2, Cecil County Future RWIS Sites

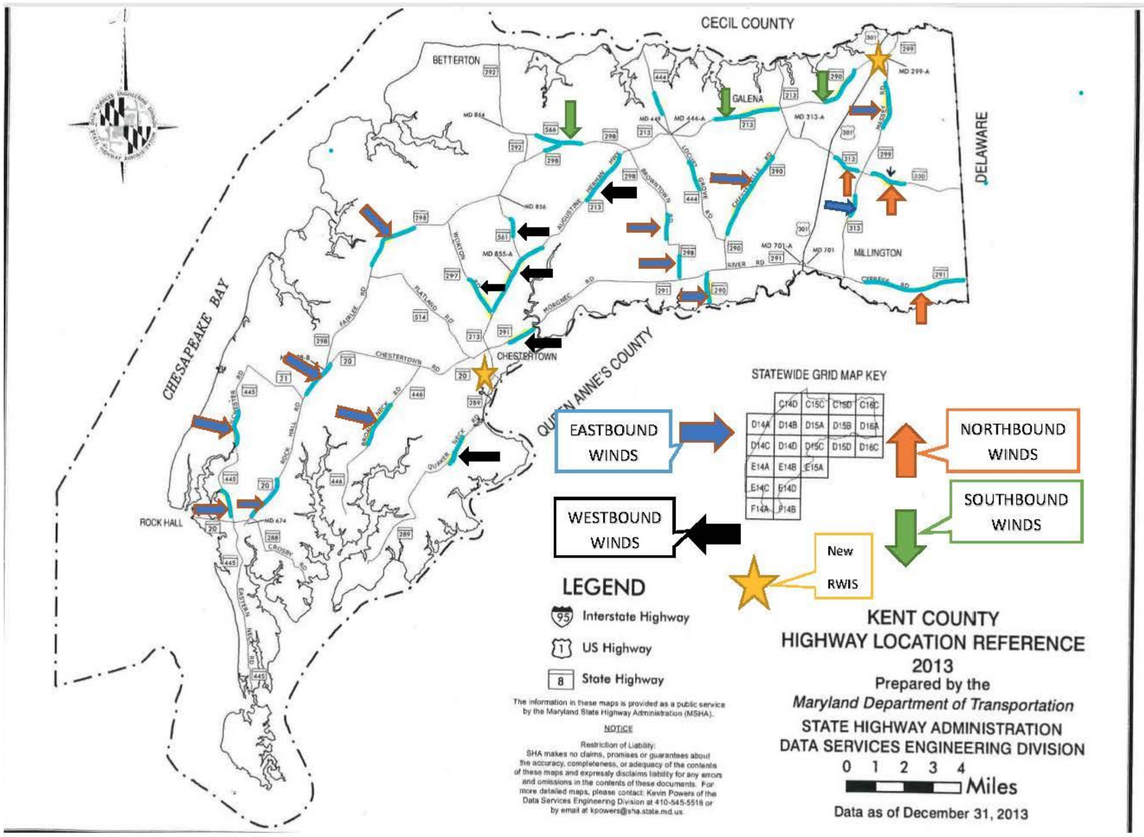
1. MD 272 at MD 273
2. MD 272 at Turkey Point
3. MD 213 at MD.310

Snow drifting locations circled in red. The blue arrows on the map are the locations we would like to add RWIS locations.

We did add one more RWIS location to our wish list it is MD 279 at MD 277 in Elkton, MD close to the Delaware line.



District 2, Kent County Drifting Snow location and Future RWIS sites



District 2, Queen Anne's County

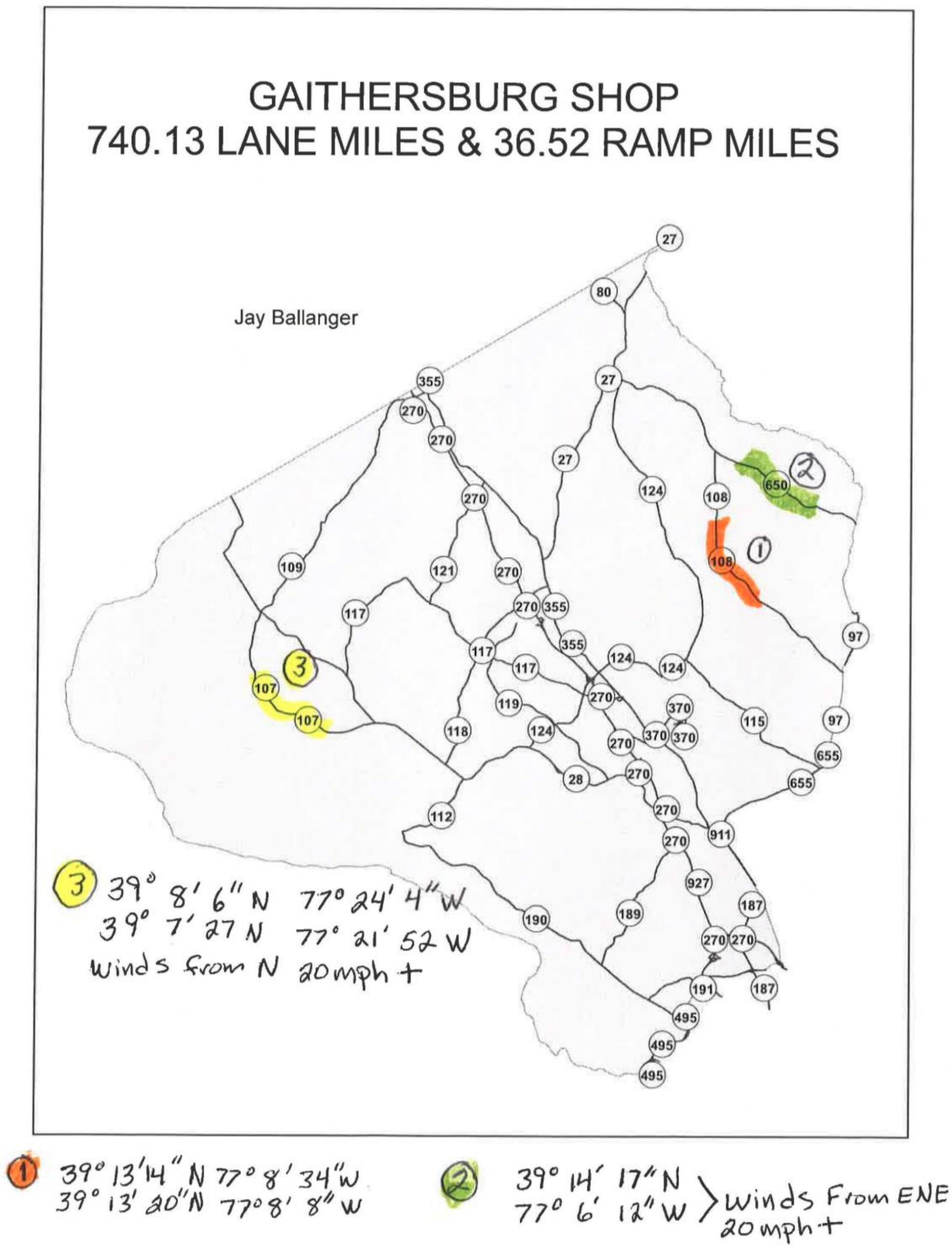
Drifting snow in Queen Anne's County

Area #1 **Orange**
MD 300 – MP(mile post) 0.00 – 0.85
MD 300 – MP 0.00 – MP 3.92, then MP 4.00 – MP 9.63
MD 313 – MP 9.08 – MP 11.53
MD 544 – MP 0.00 – MP 2.92
MD 213 – MP 20.30 – 19.52
Area # 2 – **Green**
MD 19 – MP 3.19 – MP 8.60
MD 213 – MP 8.93 – 15.76
MD 304 – MP 0.00 – 2.40, then MP 3.98 – MP 5.79
MD 305 – MP 2.89 – MP 5.08
MD 313 – MP 0.00 – MP 5.66
MD 405 – MP 5.98 – MP 8.59
Area # 3 – Blue
MD 18 – MP 1.32 – MP 1.69, then MP 2.72 – MP 4.07
MD 213 – MP 0.82 – 0.97, then MP 5.23 – MP 6.43
MD 309 – MP 5.51 – MP 9.11
MD 481 – MP 0.70 – MP 5.03
US 50 – MP 16.43 – MP 17.32

US 301 – MP 11.95 – MP 20.48

District 3, Montgomery County Drifting Snow and RWIS locations

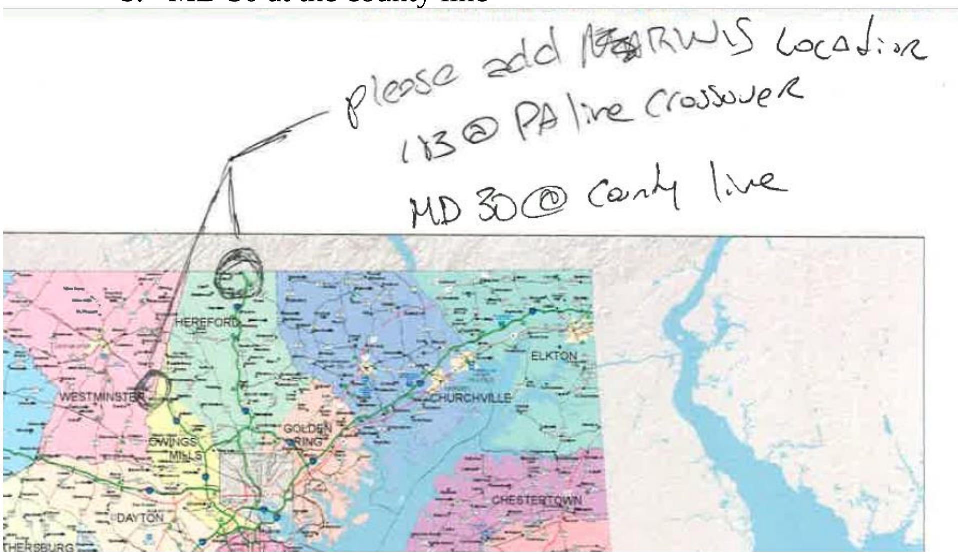
In the map of Gaithersburg's area of Montgomery County with the areas that experience drifting during dry snow storms. Areas 1 & 2 experience moderate to heavy drifting when the wind comes from the ENE at 20+mph. The snow is carried across several hundred yards of open farmland and sod fields. The roadway is sunken with banks on each side and the wind can't carry the snow up the far bank and it lays on the road. At area 3, the snow is again carried over several hundred yards across sod fields when the wind is in a northernly direction at 20+mph. The placement of the RWIS stations in Districts 3 & 7 and the ICC give a good representation of the conditions across the Gaithersburg shop's area. As a wish we had one location, I would like to see on placed in the vicinity of MD 107 and MD 109 in Poolesville as most of our westerly storms come across the Potomac river out of Leesburg Virginia into Montgomery County there. Poolesville is rural with little information coming from that area of the County. Speaking to the RME's at Fairland, Laurel, and Upper Marlboro shops they report they have no areas that experience any drifting and they are satisfied with the number and locations of the RWIS stations.



District 4, Owings Mills Shop in Baltimore County Drifting Snow location and Future RWIS sites

1. MD 30 from Weywood Dr. to the Baltimore/Carrol County line there is about 10 to 15 spots that the Owings Mills shop has consistent drifting issues when we get North/West winds.

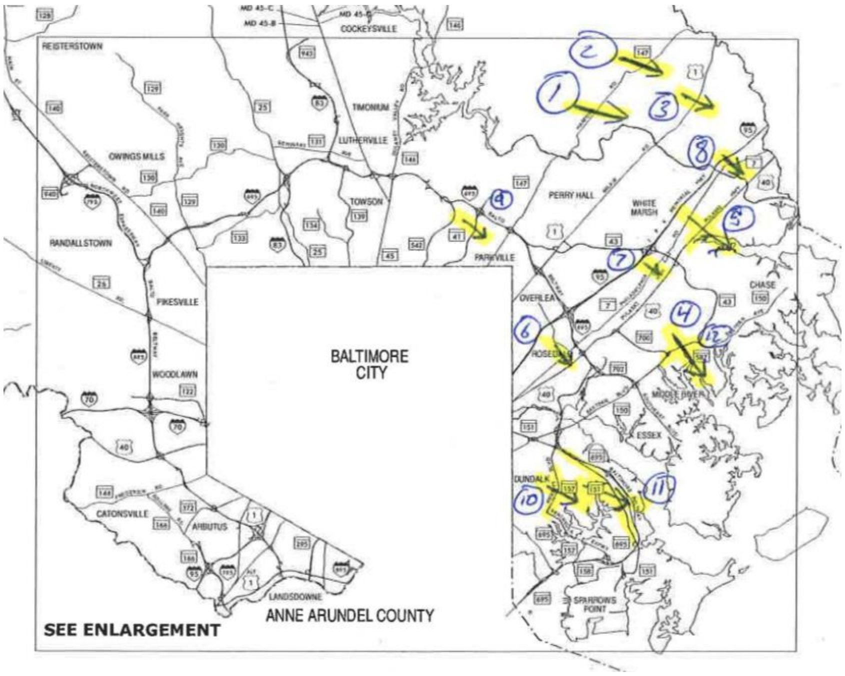
2. RWIS sites that I could see being beneficial to Owings Mills shop and bordering sister shops would be MD 30 at the county line, I70 at county line and MD 140 at the county line.
3. Additional RWIS sites shown on map below:
    a. I83 at the PA line
    b. MD 30 at the county line



District 4, Golden Ring Shop in Baltimore County Drifting Snow and RWIS Locations

Golden Ring shop's drifting areas.

1. MD 147 at Long Green Pike
2. MD 147 north of Mt. Vista
3. US 1 north of Mt. Vista
4. MD 150 between MD 700 and MD 43
5. US 40 between Stevens and Days Cove Road
6. MD 7 west of MD 588
7. MD 7 between Campbell Blvd. and MD 43
8. MD 7 at Raphael Road
9. MD 41 between I 695 and Putty Hill
10. MD 157 between Wise Ave. and Peninsula
11. MD 695 between MD 150 and MD 151 (Exit 42)
12. MD 587



District 4, Harford County Drifting Snow locations

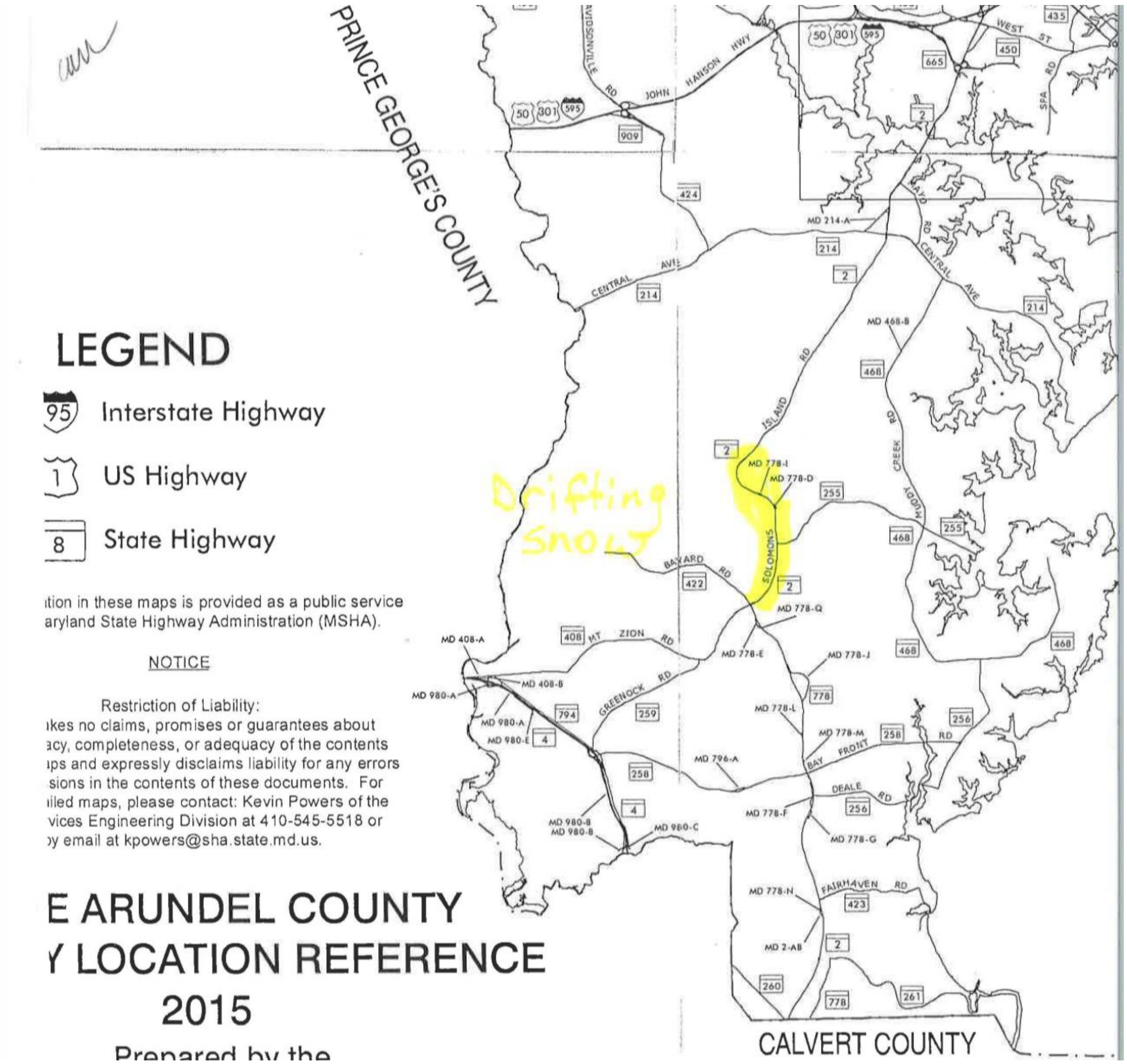
Snow drift areas in Harford County:

- MD 165-PA line through Baltimore County Line
- MD 24 – MD 165 through Davies Road
- MD 146 – MD 23 through Baltimore county line
- MD 23 – PA line through MD 146
- MD152 – Pocock Road thru Carrs Mill Road
- MD 440 – MD 543 Thru Glen Cove Road
- US 1 – Forge Hill Road – Business 1
- MD 623 – Flintville Road – Padrick Road
- MD 161 – MD155 – US 1
- MD 543 – MD165-US 40
- MD 7 – Edgewood Road – US 40
- MD132 – Beards Hill Road (Section)
- MD 755 – US 40 – APG Gate
- MD 624 – St. Marys Road – PA Line
- MD 136 – Amos Mill Road – MD 23
- MD 159 – Canning House Road
- MD 22 Shucks Road – Asbury Road
- MD 136 Hookers Mill Road - James

District 5, Annapolis Shop in Anne Arundel County Drifting Snow Locations

The attached map that shows an area on MD 2 in Anne Arundel County that experiences drifting when the conditions are right. Meaning the winds are blowing from the east or west. Normally from the west in an eastern direction.

I cannot think of another area in Anne Arundel County that would be of any benefit at this time.



District 5, LaPlata Shop in Charles County Snow Drifting and RWIS Locations

Snow drift locations:

- MD 231 at Serenity Farms
- MD 229 at Robin Manor
- MD 6 at Round Hill Road
- MD 234 at Allen's Fresh Road

- MD 234 at Stine’s Store Road
- MD 225 at Hunts Road
- MD 257 at Banks O’ Dee Road

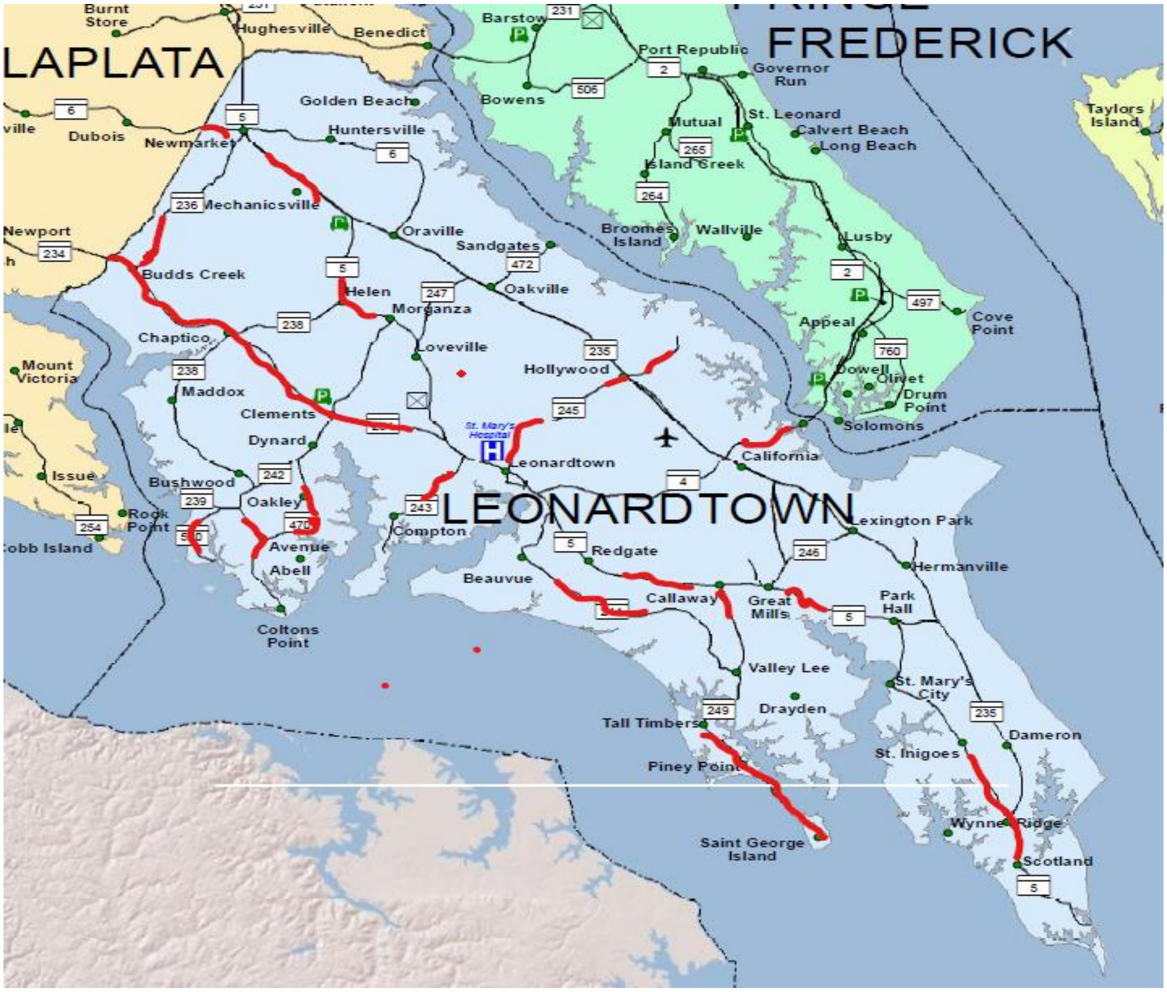
Projected weather stations:

- MD 6 at MD 224 (Riverside Road)
- MD 6 at Dubois Road
- MD 6 IS 37.83 Miles Total. I think we could benefit placing stations on the two opposite ends, which are stated above. MD 6 at Riverside is right on the Potomac, and the conditions could vary from all other areas in the county.

Majority of the time I believe we get northeast winds.

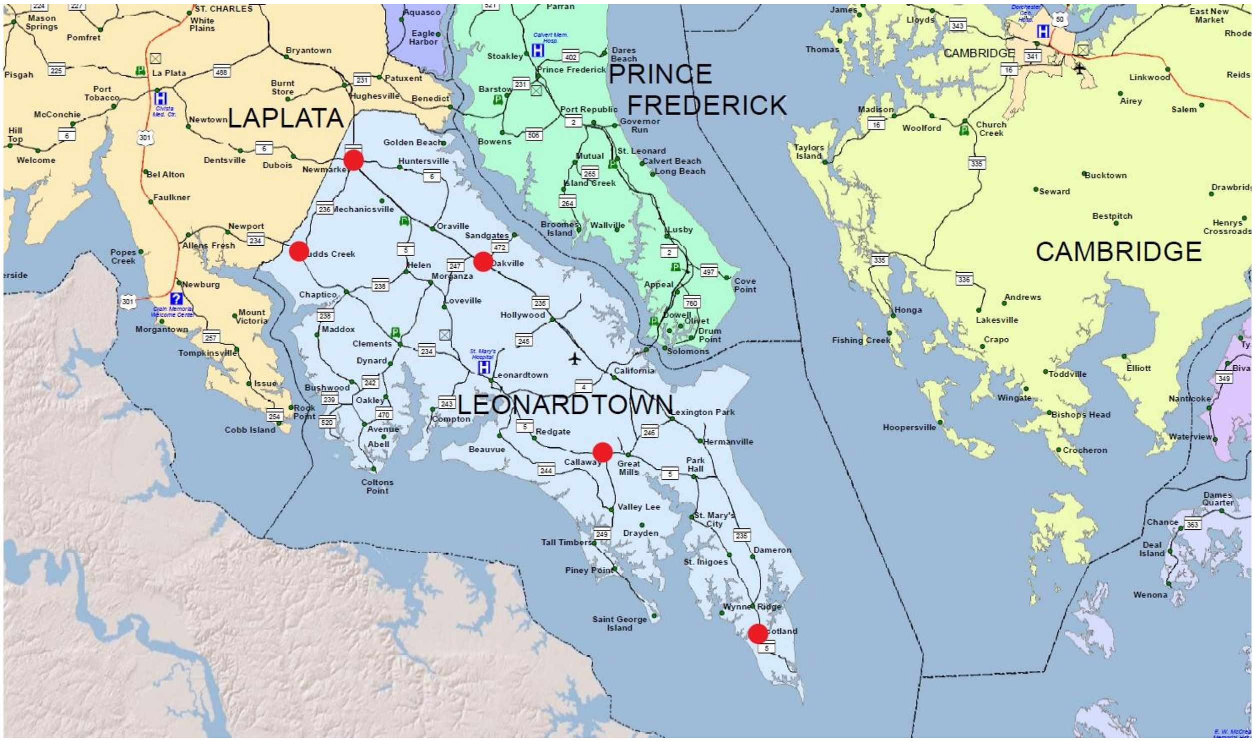
District 5, St Mary’s County Snow Drifting locations

Snow drifting location shown in red on roads. Occurs when snow is dry, and when wind originates from the west, but can also occur with north-south winds.

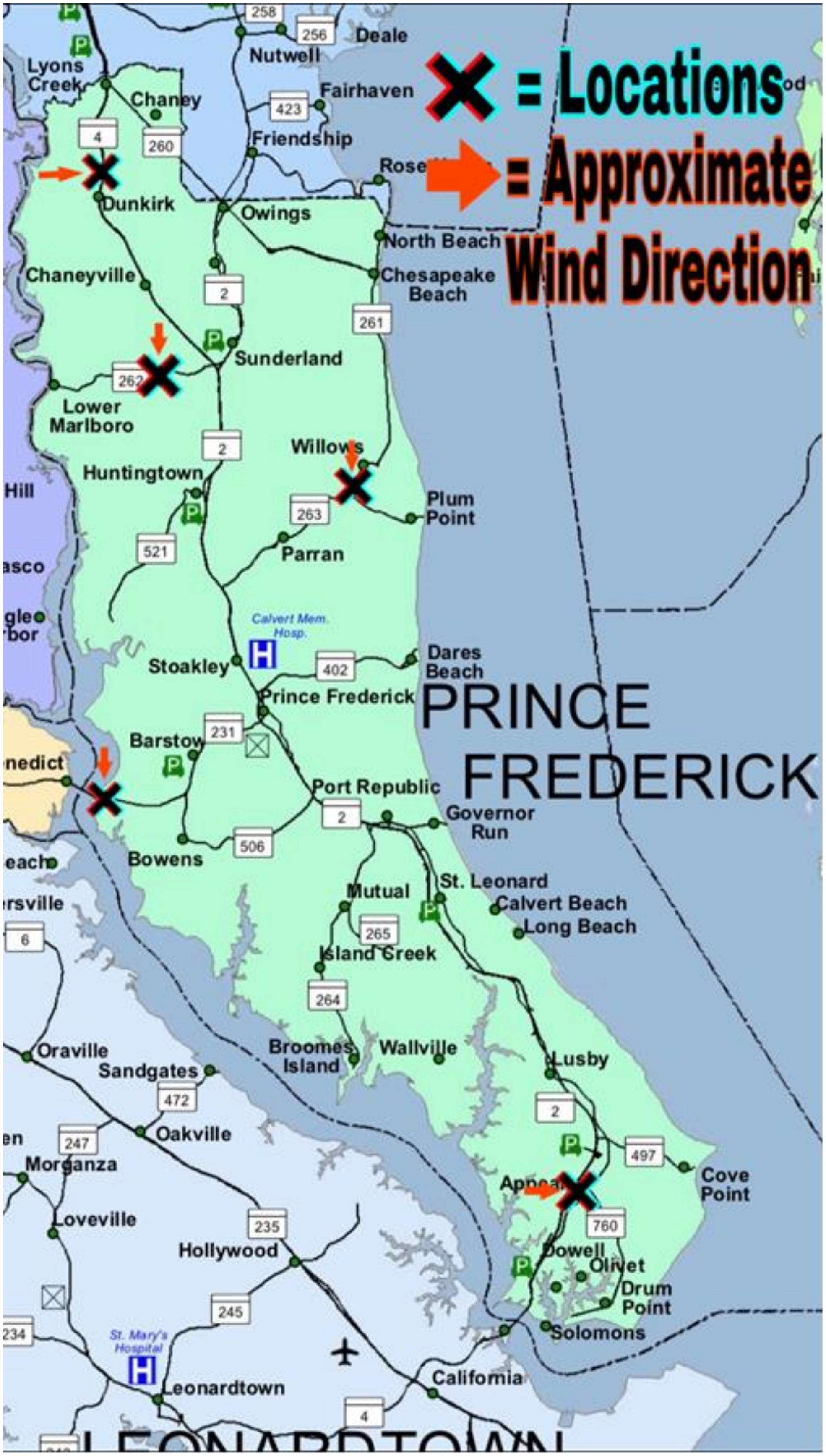


District 5, St. Mary’s Recommended RWIS locations

The most important locations would be the one farthest south and either of the two spots to the north of my county (St. Mary's).

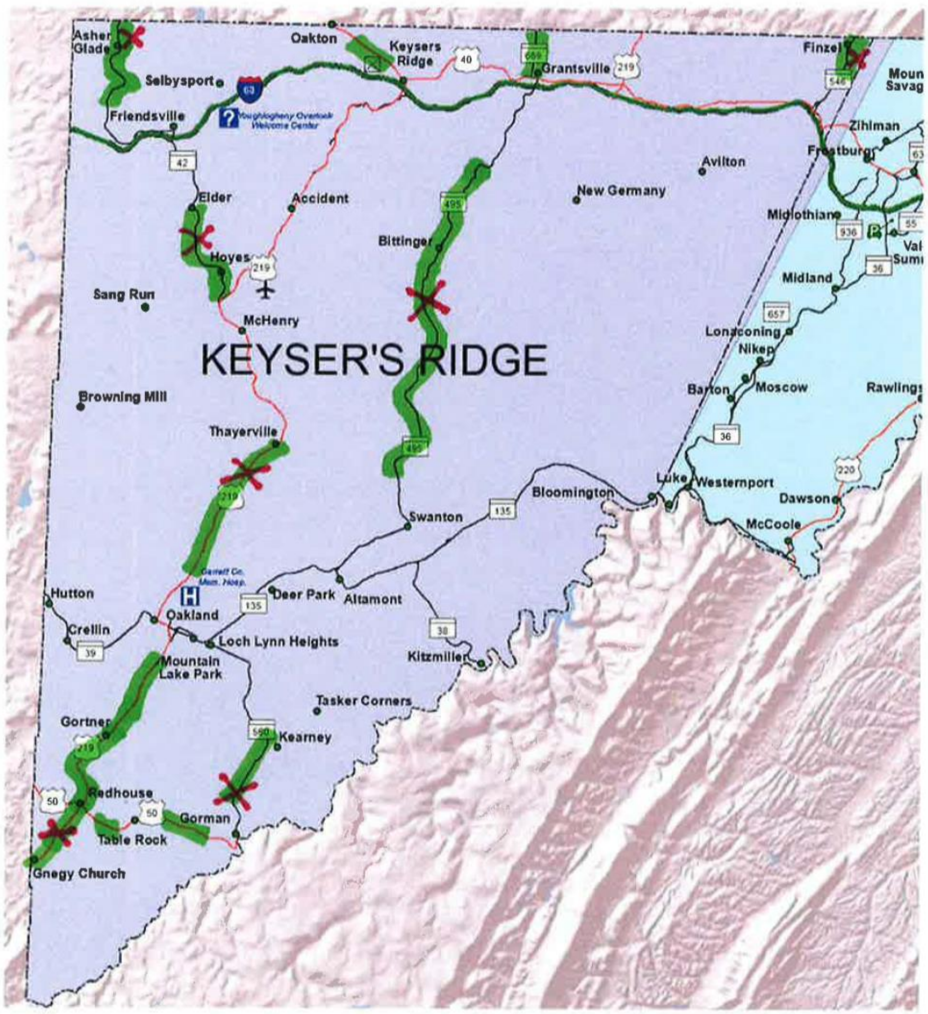


District 5, Prince Fredrick Shop in Anne Arundel County Drifting Snow location and Future RWIS sites


= Locations
= Approximate
Wind Direction
Lyons Creek
Chaney
Dunkirk
Owings
Nutwell
Deale
Fairhaven
Friendship
North Beach
Chesapeake Beach
Chaneyville
Sunderland
Lower Marlboro
Huntingtown
Willows
Plum Point
Parran
Calvert Mem. Hosp.
Stoakley
Dares Beach
Prince Frederick
PRINCE FREDERICK
Barstow
Port Republic
Governor Run
Bowens
Mutual
St. Leonard
Calvert Beach
Long Beach
Island Creek
Broomes Island
Wallville
Lusby
Oraville
Sandgates
Oakville
Morganza
Loveville
Hollywood
Cove Point
Dowell
Olivet
Drum Point
Solomons
St. Mary's Hospital
Leonardtown
California

District 6, Garrett County Drifting Snow location and Future RWIS sites

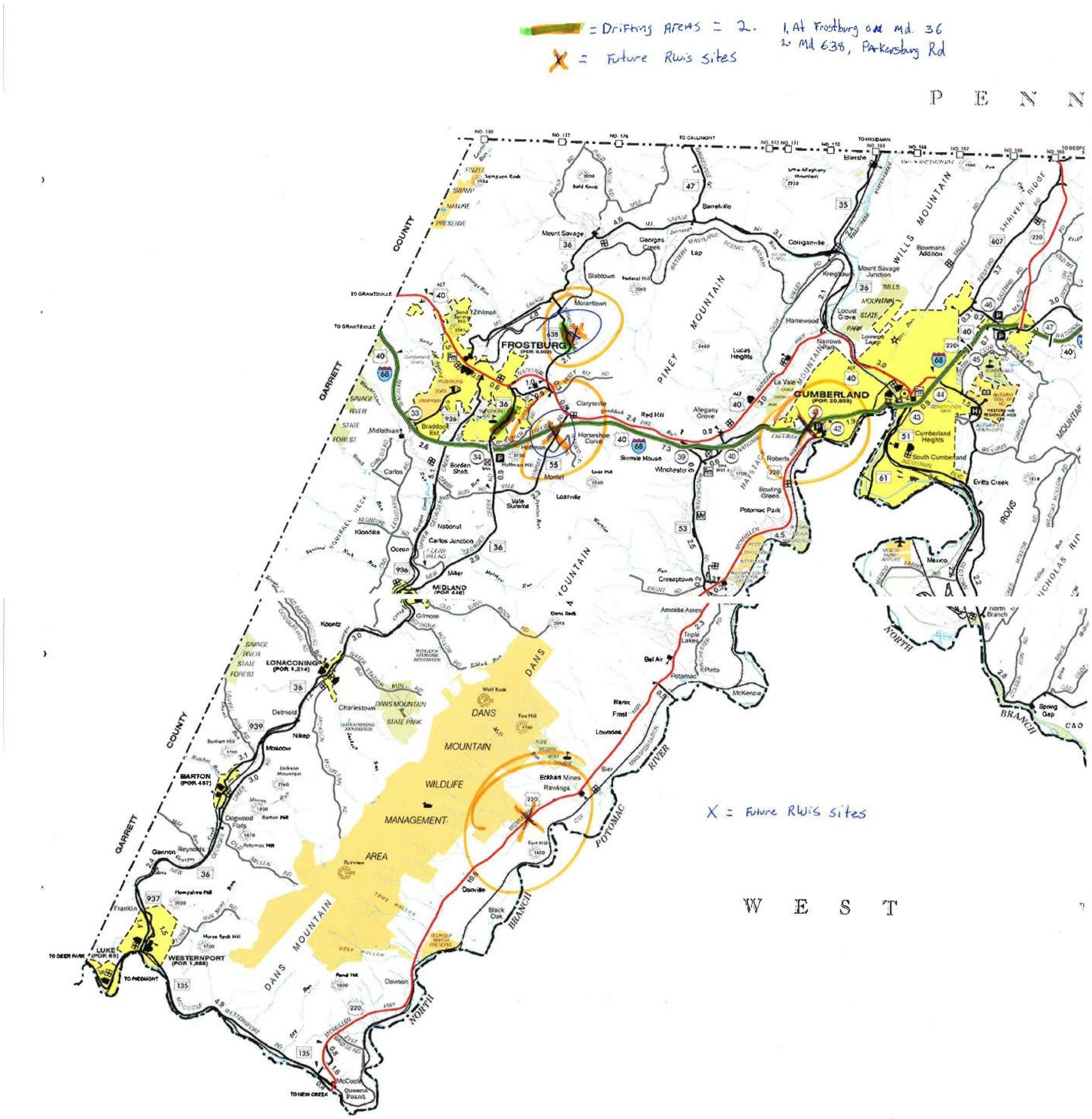
Drifting snow location shown as green highlighted areas with winds occurring from the west to the east. Future RWIS sites shown as red X's.

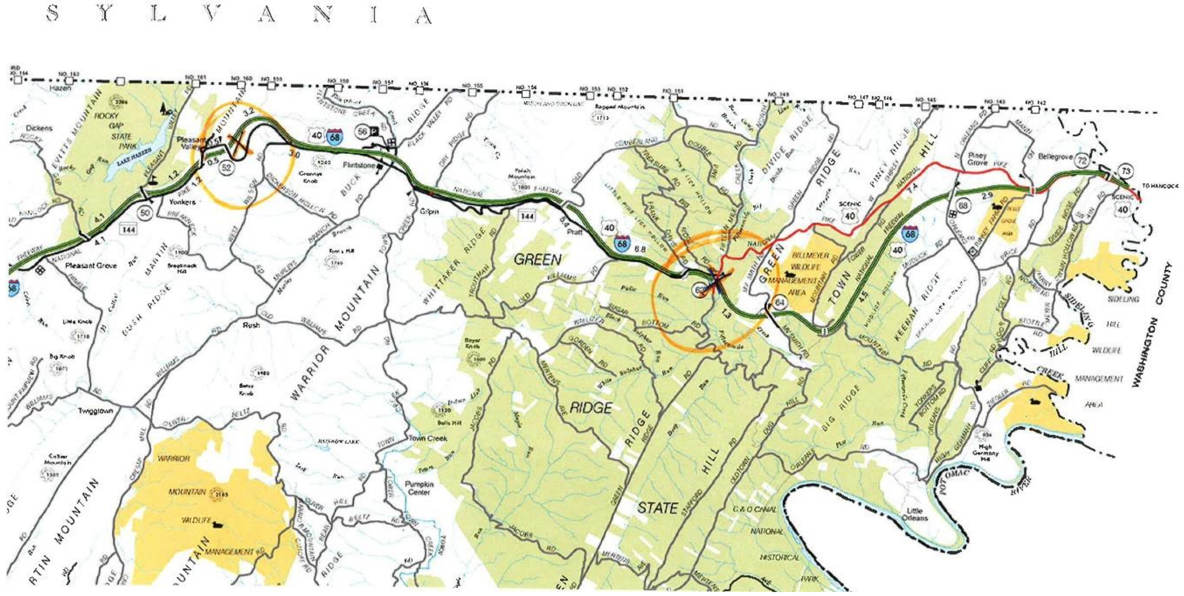


District 6, La Vale Shop Drifting Snow location and Future RWIS sites

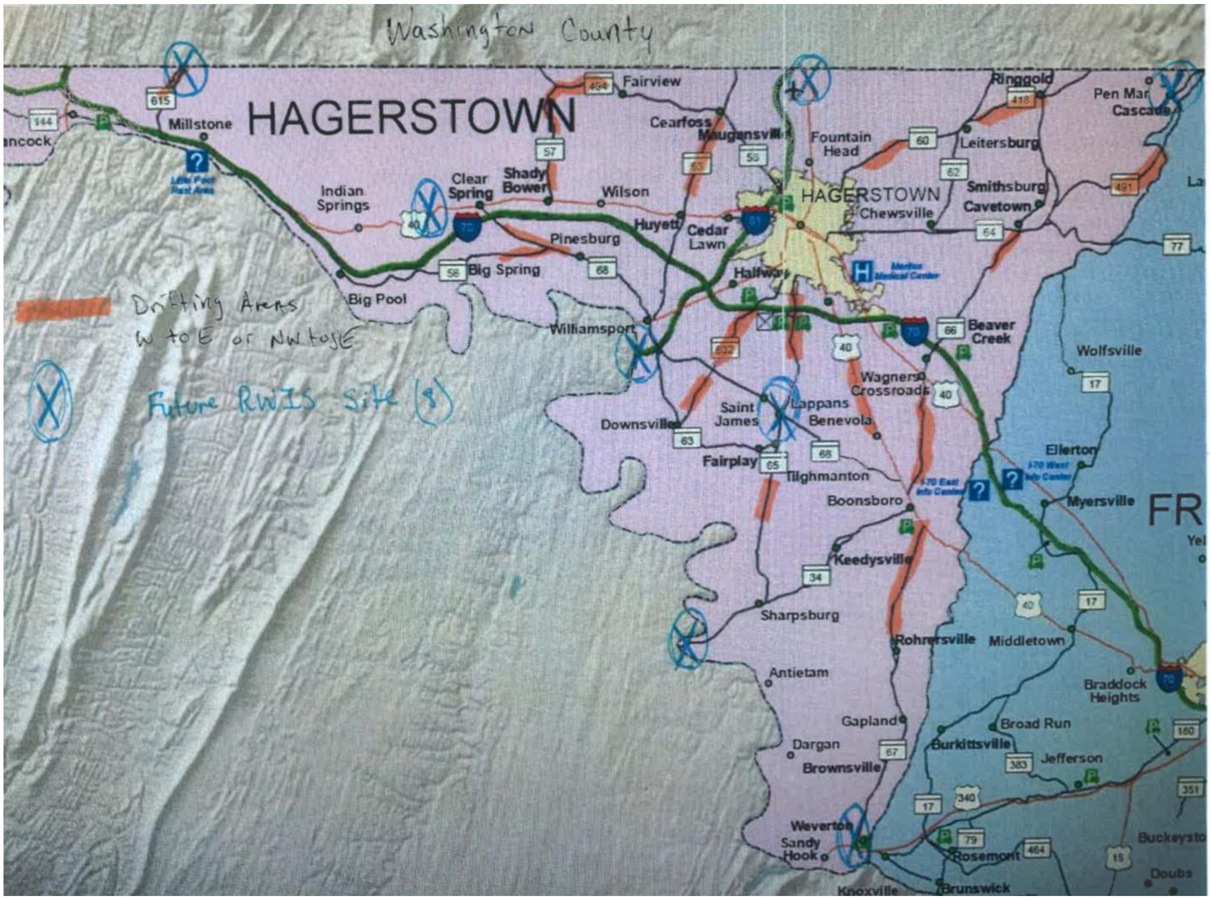
Drifting snow was identified at two key locations in La Vale, 1) at Frostburg on MD 36 and 2) at MD 638 at Packersburg Rd.

Six potential RWIS sites were identified.


= Drifting Areas = 2.
1. At Frostburg on Md. 36
2. Md 638, Parkersburg Rd
X = Future RWis sites
P E N N
GARRETT COUNTY
FROSTBURG
CUMBERLAND
LONACONING
BARTON
WESTERNPORT
LUKE
DANS MOUNTAIN
WILDLIFE MANAGEMENT AREA
POTOMAC RIVER
NORTH BRANCH
X = Future RWis sites
W E S T

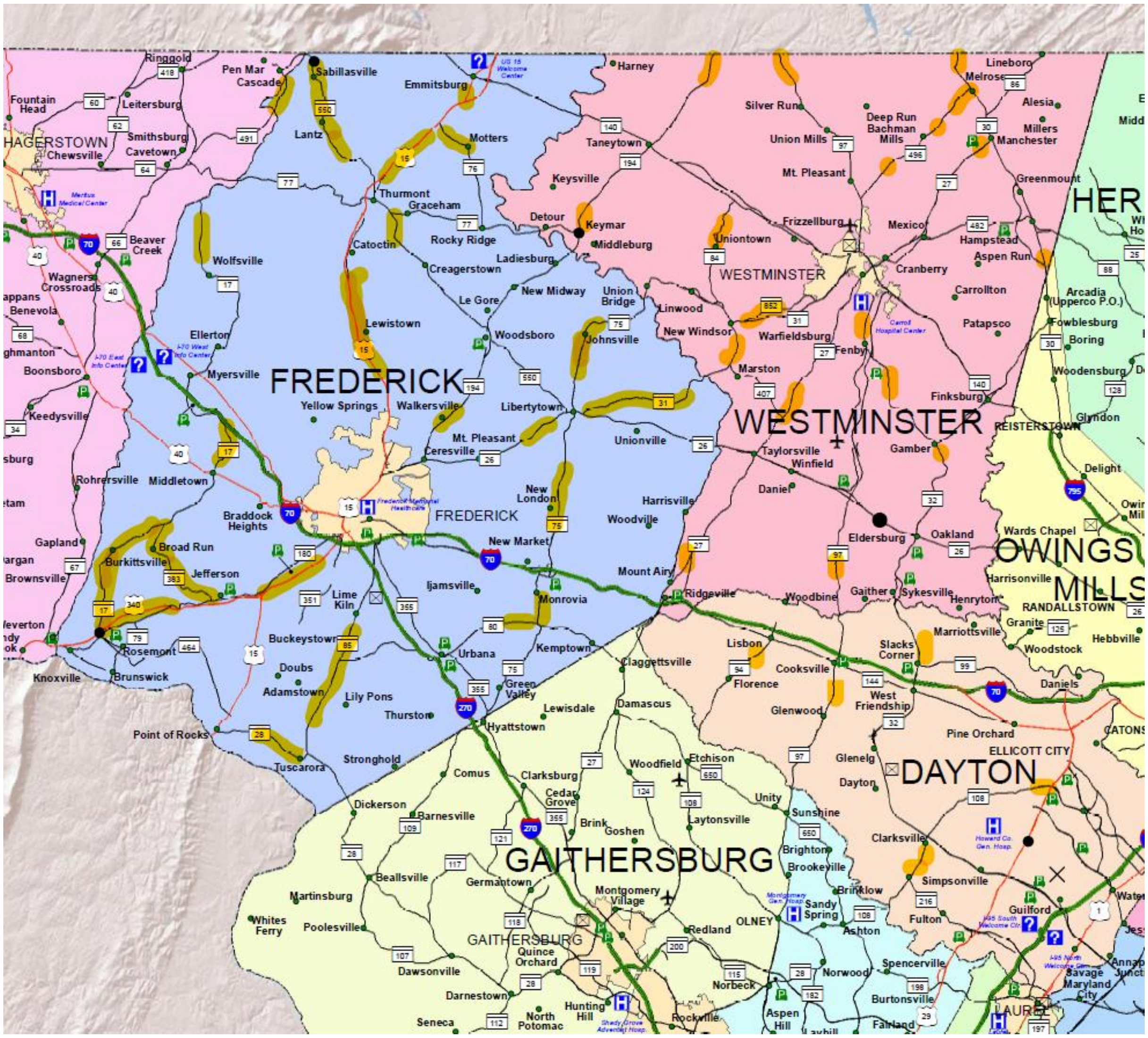


District 6, Washington County Drifting Snow location and Future RWIS sites



District 7 Drifting Snow location and Future RWIS sites

Road highlighted in orange indicate where snow drifting occurs. Drifting snow occurs when winds come from the north/northwest. The large black dots are the proposed RWIS locations.



Appendix D – Data

The following table shows variation amongst the original files sampled for the project. (Note: This table is broken up into pieces for readability; the summary of all of the data was found in 5.2 Data.)

Processing Historical Data from Iteris

The historical data from Iteris provided data, by month, in three separate files: atmos, sub, and pavement (also sometimes called "departure", "unknown", "deck"). (Note: This means that instead of just one file, there were three files for each month, for the six months across a "winter" season, meaning that eighteen files had to be processed to make a "winter" season.) These files were in a .txt file format; they were converted to Excel for ease of data processing. Some of these three key files (atmos, sub and unknown) were not available for every location, for every month. Some .txt files were determined to be "empty," which means no data (e.g. no numbers) were found within (as shown in yellow in the sample data, found in Table 32); those with gaps in the data (e.g. did not have data for the entire month) were shown in red. Once each of the files was imported into Excel, they (atmos, sub and unknown data) had to be combined into one file for the month. These month files then had to be combined into a file for an entire storm season, making sure that there were not missing days at the beginning of a month or the end of a month. Again, similar to the current vendor, the time periods also had to be converted from Unicode into a date, and time, which again, did not always translate well and was time consuming. Table 33 shows, in various shades of blue, winter seasons that were anticipated as having "complete" data. The different shades of blue hint at those that are clearer in which file (e.g. pavement0 vs. pavement1) should be used. For those in orange, this signifies that no file was provided for this month. A more complete summary of all of the RWIS sites and the missing, incomplete data, and so forth are provided below.

Table 32. Summary table of available data and how complete the data sets are.

	From Oct 1, 2017 through Mar 31, 2018	Minimum	Average	Maximum	Std Dev.	I_70_at_FredrickWash_County_Line	Column	Minimum	Average	Maximum	Std Dev.	I-68 at SavageMT	Column	Minimum	Average	Maximum	Std Dev.
UTCTimestamp						X		10/1/2017	-	3/31/2018	-						
Time_Stamp (date and time)	X	10/1/2017	-	3/31/2018	-							X	A	10/1/2017	-	3/31/2018	-
date																	
time																	
Air Temperature Â°F						X		-0.16	39.991805	81.43	14.939497						
Road Temperature °F	X	-3.202297	39.613635	100.30986	16.952231	Road Surface Temp. Â°F	M	-3.86	41.888787	100.95	16.504776	X	B	-3.202297	39.613635	100.30986	16.952231
Freezing Temperature °F	X	21.41061	31.775861	32	0.8790644	X	N	28.99	31.997337	32	0.0768908	X	C	21.41061	31.775861	32	0.8790644
Water Film Height milli-inch	X	0	0.2322541	61.496063	1.2639176	Listed as, "Water Film Height mil"	O	0	0.4245874	37.05	1.5331233	X	D	0	0.2322541	61.496063	1.2639176
Saline Concentration percent	X	0	0.2075992	9.058531	0.8099672	Listed as "Salt Concentration %"	P	0	0.0024984	2.8	0.0721266	X	E	0	0.2075992	9.058531	0.8099672
Salt Concentration lbs p.lane mile						X	X	0	0.0574853	249.7	2.2724712						
Road Condition n/a	X	0	0.9229675	7	2.1418011	X	Q	Qualitative information (none, rain, etc.)				X	F	0	0.9229675	7	2.1418011
Service Level lbs p.lane mile	X	0	0.5452396	768.619019	7.6280061							X	G	0	0.5452396	768.619019	7.6280061
Road Temperature °F	X	-3.282932	39.787988	103.40332	17.263797	Road Surface Temp. Â°F	S	5.08	45.664468	105.66	16.040302	X	H	-3.282932	39.787988	103.40332	17.263797
Sub-Surface Temp. Â°F																	
Temperature 1 °F	X	12.566509	41.775397	74.966888	12.790549							X	I	12.566509	41.774047	74.966888	12.789332
Freezing Temperature °F	X	24.779057	31.896076	32	0.5585115	X	T	27.64	31.995515	32	0.101031	X	J	24.779057	31.896076	32	0.5585115
Water Film Height milli-inch	X	0	2.0960467	46.75	3.9509999	Listed as, "Water Film Height mil"	U	0	0.5307046	50.79	2.0723575	X	K	0	2.0960467	46.75	3.9509999
Saline Concentration percent	X	0	0.0967492	6.443899	0.5171864	Listed as "Salt Concentration %"	R	0	0.0138723	30.52	0.4339782	X	L	0	0.0967492	6.443899	0.5171864
Salt Concentration lbs p.lane mile						X	V	0	0.004206	4.02	0.0946256						
Road Condition n/a	X	0	1.3717278	7	2.385559	X	W	Qualitative information (none, rain, etc.)				X	M	0	1.3717278	7	2.385559
Water Film Height milli-inch	X	0	2.4153673	412.910736	15.608154							X	N	0	2.4153673	412.910736	15.608154
Precipitation diff. milli-inch	X	0	0.1223098	77.952759	1.2521926	X; only listed as "mil" is this milli-inch?	K	0	0.1630245	148.82	1.8139602	X	O	0	0.1223098	77.952759	1.2521926
Precipitation type unknown unit	X	0	4.6974822	70	16.917453	Only listed as "Precipitation Type"	L	Qualitative information (none, rain, etc.)				X	P	0	4.6974822	70	16.917453
Visibility miles	X	0.055302	1.1528706	40	0.3212434							X	Q	0.055302	1.1528706	40	0.3212434
Temperature °Fahrenheit	X	-6.218899	35.184988	78.788269	15.98336							X	R	-6.218899	35.184988	78.788269	15.98336
Dewpoint °Fahrenheit	X	-12.52652	28.397444	72.15686	16.556043	X; different order	D	-7.89	31.964935	77.62	16.576943	X	S	-12.52652	28.397444	72.15686	16.556043
Relative humidity percent	X	21.648075	78.353769	100	18.387461	X	E	25.3	74.871685	100	18.654123	X	T	21.648075	78.353769	100	18.387461
Abs. air pressure Hecto Pascal	X	898.368042	923.87324	941.681519	7.0771702	Not listed as "absolute"	F	947.97	975.37451	996.15	7.6973019	X	U	898.368042	923.87324	941.681519	7.0771702
Wind Speed (peak) miles/hour	X	0.67639	11.52619	50.174332	6.6906974							X	V	0.67639	11.52619	50.174332	6.6906974
Wind Speed [act] mph																	
Wind Speed miles/hour	X	0	4.7151342	18.827705	2.711719	X; listed twice; if one peak?	G	0	11.505365	64.8	6.9834007	X	W	0	4.7151342	18.827705	2.711719
Wind Speed mph						X	H	0	4.6210793	27	2.6697255						
Wind direction degree	X	0	210.40325	359.978973	91.81287	X	I	0	212.57795	359.85	96.924349	X	X	0	210.40325	359.978973	91.81287
Wind direction degree	X	0.111938	224.2073	359.914978	82.460278	X	J	0	219.25516	359.98	97.460158	X	Y	0.111938	224.2073	359.914978	82.460278
Visibility feet	Listed as "NULL"	0	no value	0	no value							Listed as "NULL"	No information				
Visibility miles	Listed as "NULL"	0	no value	0	no value							Listed as "NULL"	No information				

Table 32 Continued

I495_at_American_Legion_Bridge	Column	Minimum	Average	Maximum	Std Dev.	MD_4_at_Patuxent_River	Column	Minimum	Average	Maximum	Std Dev.
X						X					
X	B	10/1/2017	-	3/31/2018	-	X		10/1/2017	-	3/31/2018	-
X						X					
X	D	3.05	43.27843231	86.9	15.17626377	X	D	9.19	45.92358803	87.67	14.29526411
Road Surface Temp. Â°F	N	4.5	49.33014191	105.8	16.77188555	Road Surface Temp. Â°F	N	5.29	48.32013157	100.58	16.04909714
X	O	-5.8	31.87219711	32	1.856110026	X	O	18.44	31.9081979	32	0.664366314
Missing the "-inch"; Water Film Height mil	P	0	0.193737519	98.58	1.626315702	Missing the "-inch"; Water Film Height mil	P	0	0.674821035	70.59	2.228805406
X	Q	0	0.085461899	22	1.143593306	X	Q	0	0.083939139	11.15	0.600639585
X	S	0	1.065435643	817.71	14.85603551	X	S	0	1.324083919	672.41	12.55264059
X	R	Qualitative information (none, rain, etc.)				X	R	Qualitative information (none, rain, etc.)			
Road Surface Temp. Â°F	T	8.38	50.35107999	106.43	16.51326974	Road Surface Temp. Â°F; SOME listed as "ERROR"	T	11.73	51.10416779	105.87	15.9546612
X	U	25.45	51.84684982	84.63	12.11981606	X; SOME listed as "ERROR"	U	29.34	53.62060795	84.56	12.00584599
X	V	28.04	31.99302855	32	0.138032606	X; SOME listed as "ERROR"	V	27.52	31.9909383	32	0.14957177
Missing the "-inch"; Water Film Height mil	W	0	0.094875186	94.68	1.039840467	Missing the "-inch"; Water Film Height mil	W	0	0.500716341	59.65	1.609680149
X	X	0	0.006515049	3.66	0.128853187	X	X	0	0.00846911	4.12	0.139740965
X	Z	0	0.065615769	83.05	1.547028512	X	Z	0	0.106312574	94.38	1.962816482
X	Y	Qualitative information (none, rain, etc.)				X	Y	Qualitative information (none, rain, etc.)			
Missing the "-inch"; Precipitation Difference mil	L	0	0.072950364	55.91	0.87661427	Missing the "-inch"; Precipitation Difference mil	L	0	0.033041097	35.04	0.487175952
Listed as "Precipitation Type"	M	Qualitative information (none, rain, etc.)				Listed as "Precipitation Type"	M	Qualitative information (none, rain, etc.)			
Dew Point Â°F	E	-7.94	33.19211464	78.89	17.50333366	X	E	-3.1	37.58346432	77.45	16.83276487
X	F	18.25	70.76652521	100	22.55407897	X	F	27.74	74.65873664	100	19.25200917
Not listed as "absolute," says "Air Pressure hPa	G	985.1	1016.695863	1039.25	8.326447794	Not listed as "absolute," says "Air Pressure hPa	G	985.85	1019.993834	1042.54	8.452502065
						Wind Speed [max] mph	H	0	18.98321652	103.46	11.87129534
						X	I	0	14.31742448	85.3	9.459098307
X; listed twice; is one peak?	H	0	8.629845548	46.95	5.87697535	X	J	0	14.32542956	75.49	9.277644214
X	I	0	3.463289443	18.56	2.493187435						
Wind Direction Â°	J	0	205.6984248	360	114.3624619	X	K	0	217.9091513	359.9	103.2626329
Wind Direction Â°	K	0	192.3726601	360	113.4905289						

Table 32 Continued

MD_24_@_Rocks_State_Park	Column	Minimum	Average	Maximum	Std Dev.	US_50_at_Choptank	Column	Minimum	Average	Maximum	Std Dev.
X						X					
X		10/1/2017	-	3/31/2018	-	X		10/1/2017	-	3/30/2018	-
X						X					
X	D	-0.64	39.5617978	78.99	14.34441298	X	D	6.76	44.61414866	82.67	13.75485529
Road Surface Temp. Â°F	N	4.52	41.39512877	89.06	14.24356228	Road Surface Temp. Â°F	N	3.75	47.78636636	102.79	15.92033774
						X	O	9.91	31.85775316	32	1.023636838
						Missing the "-inch"; Water Film Height mil	P	0	0.204139588	21.79	0.838251758
						Listed as "Salt Concentration %"	Q	0	0.126241896	16.23	0.887912149
						X	S	0	0.739555418	502.99	8.161515226
X; Actually states "DRY"	S	Qualitative information (none, rain, etc.)				X; Actually states "DRY"	R	Qualitative information (none, rain, etc.)			
						Road Surface Temp. Â°F	T	8.59	49.09010034	104.19	15.67760779
X	O	19.92	42.5168445	70.93	11.07793578	X	U	28.75	51.93085192	82	22.16634225
X	P	32	32	32	0	X	V	20.42	31.96875	32	0.352580701
Missing the "-inch"; Water Film Height mil	Q	0	0.536678428	52.32	1.340187154	Missing the "-inch"; Water Film Height mil	W	0	0.309298009	17.53	0.989650269
X	R	0	0	0	0	X	X	0	0.028836832	9.78	0.321996217
X	T	0	0	0	0	X		0	0.403511886	268.88	5.286858607
						X; Actually states "DRY"		Qualitative information (none, rain, etc.)			
Missing the "-inch"; Precipitation Difference mil	L	0	0.050999866	25.2	0.36519665	Missing the "-inch"; Precipitation Difference mil	L	0	0.140751775	108.66	1.582356235
Listed as "Precipitation Type"	M	Qualitative information (none, rain, etc.)				Listed as "Precipitation Type"	M	Qualitative information (none, rain, etc.)			
X	E	-6.54	34.07930427	77.22	16.1307015	X	E	-3.71	37.71317691	76.92	16.39916528
X	F	21.47	82.575836	100	18.42066293	X	F	30.04	78.23387079	100	17.94349183
Not listed as "absolute," says "Air Pressure hPa	G	973.77	1008.951888	1032.15	8.523505689	Not listed as "absolute," says "Air Pressure hPa	G	985.72	1019.852398	1042.56	8.528426112
X; listed twice; is one peak?	H	0	3.893528295	34.92	3.601654839	X; listed twice; is one peak?	H	0	11.89785192	63.81	8.820752921
X	I	0	1.499669588	15.18	1.635763608	X	I	0	6.852214847	41.14	5.710173873
X	J	0	101.900461	360	131.8306584	X	J	0	191.3998912	359.99	107.6583091
X	K	0	119.7816475	360	122.2599552	X	K	0	193.4534213	359.96	104.8534026

Table 32 Continued

US50_at_Kent_Narrows_Bridge	Column	Minimum	Average	Maximum	Std Dev.
X					
X	B	10/1/2018	-	3/31/2018	-
X					
X	D	9.6	44.7809447	86.1	13.61028248
Road Surface Temp. Â°F	N	6.05	47.51047696	100.14	15.42619573
X	V	30	31.9999616	32	0.008763841
Missing the "-inch"; Water Film Height mil	W	0	0.549200653	59.18	1.870035041
Listed as "Salt Concentration %"	X	0	3.60983E-05	1.88	0.008238011
X	Z	0	0.000422619	22.01	0.096446074
X; Actually states "DRY"	R	Qualitative information (none, rain, etc.)			
Road Surface Temp. Â°F	T	9.59	49.20884812	104.94	15.67711129
X	U	25.44	51.28227035	83.49	12.47835293
X	O	21.97	31.90833026	32	0.57360657
Missing the "-inch"; Water Film Height mil	P	0	0.453258065	61.81	1.784219666
Listed as "Salt Concentration %"	Q	0	0.084894393	8.64	0.527958295
X	S	0	0.807902842	432.71	8.602887681
X; Actually states "DRY"	Y	Qualitative information (none, rain, etc.)			
Missing the "-inch"; Precipitation Difference mil	L	0	0.149046659	102.36	1.652589509
Listed as "Precipitation Type"	M	Qualitative information (none, rain, etc.)			
X	E	-6.22	36.44265188	77.87	16.67626288
X	F	23.58	74.49179205	100	19.42780872
Not listed as "absolute," says "Air Pressure hPa	G	985.32	1019.446909	1042.61	8.558840878
X; listed twice; is one peak?	H	0	13.38436308	61.77	8.057836908
X	I	0	7.581656538	36.68	4.729939945
X	J	0	199.4154994	360	104.4519187
X	K	0	199.1728467	359.99	103.9976351

Table 33. Missing, Incomplete, and Full Data Available from Previous Vendor.

		2010-12	2011-01	2011-02	2011-03	2011-10	2011-11	2011-12	2012-01	2012-02	2012-03
2	MDHYA	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
3	MDCON	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	No Data	No Data	No Data	No Data	No Data	No Data
4	MDSPR	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	No Data	No Data	No Data	No Data	No Data
5	MDWEL	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	No Data	No Data	No Data	No Data	No Data
6	MDBRA	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
7	MDCAR	atmos; unknown1; unknown2	atmos; unknown1; unknown2	atmos; unknown1; unknown2	atmos; unknown1; unknown2	atmos; unknown1; unknown2	No Data	No Data	No Data	No Data	No Data
9	MDHER	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	No Data	No Data	No Data	No Data	No Data
10	MDGOR	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not download	Not download	Not downloaded	Not download	Not downloaded
11	MDSID	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	No Data	No Data	No Data	No Data	No Data
12	MDMAP	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; sub; unknown0; unknown1; unknown2; unknown3	atmos; unknown0; unknown1; unknown2; unknown3	atmos; unknown0; unknown1; unknown2; unknown3	No Data	No Data	No Data	No Data
14	MDRSP	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	No Data	No Data	No Data	No Data
15	MDHAR	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
16	MDMTA	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	sub; atmos; unknown0; unknonwn1; unknown2; unknown3	atmos; sub; deck0; deck1; unknown0; unknown1; unknown2; unknown3; pavement2; pavement3	atmos; sub; deck0; deck1; unknown0; unknown1; unknown2; unknown3; pavement2; pavement3	No Data	No Data	No Data	No Data
17	MDEMM	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; deck; unknown0; unknown1; unknown2; pavement0; pavement2	atmos; sub; deck; unknown0; unknown1; unknown2; pavement0; pavement2	No Data	No Data	No Data	No Data
19	MDKEN	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; deck0; deck1; unknown0; unknown1; unknown2; pavement2	atmos; sub; deck0; deck1; unknown0; unknown1; unknown2; pavement2	No Data	No Data	No Data	No Data
23	MDMIR	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	No Data	No Data	No Data	No Data	No Data
24	MDCRB	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; deck0; deck2; unknown0; unknown1; unknown2; pavement1	atmos; sub; deck0; deck2; unknown0; unknown1; unknown2; pavement1	atmos; sub; deck0; deck2; pavement1	atmos; sub; deck0; deck2; pavement1	atmos; sub; deck0; deck2; pavement1	No Data
26	MDGHN	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
27	MDWIS	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
31	MDFRO	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
35	MDSWA	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
37	MDFAJ	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
38	MDWES	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
39	MDWEF	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
43	MDGAI	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
44	MDRIV	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
45	MDGLB	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
46	MDVIE	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
52	MDPOC	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
53	MDOCY	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
54	MDRFD	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
55	MDOLD	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
58	MDTHM	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
59	MDTTN	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
60	MDCEN	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
95	MDCLV	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded
149	MDCAM	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded	Not downloaded

		2012-10	2012-11	2012-12	2013-01	2013-02	2013-03	2013-10	2013-11	2013-12	2014-01	2014-02	2014-03
2	MDHYA	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; deck; departure; unknown0; unknown1	atmos; sub; deck; departure; unknown0; unknown1	atmos; sub; deck; departure; unknown0; unknown1	atmos; sub; deck; departure
3	MDCON	atmos; sub; unknown	atmos; sub; unknown	atmos; sub; unknown	atmos; sub; unknown	atmos; sub; unknown	atmos; sub; unknown	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0; approach0	atmos; sub; unknown0; approach0	atmos; sub; unknown0; approach0	sub; atmos; approach
4	MDSPR	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2	atmos; sub; unknown0; unknown1; unknown2; pavement0; pavement1; pavement2	atmos; sub; unknown0; unknown1; unknown2; pavement0; pavement1; pavement2	atmos; sub; unknown0; unknown1; unknown2; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2
5	MDWEL	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck
6	MDBRA	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; sub	atmos; unknown0; unknown1; pavement0; pavement1; sub	atmos; unknown0; unknown1; pavement0; pavement1; sub	atmos; unknown0; unknown1; pavement0; pavement1; sub	atmos; sub; pavement0; pavement1
7	MDCAR	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos
9	MDHER	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; approach1	atmos; sub; deck; approach1	atmos; sub; deck; approach1; pavement1	atmos; sub; deck; approach1; pavement1	atmos; sub; deck; approach1; pavement1	atmos; sub; deck; approach1
10	MDGOR	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
11	MDSID	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement0; pavement1	atmos; sub; deck; pavement0; pavement1	atmos; sub; deck; pavement0; pavement1	atmos; sub; deck; pavement1
12	MDMAP	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	sub; deck; unknown0; unknown1; pavement1	sub; deck; atmos; unknown0; unknown1; pavement1	sub; deck; atmos; unknown0; unknown1; pavement1	sub; deck; atmos; pavement1
14	MDRSP	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
15	MDHAR	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1; pavement0; pavement1	atmos; sub; unknown0; unknown1; pavement0; pavement1	atmos; sub; unknown0; unknown1; pavement0; pavement1	atmos; sub; pavement0; pavement1
16	MDMTA	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck; sub; unknown1	atmos; deck0; deck1; sub; unknown1; pavement0	atmos; deck0; deck1; sub; unknown1; pavement0	atmos; deck0; deck1; sub; unknown1; pavement0	atmos; sub; deck; pavement0
17	MDEMM	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1; pavement1	atmos; sub; deck; unknown1; pavement1	atmos; sub; deck; unknown1; pavement1	atmos; sub; deck; pavement1
19	MDKEN	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach
23	MDMIR	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck0; unknown1; approach1; pavement1	atmos; sub; deck0; unknown1; approach1; pavement1	atmos; sub; deck0; unknown1; approach1; pavement1	atmos; sub; deck; pavement1
24	MDCRB	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
26	MDGHN	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1	atmos; sub; deck; unknown1; pavement1	atmos; sub; deck; unknown1; pavement1	atmos; sub; deck; unknown1; pavement1	atmos; sub; deck; pavement1
27	MDWIS	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; unknown0; unknown1	atmos; sub; deck; unknown0; unknown0; departure0	atmos; sub; deck; unknown0; unknown0; departure0	atmos; sub; deck; unknown0; unknown0; departure0	atmos; sub; deck; departure
31	MDFRO	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
35	MDSWA	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; unknown0	atmos; sub; pavement0; unknown0	atmos; sub; pavement0; unknown0	atmos; sub; pavement0; unknown0	atmos; sub; pavement0
37	MDFAJ	atmos; sub; deck; unknown0; unknown1; unknown2; unknown3; approach1	atmos; sub; deck; unknown2; unknown3; approach1	atmos; sub; deck; unknown2; unknown3; approach1	atmos; sub; deck; unknown2; unknown3; pavement1; approach1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
38	MDWES	atmos; deck0; deck1; pavement2	atmos; deck0; deck1; pavement2	atmos; deck0; deck1; pavement2	atmos; sub; deck0; deck1; pavement1; pavement2	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
39	MDWEF	atmos; sub; deck1; deck2; unknown0; unknown1; unknown2; unknown3	atmos; sub; deck1; deck2; unknown0; unknown3	atmos; sub1; sub3; deck0; deck1; deck2; unknown0; unknown3; pavement1	atmos; sub1; sub3; deck0; deck1; deck2; unknown0; unknown3; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
43	MDGAI	atmos; sub; deck; unknown0; unknown1; unknown2; unknown3	atmos; sub; deck; unknown0; unknown1; unknown3	atmos; sub; deck; unknown0; unknown1; unknown3	atmos; sub0; sub1; deck0; deck2; unknown0; unknown1; unknown3; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement0; pavement1	atmos; sub; deck; pavement0; pavement1	atmos; sub; deck; pavement0; pavement1	atmos; sub; pavement0; pavement1
44	MDRIV	atmos; deck0; pavement1; pavement2	atmos; deck0; pavement1; pavement2	atmos; deck0; pavement1; pavement2	atmos; deck0; pavement1; pavement2	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1
45	MDGLB	atmos; sub1; sub3; deck0; deck2; departure1; departure3	atmos; sub1; sub3; deck0; deck2; departure1; departure3	atmos; sub1; sub3; deck0; deck2; departure1; departure3	atmos; deck0; deck2; sub1; sub3; departure1; pavement1; approach3	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; departure1; pavement1	atmos; sub; deck; departure1; pavement1	atmos; sub; deck; departure1; pavement1	atmos; sub; deck; departure1
46	MDVIE	atmos; sub; unknown0; unknown1; unknown2; deck0; deck1	atmos; sub2; deck0; deck1; unknown2	atmos; sub2; deck0; deck1; unknown2	atmos; sub1; sub2; deck0; deck1; unknown2; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
52	MDPOC	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
53	MDOCY	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub; pavement0	atmos; sub; pavement0
54	MDRFD	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1
55	MDOLD	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub; pavement0	atmos; sub; pavement0
58	MDTHM	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub; approach	atmos; sub; approach
59	MDTTN	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1
60	MDCEN	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1
95	MDCLV												
149	MDCAM												

		2014-10	2014-11	2014-12	2015-01	2015-02	2015-03	2015-10	2015-11	2015-12	2016-01	2016-02	2016-03
2	MDHYA	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure
3	MDCON	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach	sub; atmos; approach
4	MDSPR	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2	atmos; sub; pavement0; pavement1; pavement2
5	MDWEL	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck	atmos; sub; approach; deck
6	MDBRA	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
7	MDCAR	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos	atmos
9	MDHER	atmos; sub; deck; approach1	atmos; sub; deck; approach1	atmos; sub; deck; approach1	atmos; sub; deck; approach1	atmos; sub; deck; approach1	atmos; sub; deck; approach1	atmos; sub; approach1	atmos; sub; approach1	atmos; sub; approach1	atmos; sub; approach1	atmos; sub; approach1	atmos; sub; approach1
10	MDGOR	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
11	MDSID	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
12	MDMAP	sub; deck; atmos; pavement1	sub; deck; atmos; pavement1	sub; deck; atmos; pavement1	sub; deck; atmos; pavement1	sub; deck; atmos; pavement1	sub; deck; atmos; pavement1	atmos	sub; deck; atmos; pavement1	sub; deck; atmos; pavement1	atmos; deck	atmos; deck	atmos; deck
14	MDRSP	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
15	MDHAR	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
16	MDMTA	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0	atmos; sub; deck; pavement0
17	MDEMM	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; deck	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
19	MDKEN	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach	atmos; sub; deck; approach
23	MDMIR	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
24	MDCRB	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
26	MDGHN	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
27	MDWIS	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure	atmos; sub; deck; departure
31	MDFRO	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
35	MDSWA	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
37	MDFAJ	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
38	MDWES	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
39	MDWEF	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
43	MDGAI	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
44	MDRIV	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1	atmos; deck; pavement1
45	MDGLB	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1	atmos; sub; deck; departure1
46	MDVIE	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1	atmos; sub; deck; pavement1
52	MDPOC	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1	atmos; sub; pavement0; pavement1
53	MDOCY	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
54	MDRFD	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1	atmos; sub; deck0; pavement1
55	MDOLD	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0	atmos; sub; pavement0
58	MDTHM	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach	atmos; sub; approach
59	MDTTN	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1	atmos; sub1; deck0; departure1
60	MDCEN	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1	atmos; sub; approach0; departure1
95	MDCLV												
149	MDCAM												

Appendix E – Early Model Performance & Testing Variables

Preliminary Model Performance

The following was the preliminary model that was developed using 104 storms, in District 6, with Maine SWI numbers as identified above.

Table 34. Preliminary Model, Testing the Data

Variable	**Coefficient**	**Standard Error**	**Z**	**Prob. |z|>Z***	**95% Confidence Interval**	
2016	-94.36	33.91	-2.78	0.0065	-161.7	-27.07
DEC	53.15	28.79	1.86	0.0679	-3.978	110.3
STORM_DUR	0.0957	0.0289	3.31	0.0013	0.0383	0.1530
50% NO PRECIP	51.10	21.28	2.40	0.0182	8.866	93.32
Constant	-36.36	18.21	-2.00	0.0486	-72.49	-0.2341

Where:

2016 = storms occurred in 2016 (in this dataset, there were only storms from 2016 and 2017)

DEC = if the storm occurred in December

STORM_DUR = the duration of the storm, measured in minutes

50% NO PRECIP = an indicator variable for when 50% of the entire time period of the storm had no precipitation

The model goodness of fit measure is $R^2 = 0.1806$ and $\bar{R}^2 = 0.1475$. As noted in Washington et al. (2003), the absolute value itself does not measure the goodness of fit measure; rather, an improvement can be cited only if a new level of understanding is concurrently seen within an improvement in the values.

Modeling with Blowing Snow

Blowing snow was identified as occurring when the air temperature was 25ºF or colder, and a count of the number of occurrences of winds greater than 10mph in the last 30 minutes of storm[5].

[5] In each RWIS site file for D6, the average wind speed over the last 30 minutes of a storm was considered. A count of the number of occurrences in that last 30 minutes of a storm that

A model was developed with data from District 6 (the Western Maryland Climate Zone) to determine if there was any possibility of statistical significance. With 1,297 data pieces from District 6, it was determined there was not enough data for statistical significance, as shown by the low Z-value in Table 35. Extracting this information to define when blowing snow occurred was time intensive and showed little promise for representation in the model, therefore it was removed from further consideration.

Table 35. Model Testing of Drifting Snow

Variable	**Coefficient**	**Standard Error**	**Z**	**Prob. |z|>Z***	**95% Confidence Interval**	
WET_PRECIP***	93.9263	3.04528	30.84	0.0000	87.9577	99.8950
STORM_DURATION ***	0.01967	0.00124	15.88	0.0000	0.01724	0.02210
WPREC***	17.7304	1.87057	9.48	0.0000	14.0641	21.3966
SUSTWIND***	-3.59907	1.05275	-3.42	0.0006	-5.66241	-1.53572
FEB*	2.14584	1.15453	1.86	0.0631	-0.11700	4.40868
DRIFTING	-0.41545	1.77387	-0.23	0.8148	-3.89216	3.06126
Constant***	-10.8935	1.77680	-6.13	0.0000	-14.3760	-7.4111

***, **, * = Significance at 1%, 5%, and 10% levels.

The model goodness of fit measure is R^2 = 0.64862 and $\bar{R}^2$ = 0.64699. However, as one of the variables in the model is not statistically significant, such a model would not be retained in this structure. It is shown above to show how the variable was not statistically significant.

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exceeded 10 mph was made. So, if all 30 minutes' readings exceeded 10 mph, a count of 6 was produced. The counts were used to create a sustained wind factor. Then a check was run that looked at the sustained winds value and whether there were 6 or more snow readings throughout the storm (as identified by precipitation type readings). If those two conditions were met, then the storm was classified as having the potential for blowing and drifting to be present.

Appendix F – Variables Considered and Used in SWI

Definition of all Data Variables

The following section provides a definition of key variables discussed in this report. Variables in bold were used in the final SWI model. Table 36 provides a summary of RWIS sensor channel descriptions, units for each variable, sensor model information, the sensors data range limits, and links to appropriate Lufft manual for more information.

Average Air Temperature: air temperature, average (degrees Fahrenheit) during storm

Average Surface Temperature: road surface temperature, average (degrees Fahrenheit) during storm

[AVG_WIND]: wind speed, average (mph) during storm

CALM: if the average wind speed of a storm, AVG_WIND, was less than 6 mph, an indicator variable, CALM, was created and represented these storms.

Climate Zone

- Northern Tier **[NORTH]**
- Metro **[METRO]**
- Western Maryland **[WESTMD]**
- Southern Maryland
- Upper Shore **[USHORE]**
- Lower Shore

[DAY]: storms occurring completely within the 7:30am to 5pm time frame.

Maryland #: The Maryland Severe Weather Index Number (Maryland #) is a dependent variable, derived using: 1) the wet precipitation and 2) wind.

Month of Storm

- October [OCT]
- November [NOV]
- December **[DEC]**
- January **[JAN]**
- February [FEB]
- March [MAR]

NO_PRECIP_RATIO: The number of 5-minute time periods where no precipitation occurred was called NUM_NO_PRECIP. The total number of 5-minute time periods in a storm was called TOTAL_NUM. Therefore, the ratio of no precipitation 5-miute time periods to the total number of time periods was the NO_PRECIP_RATIO.

[NUM_NO_PRECIP]: Number of 5-minute observations without precipitation during storm

Storm: A "storm" was defined as pavement temperature at or below 35ºF and the presence of precipitation. A storm ended when precipitation has not occurred for 4 hours.

[STORM_DURATION]: length of storm in minutes

[TOTAL_NUM]: Number of storm observation that were only one 5-minute observation

UTC Times: Coordinated Universal Time

[WET_PRECIP]: wet precipitation total during storm in inches

Winter Season: October through March, example October – December 2017 through January – March 2018 would represent the 2017-2018 winter season.

Table 36. Summary table of RWIS sensor channel description, units, model, data range, and links to the Lufft manual.

Sensor channels used for MDSHA SmartView - Aug. 2018							
Channel Description	**Value**	**Units**	**Sensor Model**	**Channel Number**	**Min value**	**Max value**	**Link to manual**
air temp	act	f	WS300	105	-58	140	https://www.lufft.com/download/manual-lufft-wsx-weather-sensor-en/
dew point	act	f	WS300	115	-58	140	
rel hum	act	%	WS300	200	0	100	
air pressure	act	hPa	WS300	300	300	1200	
wind speed	max	mph	WS200	450	0	167.8	https://www.lufft.com/download/manual-lufft-wsx-weather-sensor-en/
wind speed	avg	mph	WS200	410	0	167.8	
wind direction	act	degree	WS200	500	0	359.9	
wind direction	max	degree	WS200	540	0	359.9	
precip dif	act	mil	R2S	631	0	3937	https://www.lufft.com/download/manual-lufft-r2s-umb-en/
precip type	act	none	R2S	700	0	255	
road surface temp	act	F	IRS31 Pro	102	-40	176	https://www.lufft.com/download/manual-lufft-irs31pro-umb-en/
freeze temp	act	F	IRS31 Pro	152	-40	0	
water film height	act	mil	IRS31 Pro	602	0	393.7	
salt concentration	act	%	IRS31 Pro	801	0	100	
road condition	act	none	IRS31 Pro	900	0	99	
salt concentration	act	lbs per lar	IRS31 Pro	920	0	1280	
sub surface temp	act	F	IRS31 Pro	112	-40	176	
Visibility	average	miles	VS2K	656	0.006	0.6	https://www.lufft.com/download/manual-lufft-vs2kvs20k-en/
Visibility	act	miles	VS2K	606	0.006	0.6	
Visibility	act	feet	VS2K	604	32	3000	
Road Temperature	act	F	NIRS31	101	-40	158	https://www.lufft.com/download/manual-lufft-nirs31-umb-en/
Freezing Temperature	act	F	NIRS31	111	-40	32	
Water fIlm Height	act	mil	NIRS31	605	0	78.7	
Saline Concentration	act	%	NIRS31	810	0	100	
Road Condition	act	none	NIRS31	900	0	99	

Figures for Each Variable

The data that was process and the calculated variables are shown in the figures below. When interpreting the figures below it is important to note that the figure is a map of Maryland, broken down into defined climate zones (Figure 61). The figures show varying size dots of different colors, these dots represent unique RWIS sites across the state of Maryland. For each dot the size indicates the quantity of data that was used to determine the value – such that the larger the dot the more storms worth of data were available (see the Legend in each figure for the defined number of storm events tied to the dot size). The color of each dot is associated with value shown in each figure (see the Legend in each figure for the defined color and data range associated with it).

All maps are classified using natural breaks (jenks), this method creates classes based on the natural groupings inherent in the data. Class breaks are identified in a manner that best groups similar values and that maximizes the differences between classes (ESRI). The figures show data as the mean, median, minimum, and maximum values. By showing the mean you see the average values. In many cases the mean values are skewed by a few high values, therefore we show the median value, or the middle value if all the data were lined up, where half of the data/values are larger, and half are smaller. Both the median and the mean describe the central tendency of the data but means can be skewed very high or very low values. The median values are typically lower than the mean values because for many variables there are significantly more lower values. By showing the minimum and maximum values you can see the range of the data/values.

Maryland Index

The Maryland Index number (5.4.1.1 Maryland #) variable is based on precipitation and wind values and is shown in Figure 61, Figure 62, Figure 63, and Figure 64. Overall, the central portion of the Northern Tier seems have higher Maryland Index values.

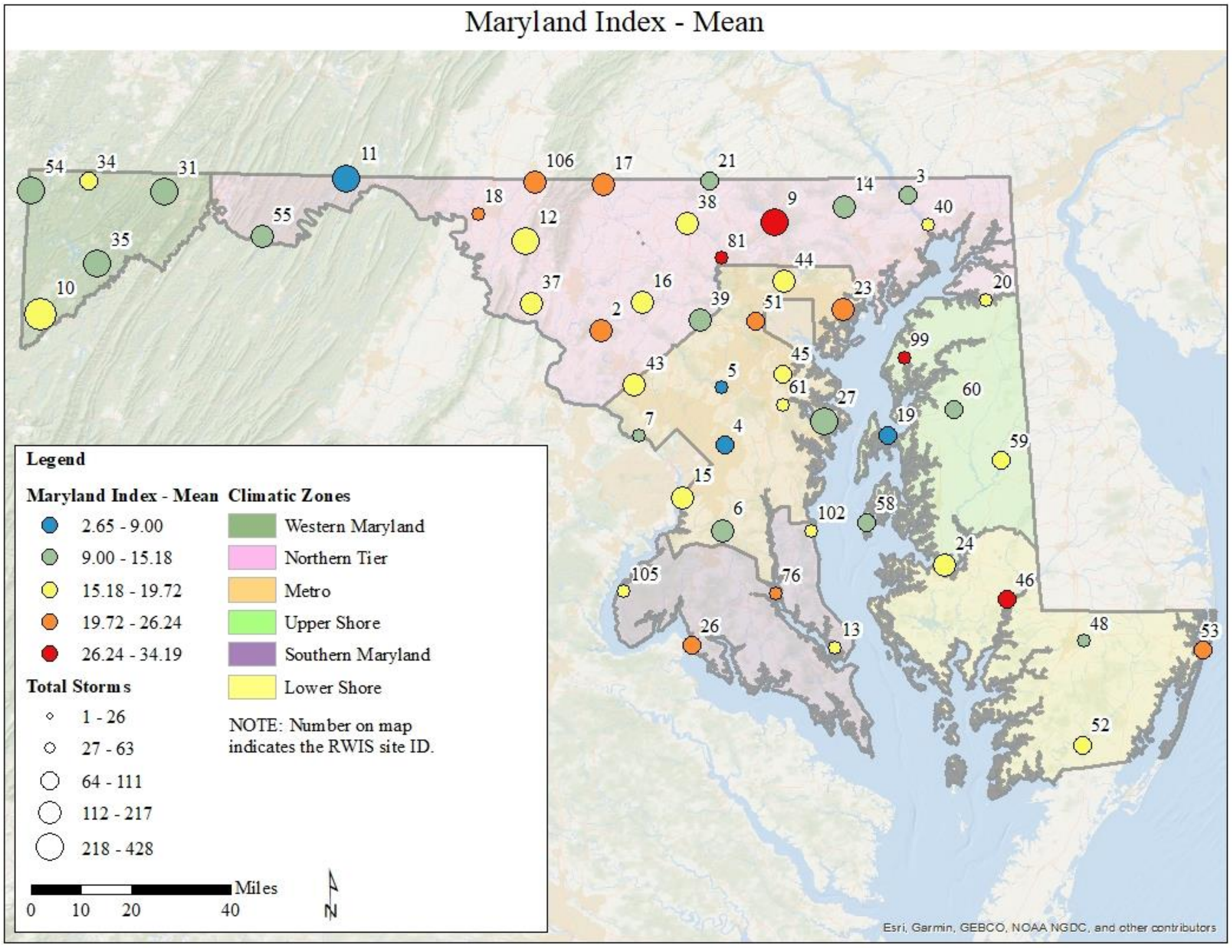


Figure 61. Shows the mean Maryland Index number from all data collected from 2012-2019 in the state of Maryland.

Mean

The Maryland Index number mean values ranged from 2.65 to 34.19. No major geographic patterns can be observed in Figure 61, though the central portion of the Northern Tier trends towards higher Maryland Index number values.

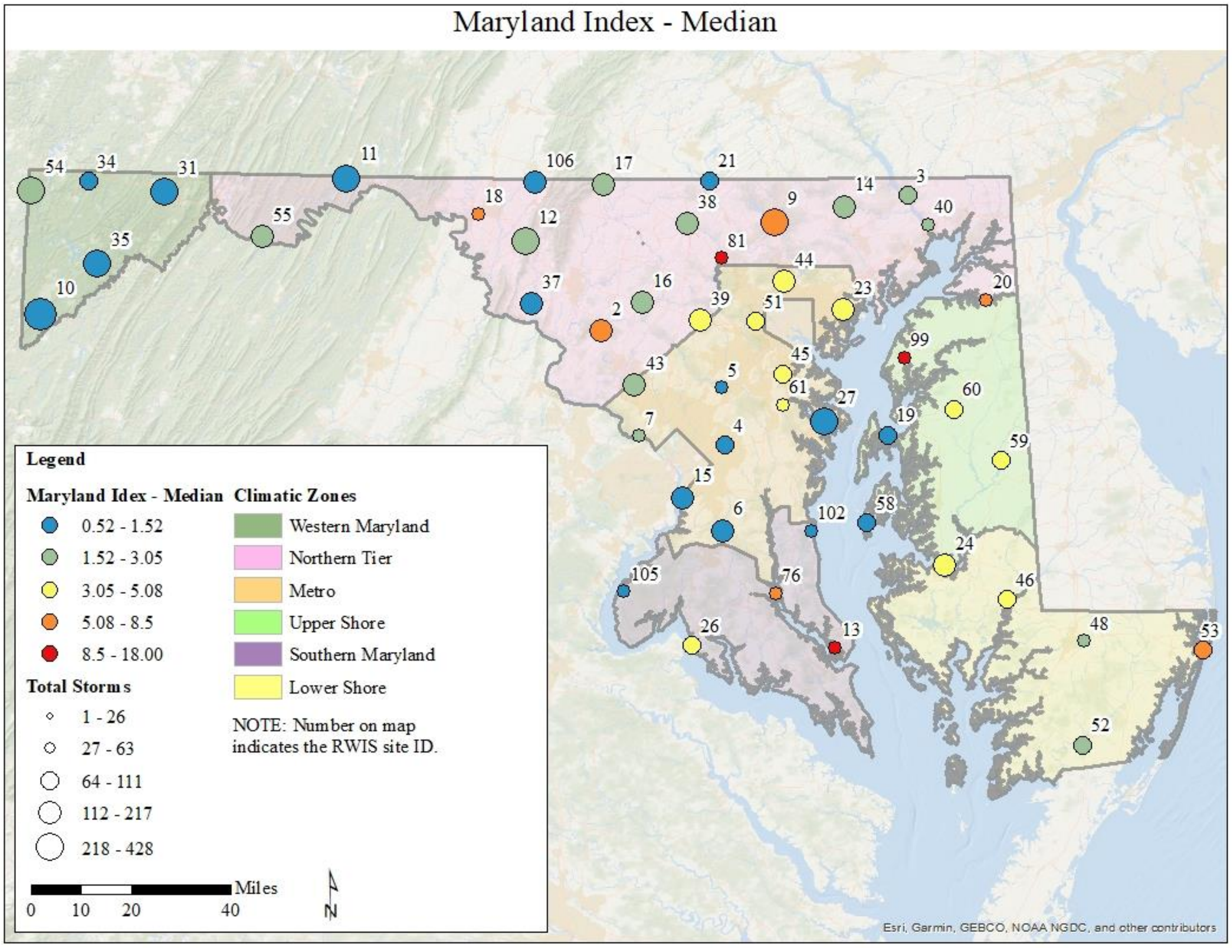


Figure 62. Shows the median Maryland Index number from all data collected from 2012-2019 in the state of Maryland.

Median

The Maryland Index number median values ranged from 0.52 to 18. The Western portion of the state tends to have lower values, as well as the southern portion of the Metro climate zone (Figure 62). There is a cluster of moderate to higher Maryland Index number values around the north-eastern portion of the Metro climate zone.

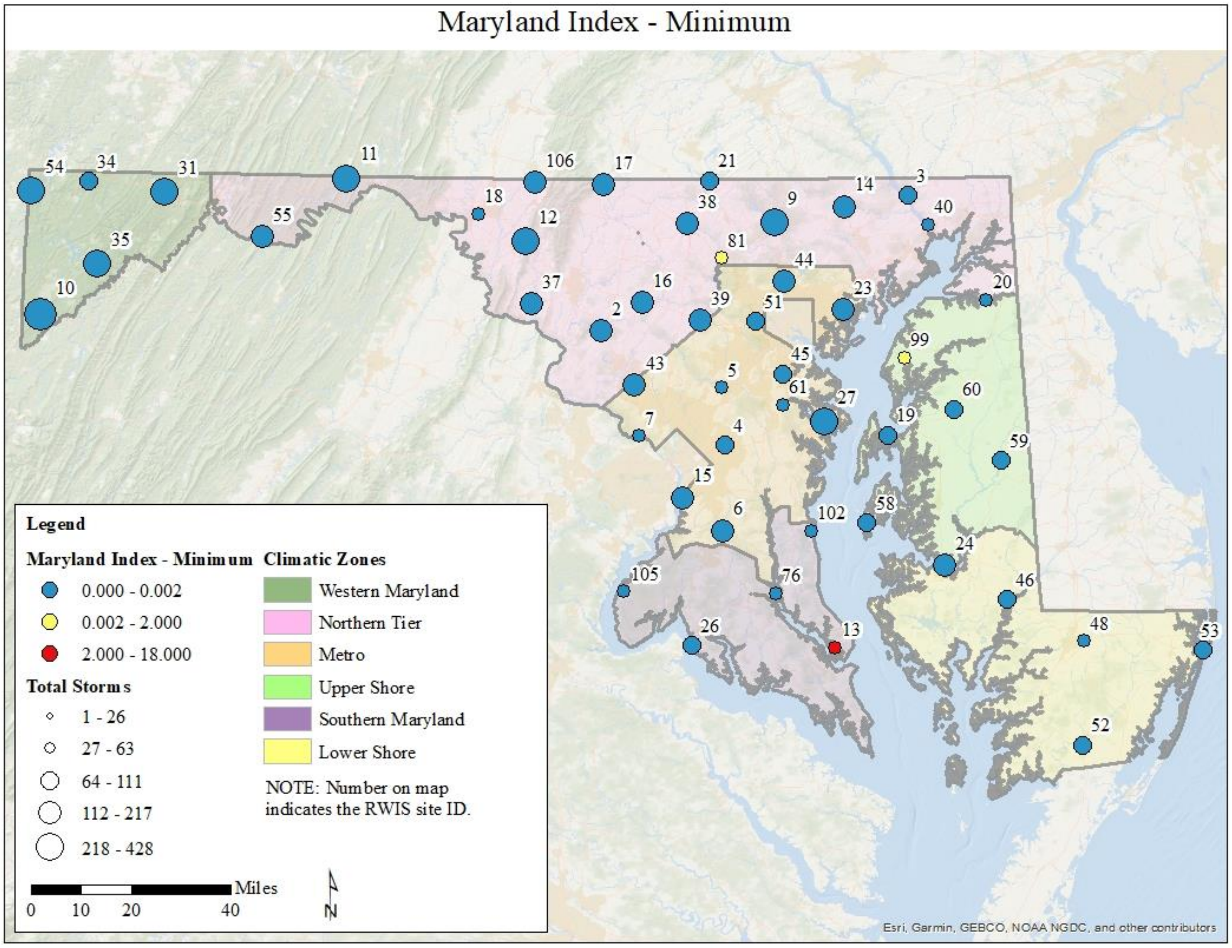


Figure 63. Shows the minimum Maryland Index number from all data collected from 2012-2019 in the state of Maryland.

Minimum

The Maryland Index number minimum values ranged from 0 to 18. RWIS site 13, the small red dot in the Southern Maryland climate zone, is skewing the overall data classifications for this variable (Figure 63). If RWIS site 13 were removed, the minimum Maryland Index number values would range between 0 and 2. The majority of RWIS sites have minimum Maryland Index numbers in the 0.000 to 0.002 range (blue dot). RWIS site 81 in the Northern Tier climate zone and RWIS site 99 in the Upper Shore climate zone are at the moderate end, whereas RWIS site 13 in the Southern Maryland climate zone has the highest value at 18. Note that RWIS sites 13, 99, and 81 all have small dot, meaning less data supports these results.

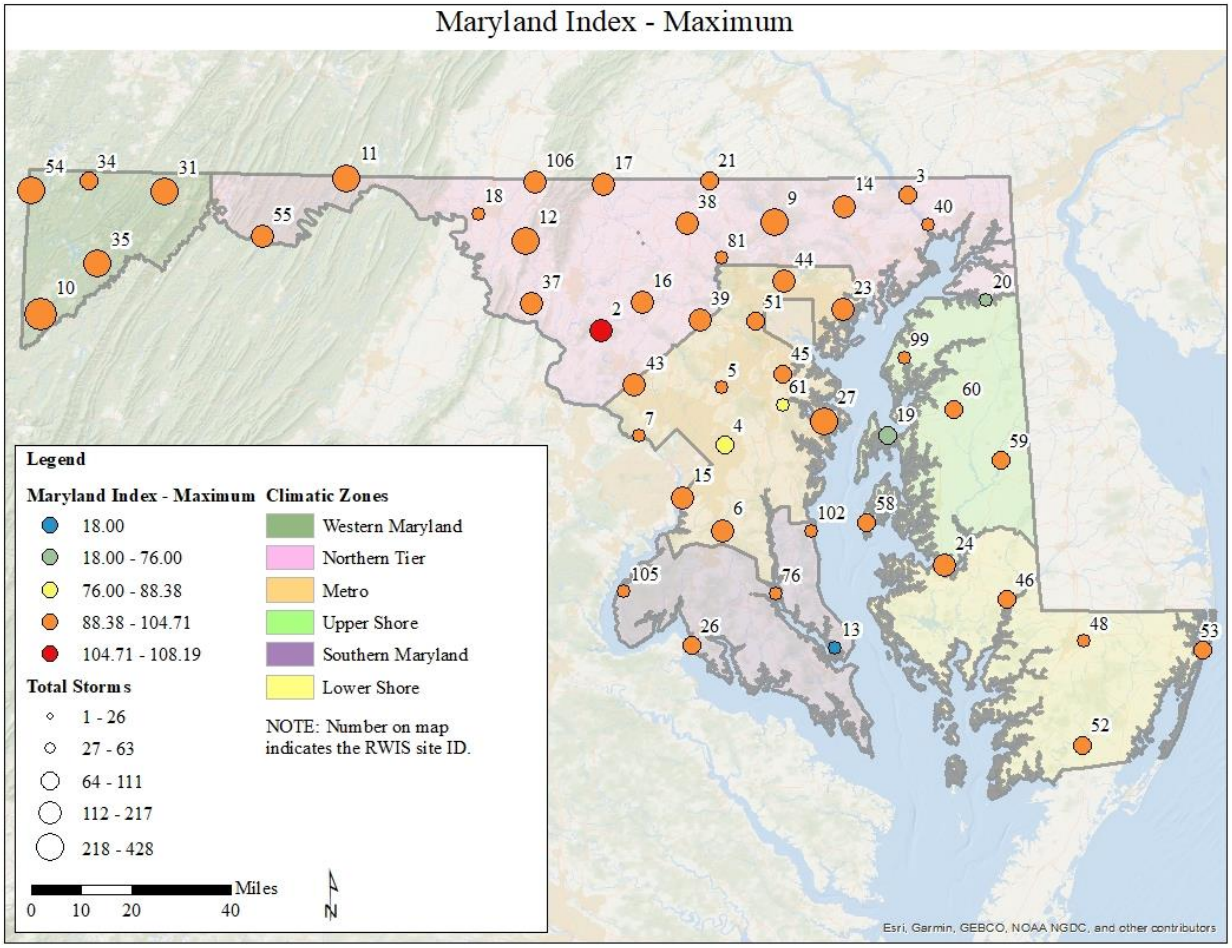


Figure 64. Shows the maximum Maryland Index number from all data collected from 2012-2019 in the state of Maryland.

Maximum

The Maryland Index number maximum values ranged from 18 to 108.19. Again, RWIS site 13 may be skewing the maximum Maryland Index number classifications but on the low end now (Figure 64). If RWIS site 13 was removed, the Maryland Index number values would range between 76 and 108.19. The majority of RWIS sites range from 88 to 104.71 (orange dot). RWIS site 2 in the Northern Tier climate zone has the highest maximum Maryland Index number value at 108.19.

Number of Storms by Month of Winter Season Historically

The number of storms that occurred are shown by month and year. Note that a winter season was defined as October through March. Data from the month of April was also processed where available but insufficient data was present to include in the model. As data is massed overtime, it may be feasible to include April storm data in future iterations of the SWI model.

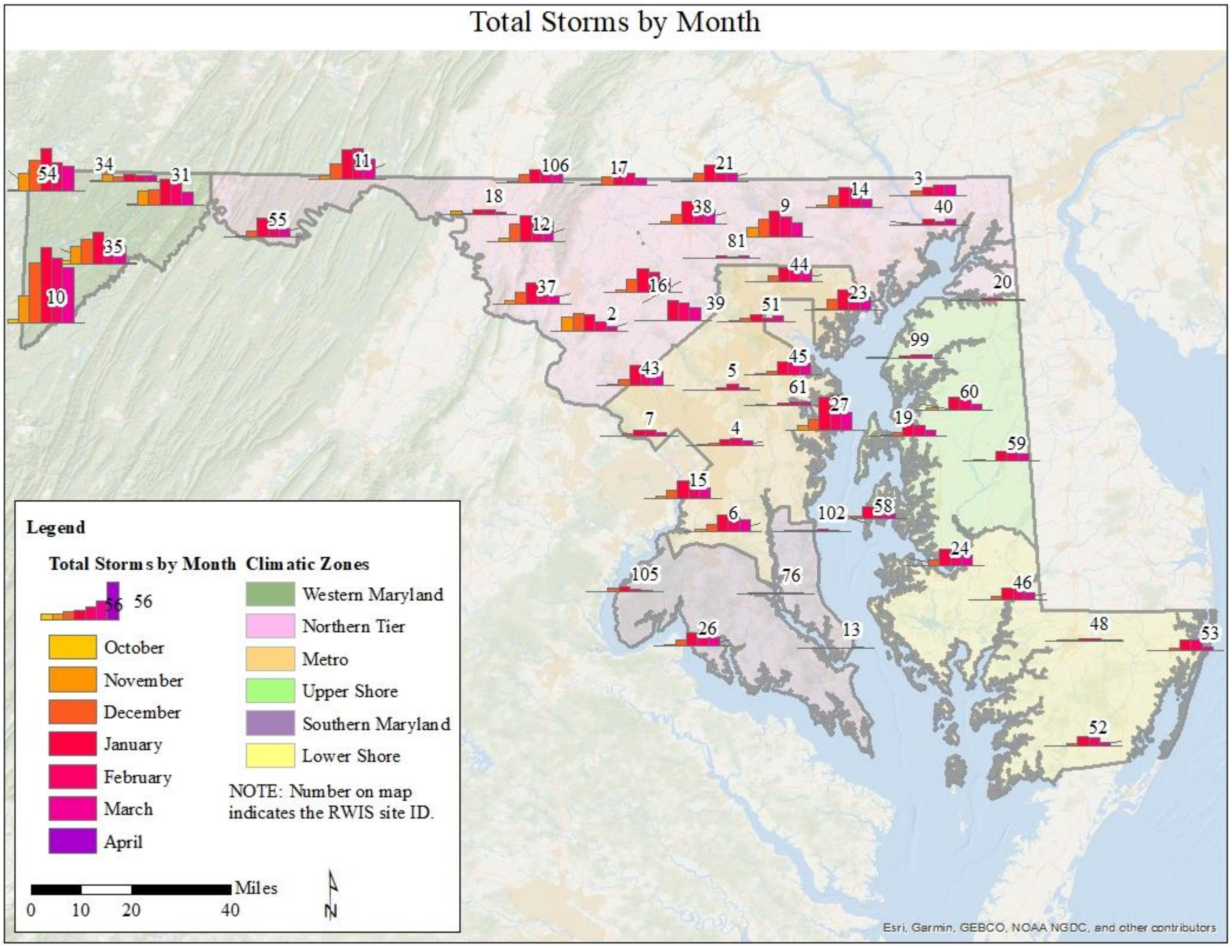


Figure 65. Shows the total number of storms per month from all data collected from 2012-2019 in the state of Maryland.

Storms by Month

Figure 65 shows a summary of the total number of storm events per month identified at each RWIS site in Maryland. The majority of RWIS sites have a peak number of storms in January with the number of storms slowly declining into February and March. Note from the **Error! Reference source not found.** that the months of October and April did not have significant (sufficient) numbers of storm events to be considered in the model, which can be observed in Figure 65.

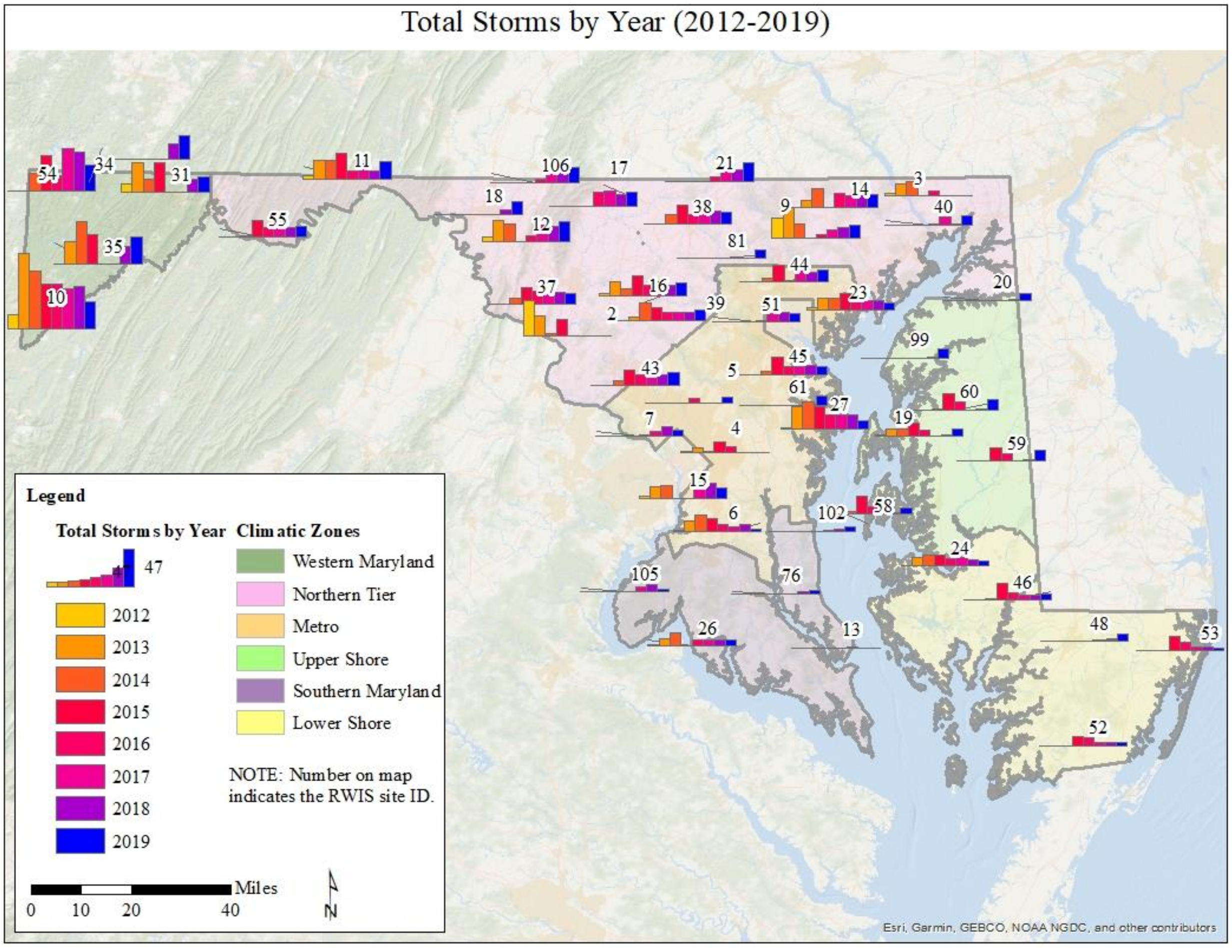


Figure 66. Shows the total number of storms per year from 2012-2019 in the state of Maryland.

Storms by Year

Figure 66 shows a summary of the total number of storm events per year identified at each RWIS site in Maryland. Generally speaking, the western part of the state - the Western Maryland and Northern Tier climate zones, experienced more storms each year than the rest of the RWIS sites across the state, with a few exceptions (RWIS site 27).

Precipitation Intensity During a Storm Event

Total number of 5-Minute Observations during a storm with precipitation

To determine the intensity of precipitation during storm event the total number of 5-minute observations was considered and is shown as mean, median, minimum, and maximum values in Figure 67, Figure 68, Figure 69, and Figure 70. Generally, these figures show the Western Maryland climate zone to have lower total number of observations with precipitation; and the central portion of the Northern Tier climate zone and north-eastern portion of the Metro climate zone seems to have higher total number of observations with precipitation.

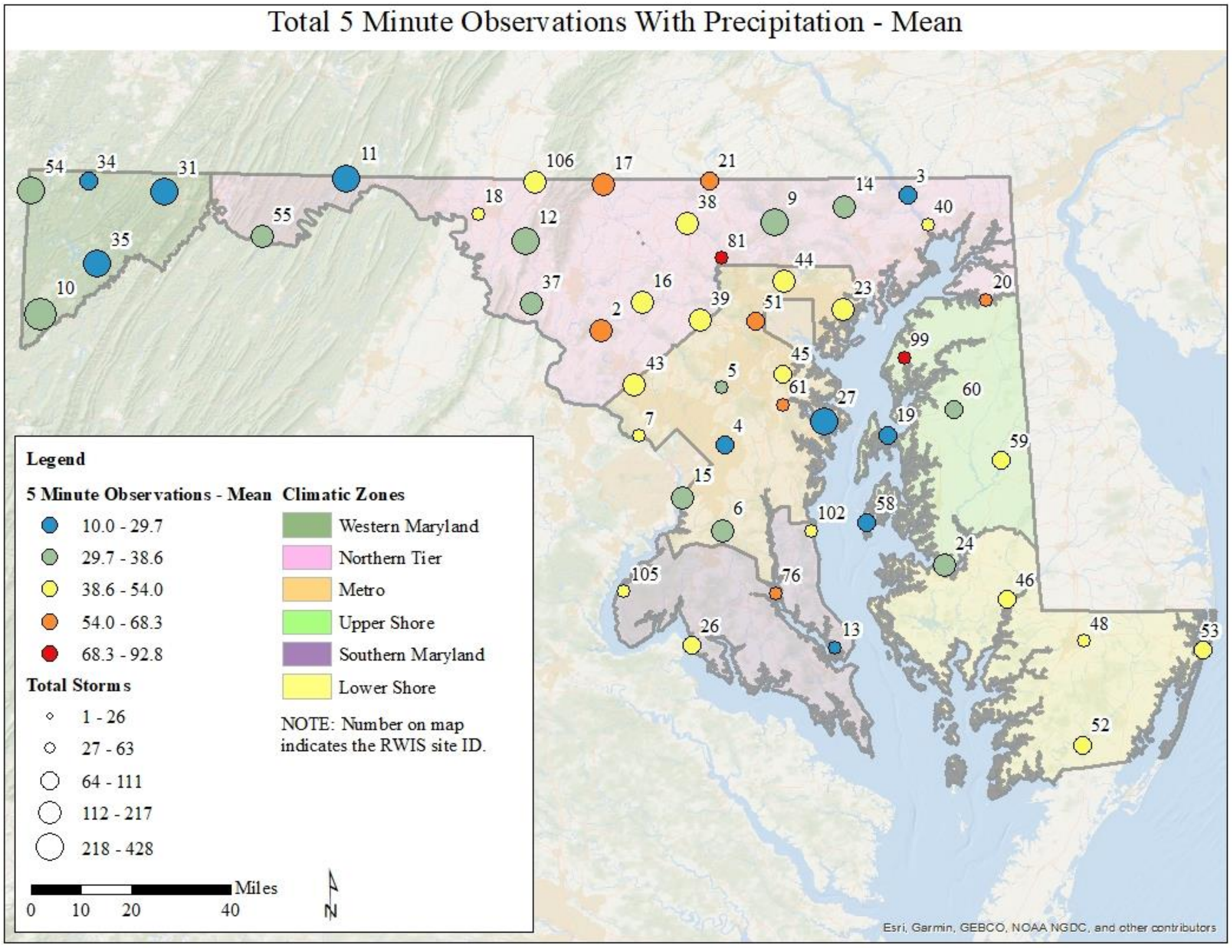


Figure 67. Shows the mean of total number of 5-minute observations with precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Mean

The mean number of total 5-minute precipitation observations ranged from 10 to 92.8 (Figure 67). RWIS sites in the Western Maryland climate zone and the western portion of the Northern Tier climate zone have lower mean values for the total number of 5-minute precipitation observations. The central portion of the Northern Tier climate zone shows higher mean values for the total number of 5-minute precipitation observations ranging from 38.6 to 92.8 observations.

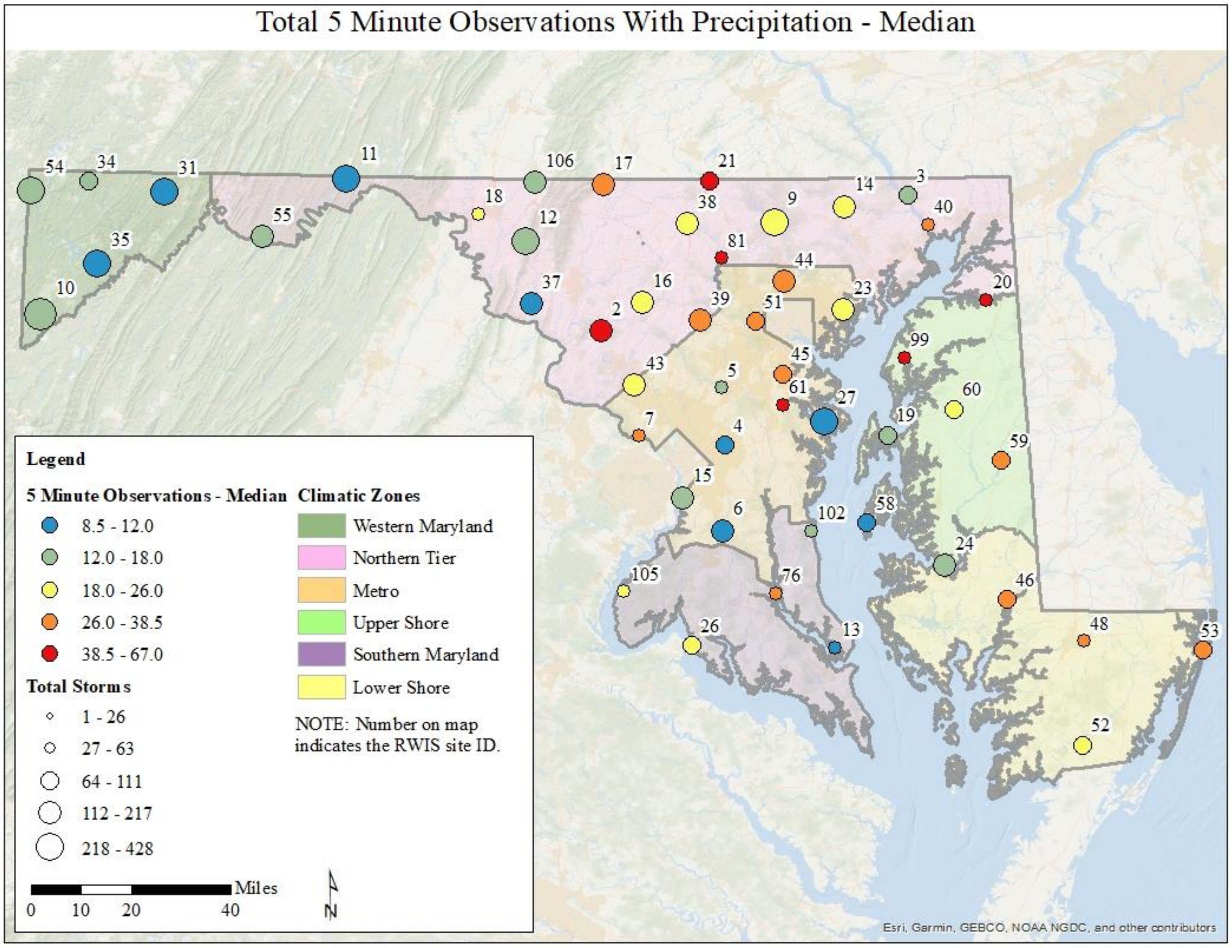


Figure 68. Shows the median of total number of 5-minute observations with precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Median

The median number of total 5-minute precipitation observations ranged from 8.5 to 67 (Figure 68). The central portion of the state had higher median values for the total number of 5-minute precipitation observations, in particular the central portion of the Northern Tier climate zone and the northern portion of the Metro climate zone. The eastern portion of the state shows higher median values for the total number of 5-minute precipitation observations, ranging from 26 to 67 observations. The Western Maryland climate zone and the southern portion of the Metro climate zone show lower median values for the total number of 5-minute precipitation observations.

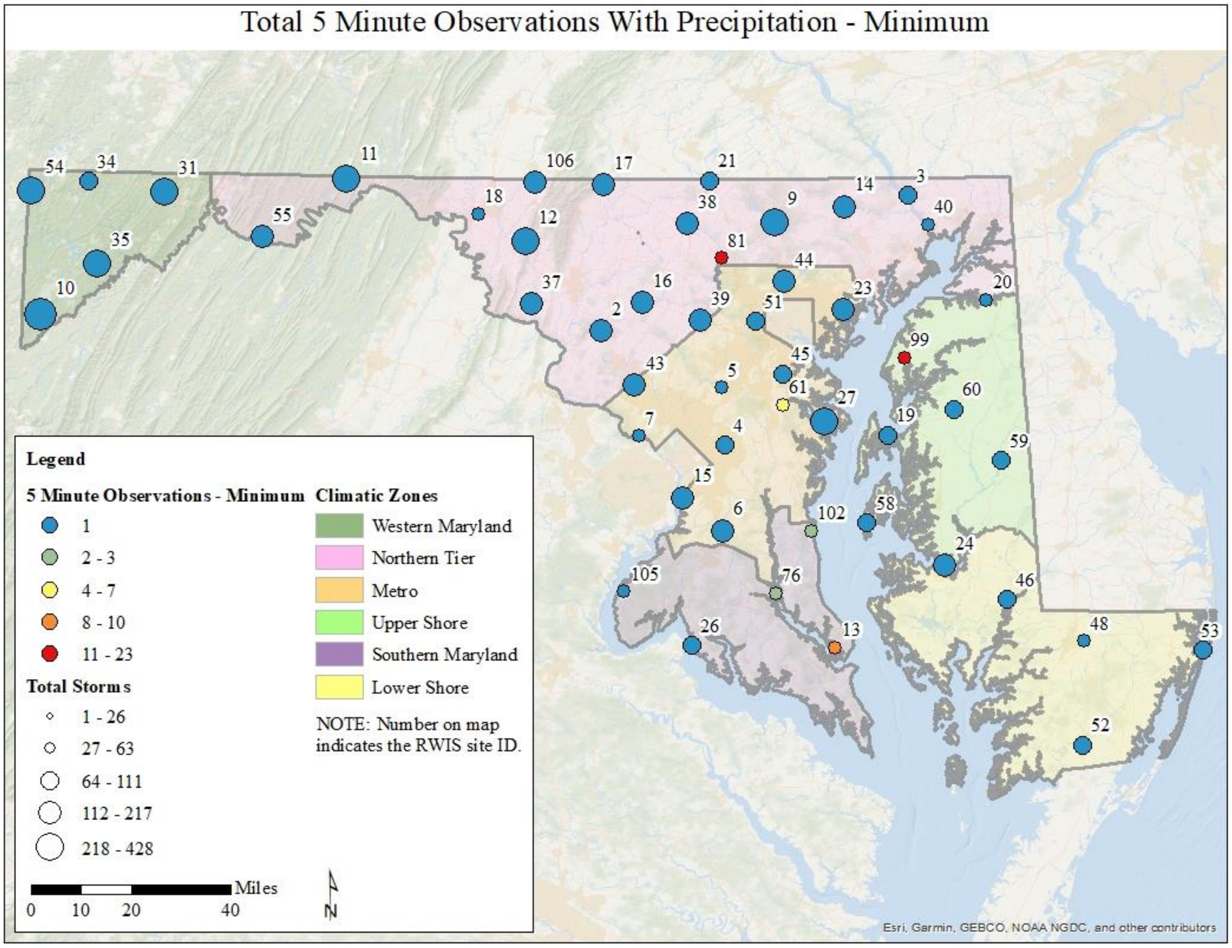


Figure 69. Shows the minimum number of total 5-minute observations with precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Minimum

The minimum number of total 5-minute precipitation observations ranged from 1 to 23 (Figure 69). The majority of minimum total number of 5-minute precipitation observations have one observation (blue dot). The north-east portion of the Southern Maryland climate zone shows the minimum number total number of 5-minute precipitation observations ranging from 2 to 10, with a few sites scattered in the Metro and Upper Shore climate zones having higher minimum number of total 5-minute precipitation observations as well.

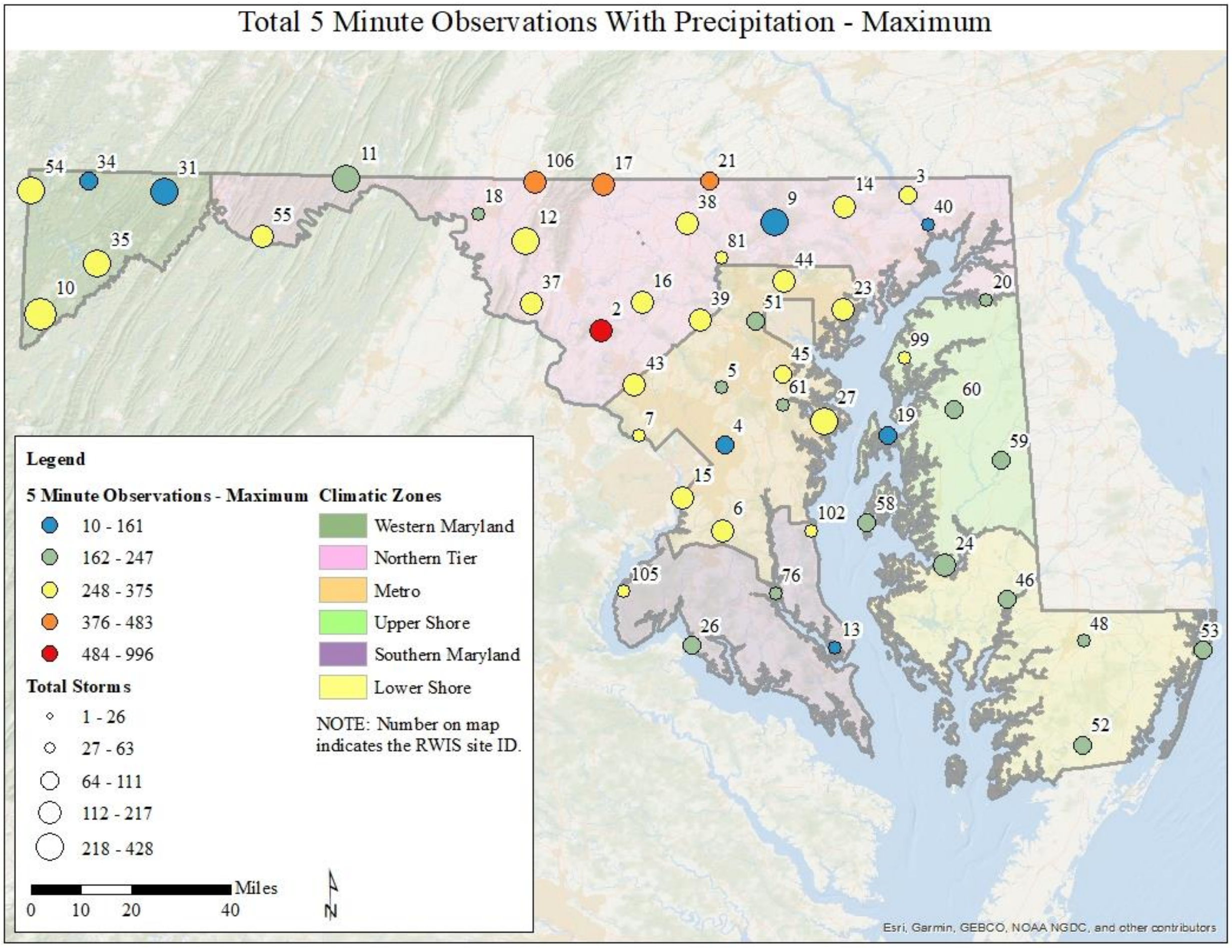


Figure 70. Shows the maximum number of total 5-minute observations with precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Maximum

The maximum number of total 5-minute precipitation observations ranged from 10 to 996 (Figure 70). RWIS site 2 in the Northern Tier climate zone has the highest number of total 5-minute precipitation observations and the area surrounding RWIS site 2 has similarly higher maximum number of total 5-minute precipitation observations. The Upper and Lower Shore climate zones all have maximum number of total 5-minute precipitation observations on the lower end of the data set.

Total Number of 5 minutes No Precipitation Observations During a Storm

To determine the intensity of precipitation during storm events the number of total 5-minute observations with no precipitation was considered and is shown as the mean, median, minimum, and maximum values in Figure 71, Figure 72, Figure 73, and Figure 74. Looking at the median values, the Western Maryland climate zone, the central portion of the Northern Tier climate zone, and the north-eastern portion of the Metro climate zone have greater numbers of 5-minute intervals during storm events with no precipitation. The Upper Shore and Lower Shore tend to have much lower numbers of 5-minute intervals during storm events with no precipitation.

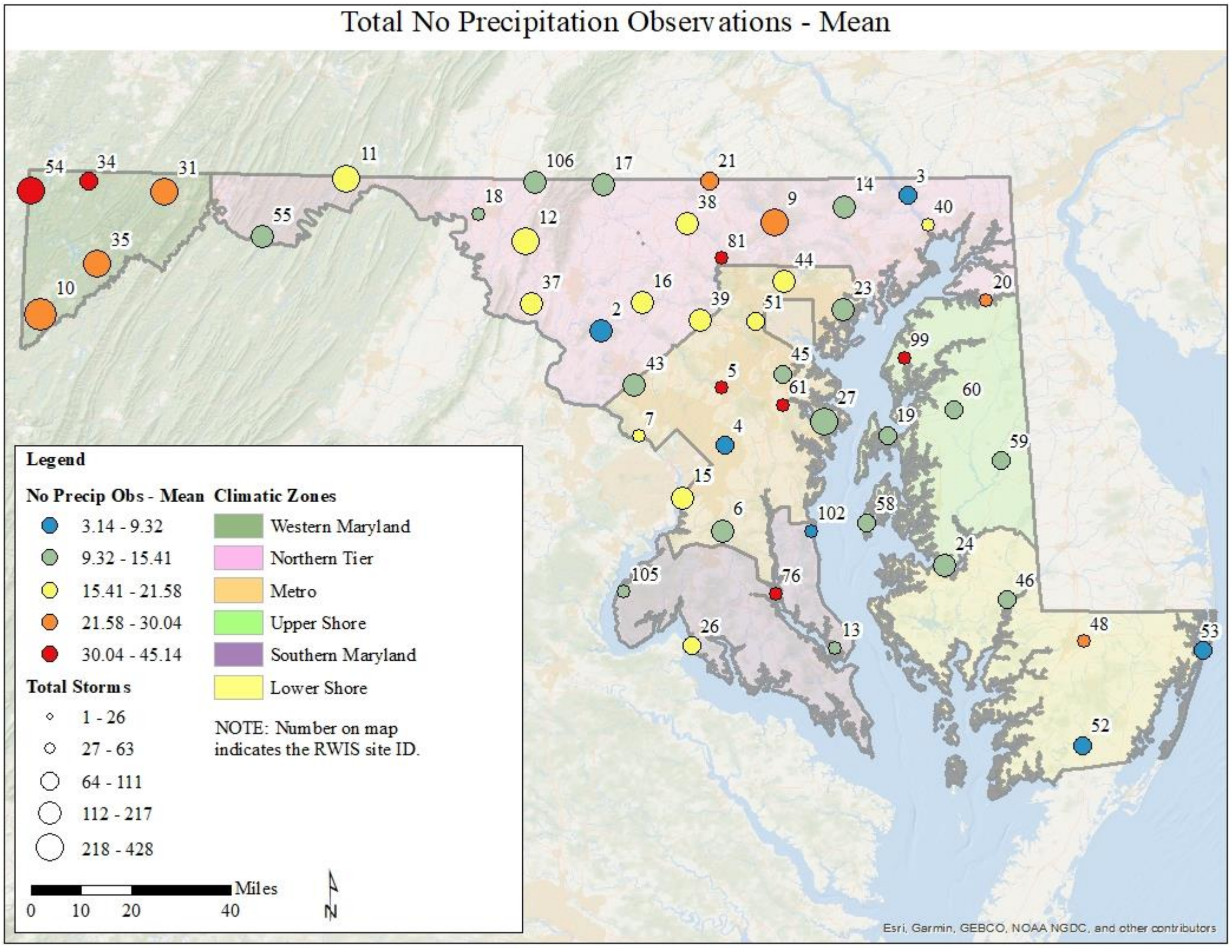


Figure 71. Shows the mean number of total 5-minute observations with no precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Mean

Mean number of total 5-minute with no precipitation observations ranged from 3.14 to 45.14 (Figure 71). The Western Maryland climate zone and the central portion of the Northern Tier climate zone have higher numbers of total 5-minute with no precipitation observations. The Upper Shore climate zone extending into the Lower Shore have much lower numbers of total 5-minute with no precipitation observations, with the exception of RWIS site 48.

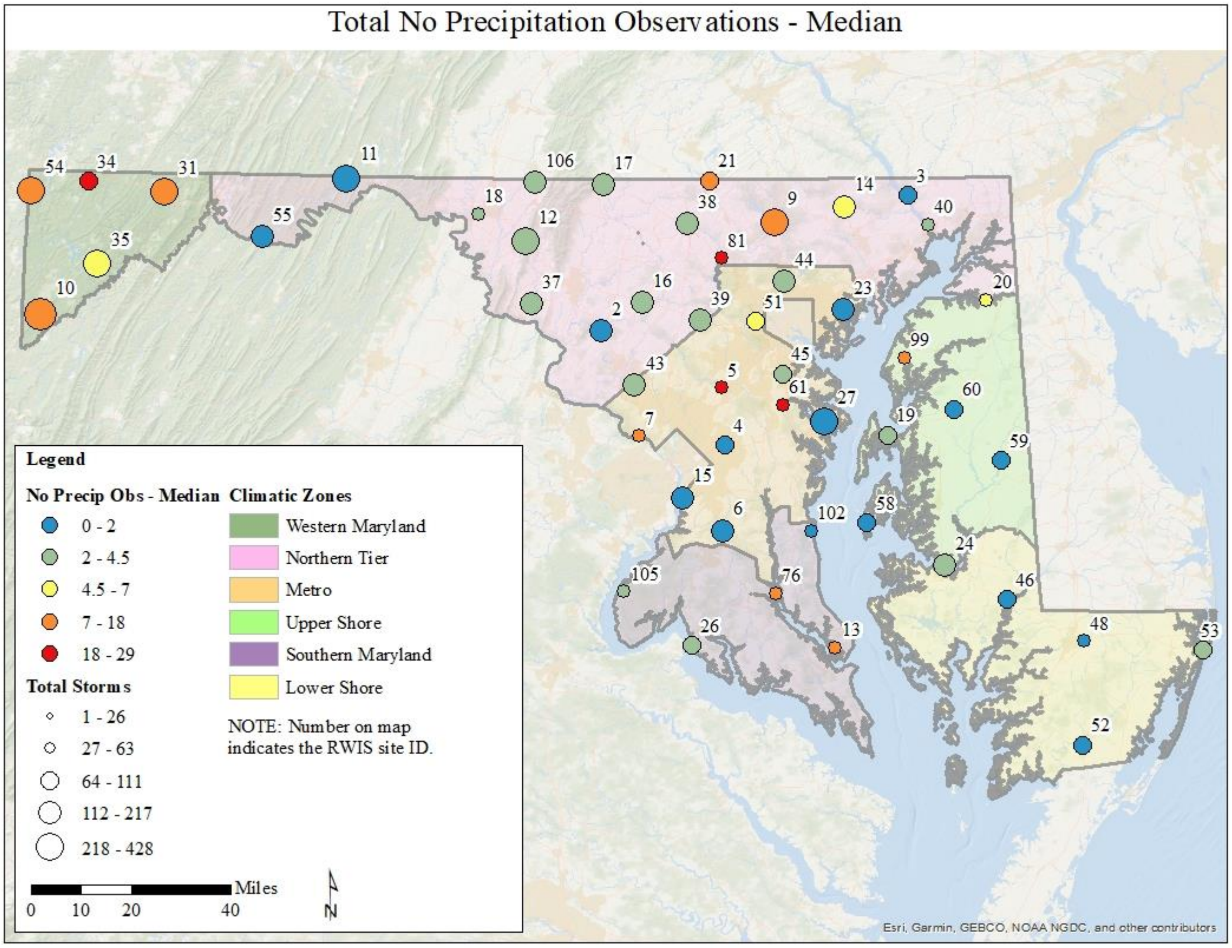


Figure 72. Shows the median number of total 5-minute observations with no precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Median

Median number of total 5-minute with no precipitation observations ranged from 0 to 29 (Figure 72). Similar to the map showing the mean values, the Western Maryland climate zone and the central portion of the Northern Tier climate zone have a greater number of total 5-minute with no precipitation observations. The southern portion of the state has lower number of total 5-minute with no precipitation observations.

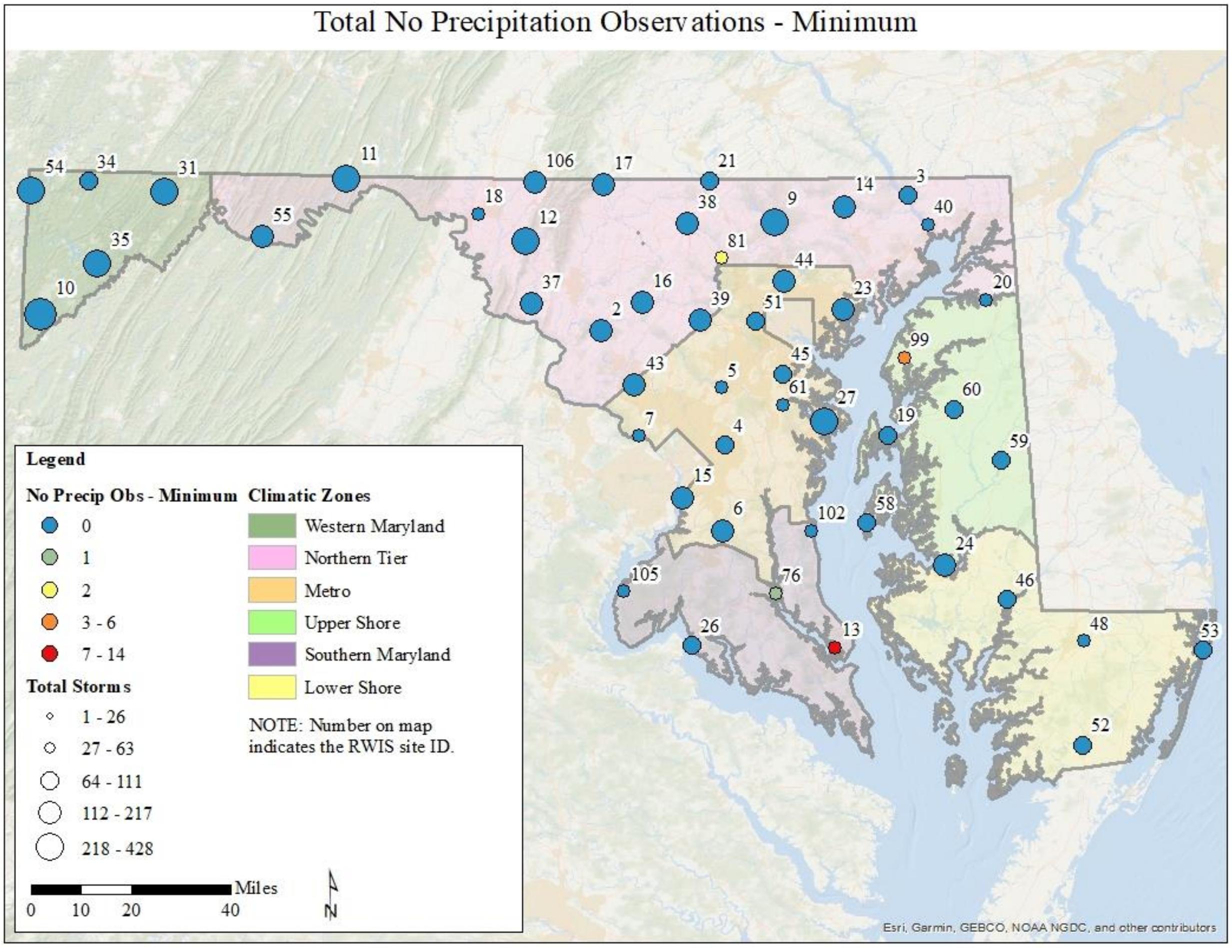


Figure 73. Shows the minimum number of total 5-minute observations with no precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Minimum

Minimum number of total 5-minute with no precipitation observations ranged from 0 to 14 (Figure 73). The majority of RWIS sites have a 0 value for the number of total 5-minute with no precipitation observations, with the exception of RWIS sites 13, 76, 81, and 99 – though it should be noted that these sites all have a lower number of total storms shown as smaller dot size.

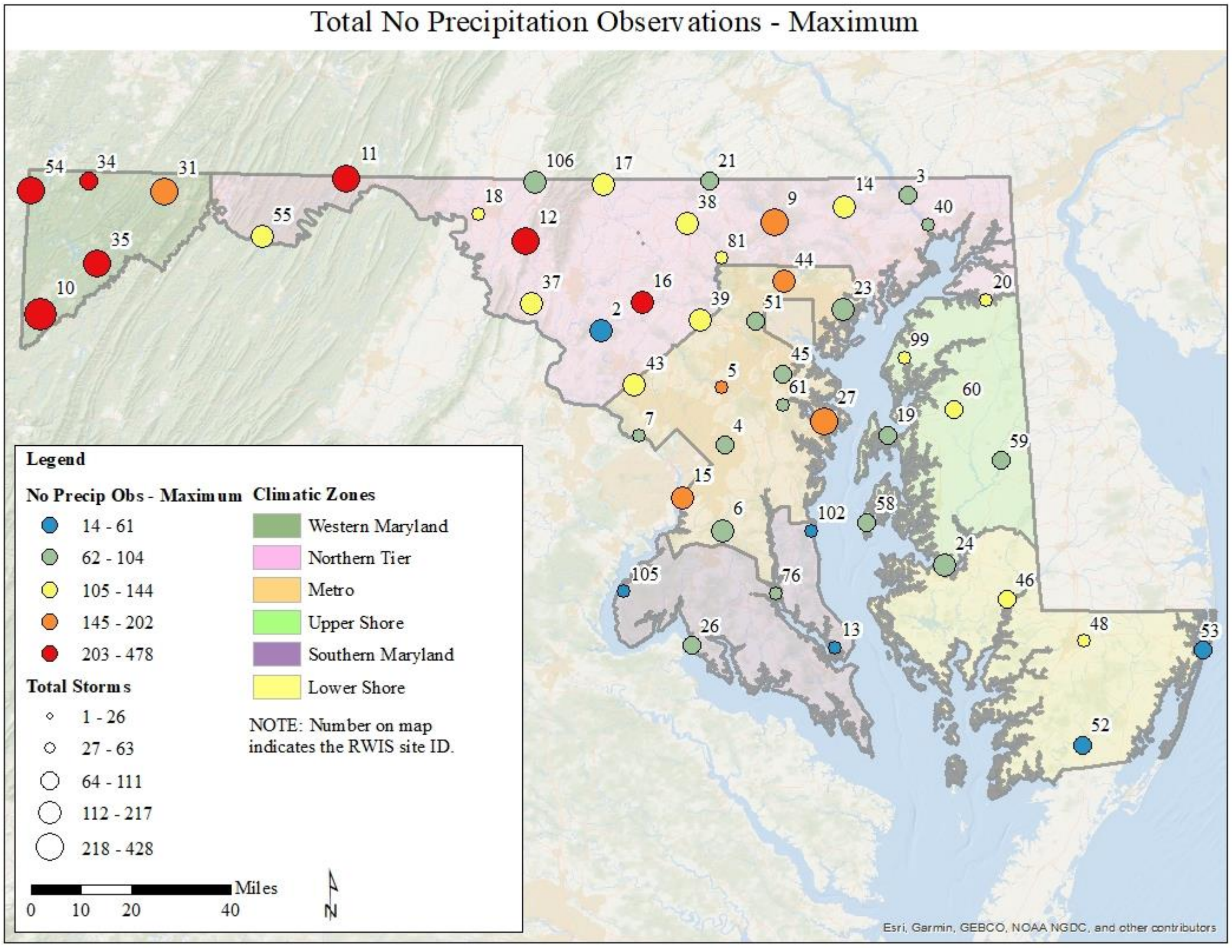


Figure 74. Shows the maximum number of total 5-minute observations with no precipitation during a storm event from all data collected from 2012-2019 in the state of Maryland.

Maximum

Maximum number of total 5-minute with no precipitation observations ranged from 14 to 478 (Figure 74). The Western Maryland climate zone extending into the western portion of the Northern tier have the highest number of total 5-minute with no precipitation observations. The rest of the state has maximum values in the middle of the range with the southern portion of the state having some of the lowest maximum number of total 5-minute with no precipitation observations.

Total Observations

To determine the duration of storm events the total observations (both with and without precipitation) was considered and is shown as the mean, median, minimum, and maximum values in Figure 75, Figure 76, Figure 77, and Figure 78. Most of the state trends towards the mid-range of values for median total precipitation observations. There is a small cluster of sites in the north-west portion of the Northern Tier that have much lower total observations. The northern portion of the state maximum total observations are in general higher, when compared to the southern portion of the state.

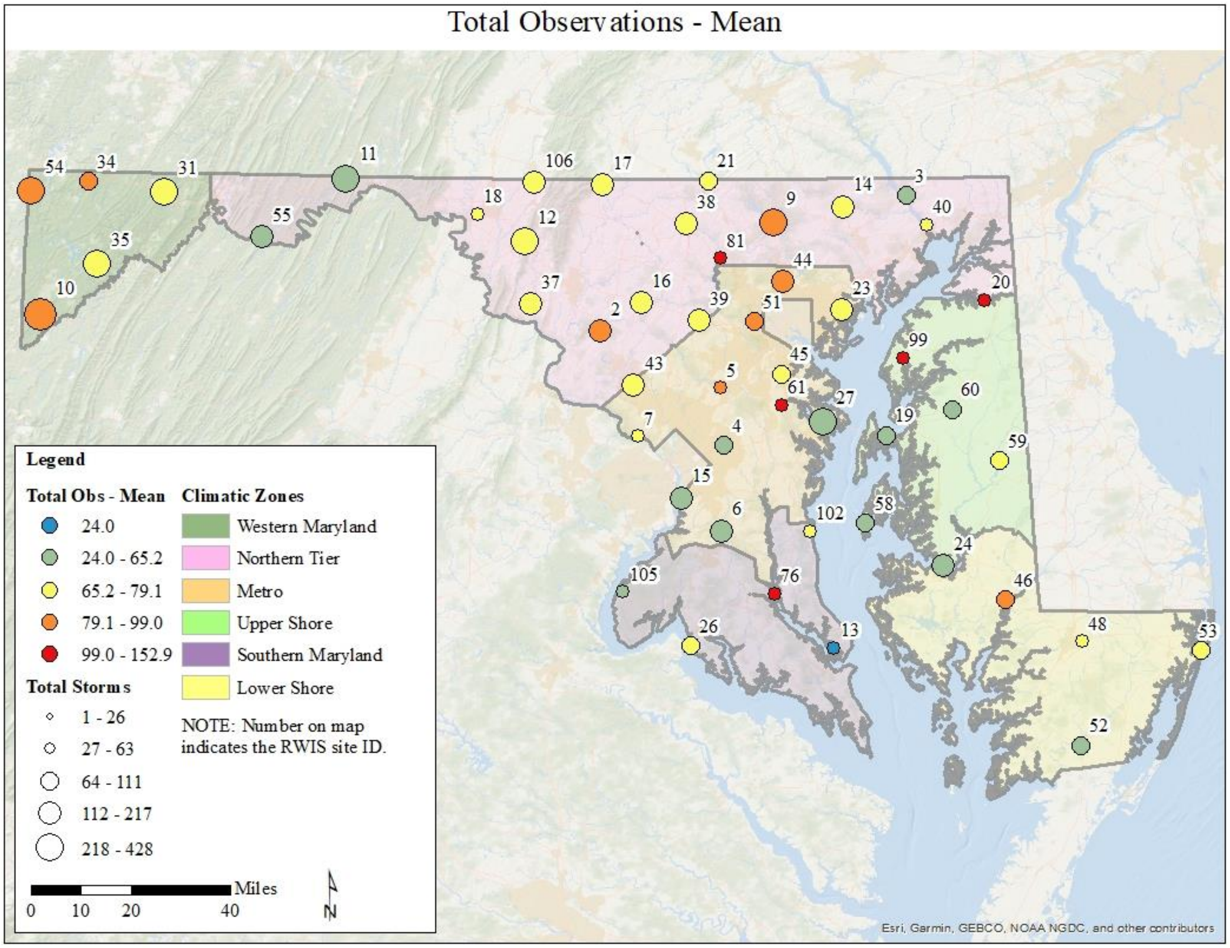


Figure 75. Shows the mean number of total observations from all data collected from 2012-2019 in the state of Maryland.

Mean

The mean number of total observations ranged from 24 to 152.9 (Figure 75). The majority of the state trends towards the mid-range total observations (24-99, or green, yellow, and orange dots). There are a few sites in the northern portions of the Metro and Upper Shore climate zone with higher numbers of total observations. Note that the RWIS sites with red dots (20, 61, 76, and 81) also are small and therefore note based on a large amount of data.

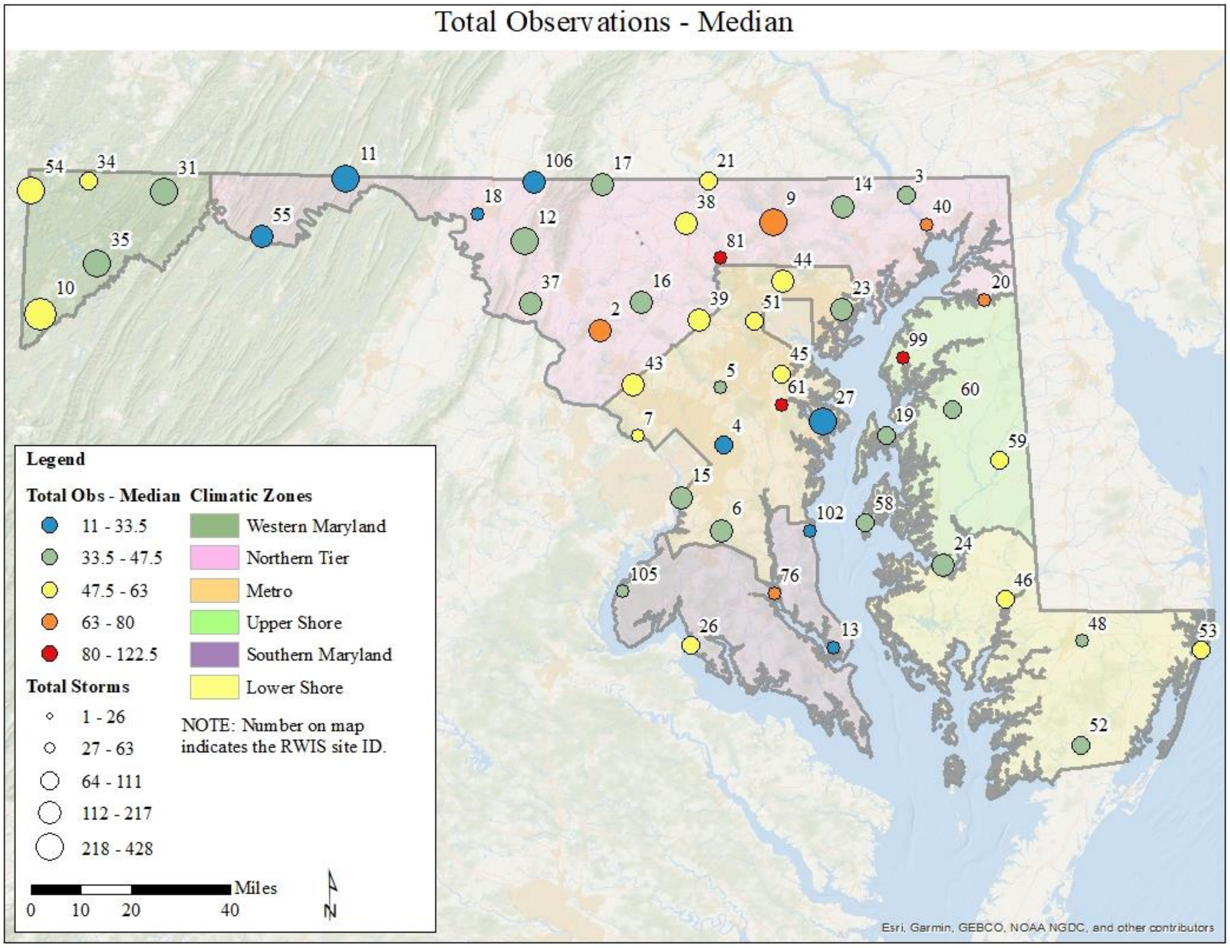


Figure 76. Shows the median number of total observations from all data collected from 2012-2019 in the state of Maryland.

Median

The median number of total precipitation observations ranged from 11 to 122.5 (Figure 76). In this figure, there appears to be greater variability in number of total precipitation observations across the state when compared to mean observations in Figure 75.

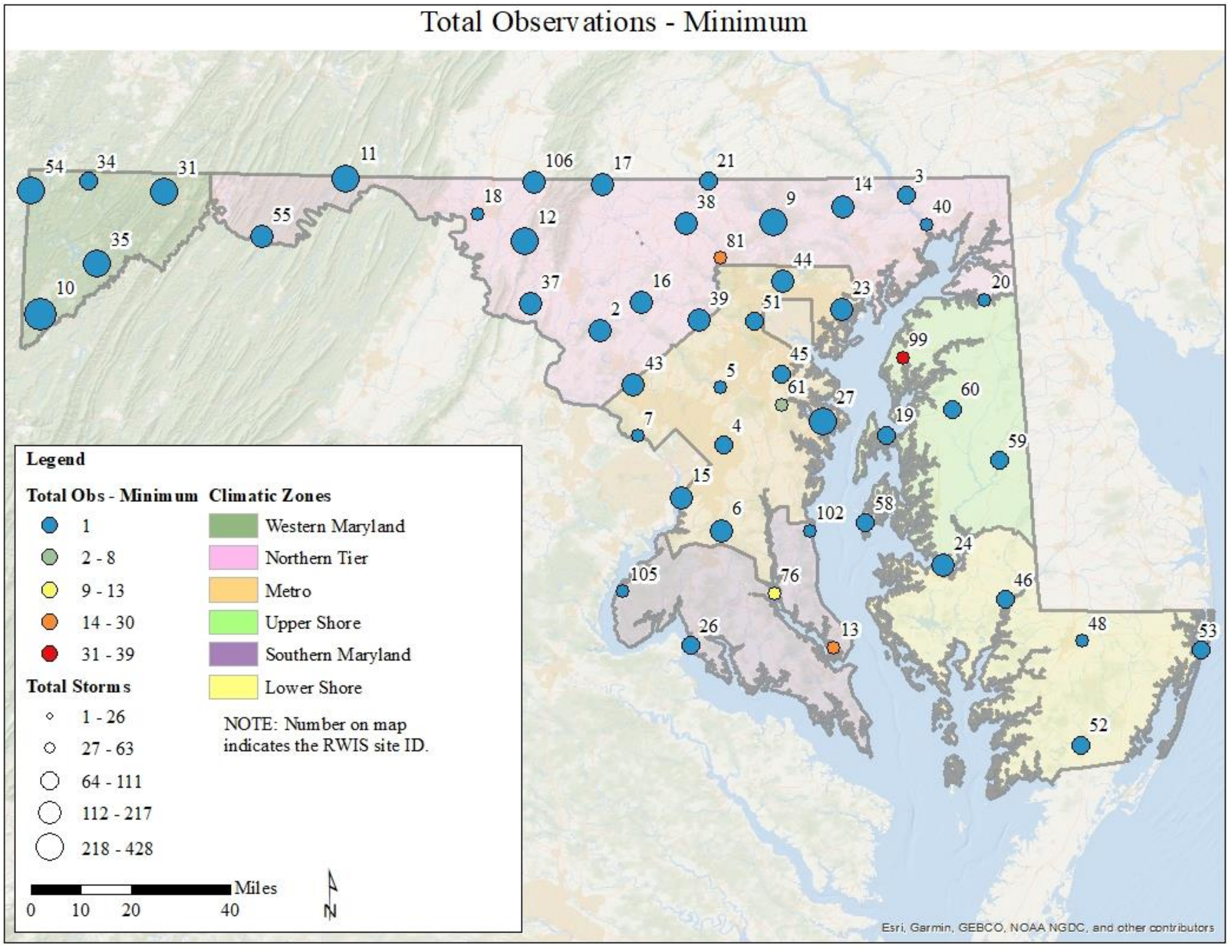


Figure 77. Shows the minimum number of total observations from all data collected from 2012-2019 in the state of Maryland.

Minimum

The minimum number of total observations ranged from 1 to 39 (Figure 77). The majority of RWIS sites across the state have a total observation value of "1", except for sites 13, 76, 81, and 99 – again, these sites all have a lower number of total storms which might be factor here.

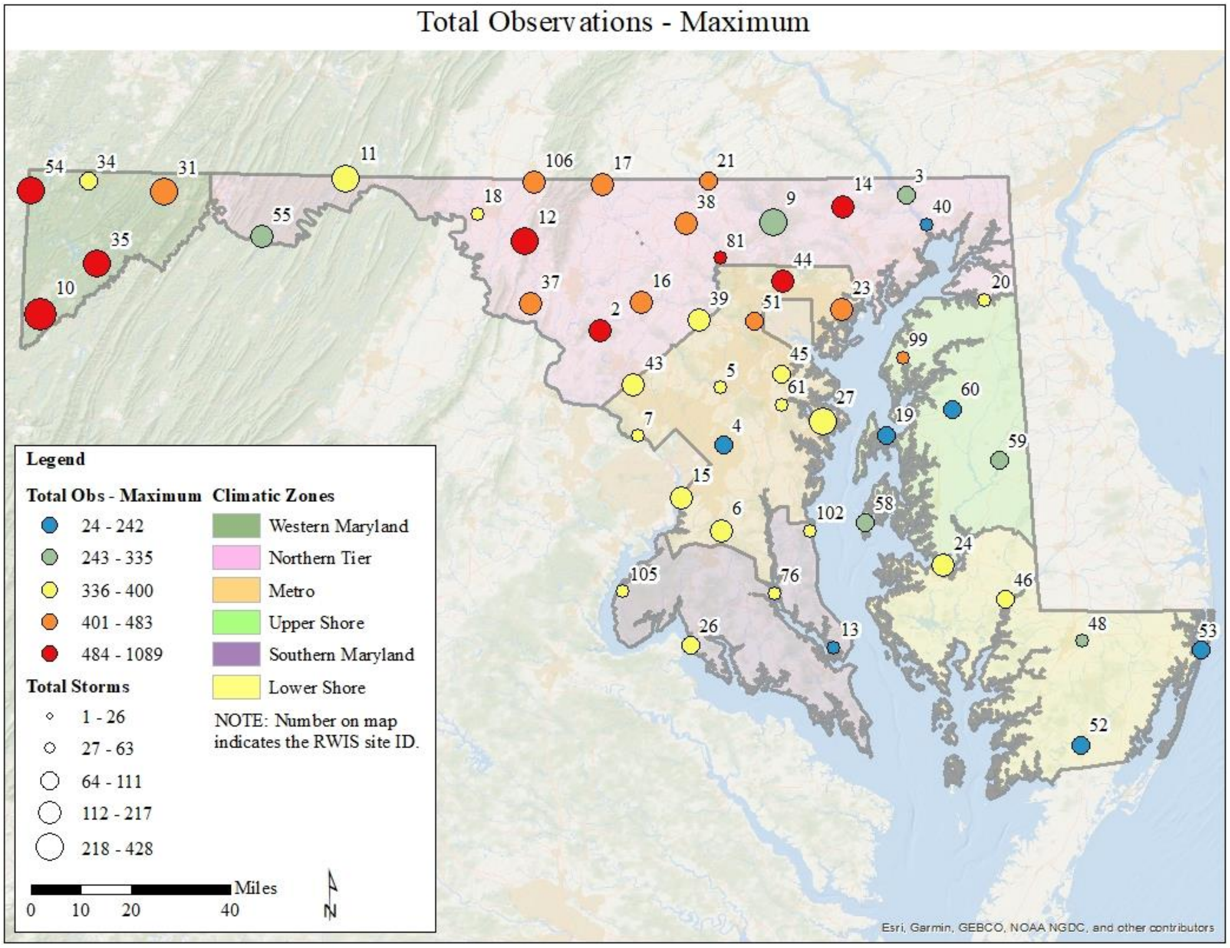


Figure 78. Shows the maximum number of total observations from all data collected from 2012-2019 in the state of Maryland.

Maximum

The maximum number of total observations ranged from 24 to 1,089 (Figure 78). The northern portion of the state tends to have higher maximum number of total observations compared to the southern portion of the state.

Wet Precipitation Total (inches)

The total precipitation, or wet precipitation total in inches, is shown as the mean (Figure 79), median (Figure 80), minimum (Figure 81), and maximum (Figure 82). Overall, more storm events (larger dots) with precipitation occurred in the northern part of the state. The mean wet precipitation totals are skewed toward higher values, or more severe, with a few exceptions (RWIS sites 99 and 20 in the Upper Shore climate zone, 81 and 18 in the Northern Tier climate zone, and 13 in the Southern Maryland climate zone). The Western Maryland climate zone and the southern portion of the Metro climate zone have lower median wet precipitation values.

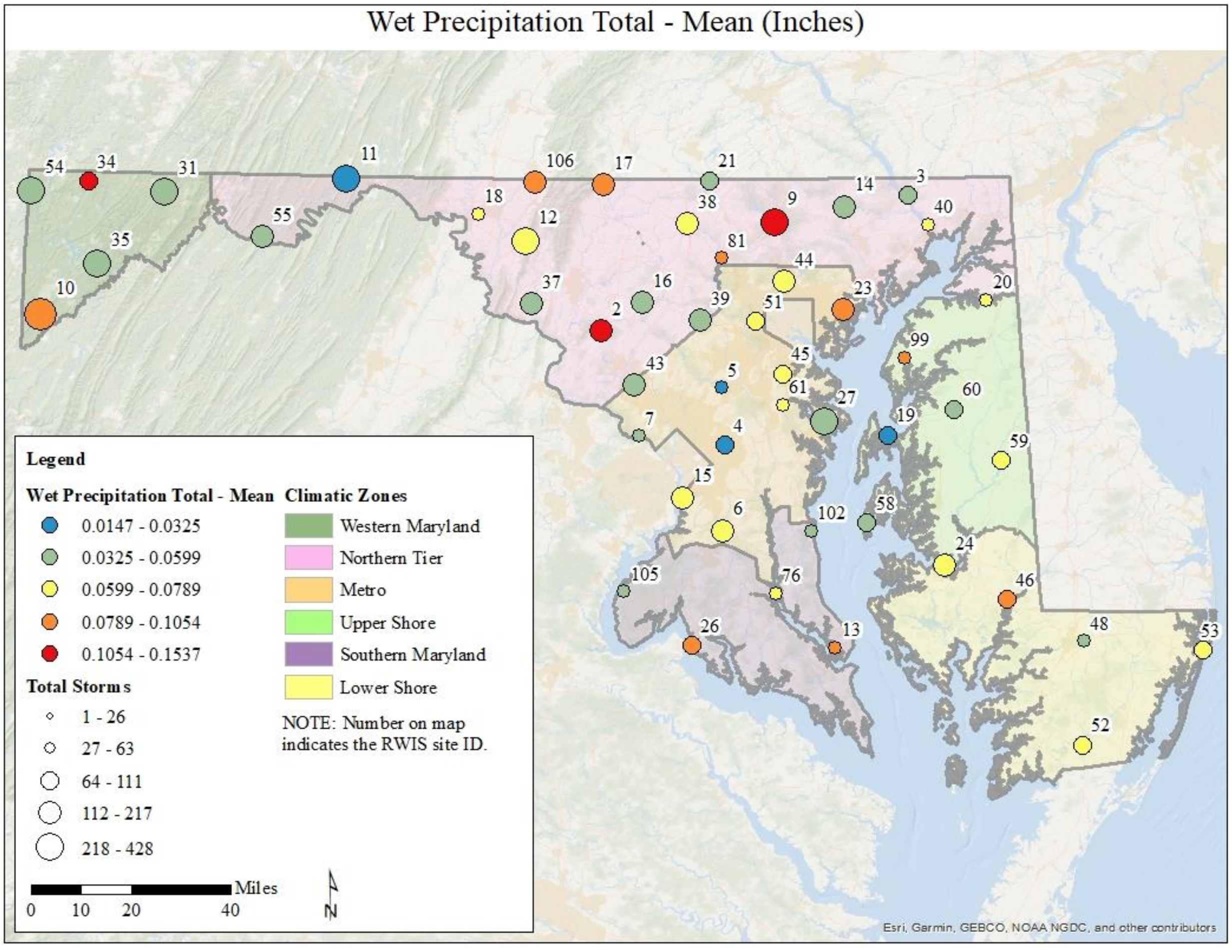


Figure 79. Shows the mean wet precipitation total in inches for all storm events at each RWIS location in Maryland from 2012-2019.

Mean

The mean wet precipitation totals ranged from 0.0147 to 0.1537 inches (Figure 79). The mean wet precipitation totals are highly variable across the state.

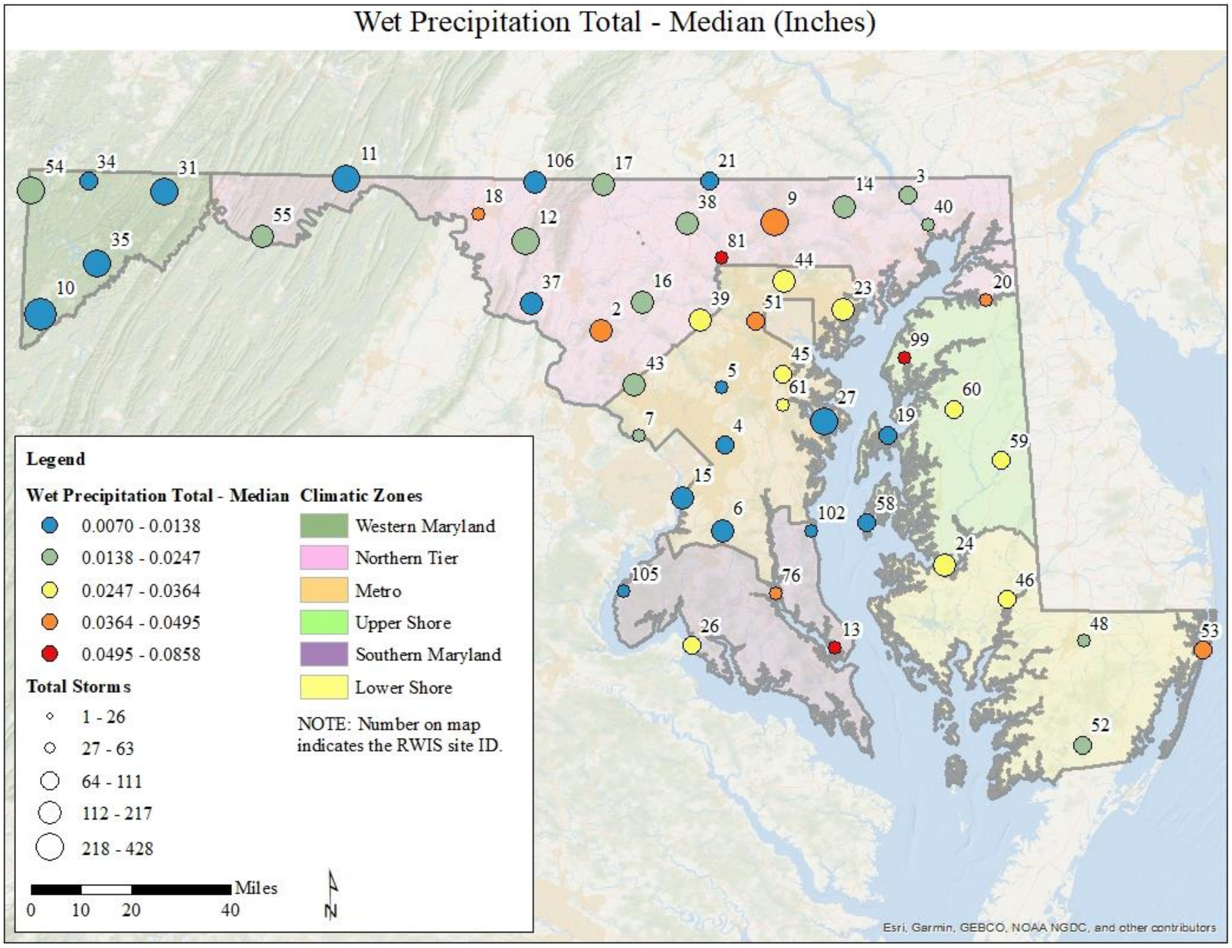


Figure 80. Shows the median wet precipitation total in inches for all storm events at each RWIS location in Maryland from 2012-2019.

Median

The median wet precipitation totals ranged from 0.0070 to 0.0858 inches (Figure 80). The Western Maryland climate zone and the southern portion of the Metro climate zone have lower median wet precipitation totals. As was mention previously, the median wet precipitation totals are lower for most RWIS sites when compared to the mean wet precipitation totals (Figure 79), due to lower overall values being skewed by a few higher values.

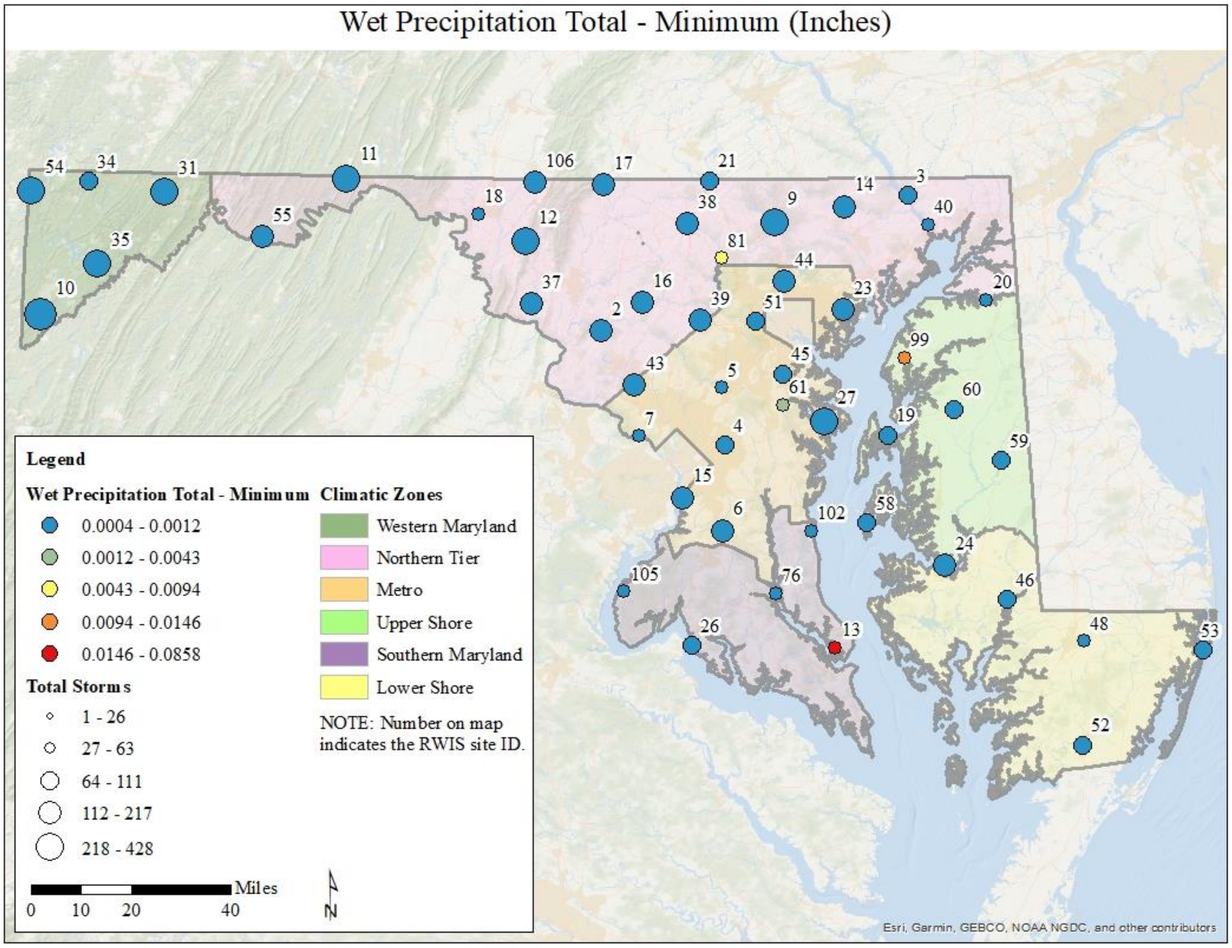


Figure 81. Shows the minimum wet precipitation total in inches for all storm events at each RWIS location in Maryland from 2012-2019.

Minimum

The minimum wet precipitation totals ranged from 0.0004 to 0.0858 inches (Figure 81). The majority of RWIS sites across the state have wet precipitation totals near the 0.0004 inches, with the except of RWIS sites 13, 61, 81, and 99 – though these sites have a fewer number of storms (smaller dots) which may be a factor here. The minimum wet precipitation totals are consistently low, and likely associated with the detection thresholds of the RWIS sensors.

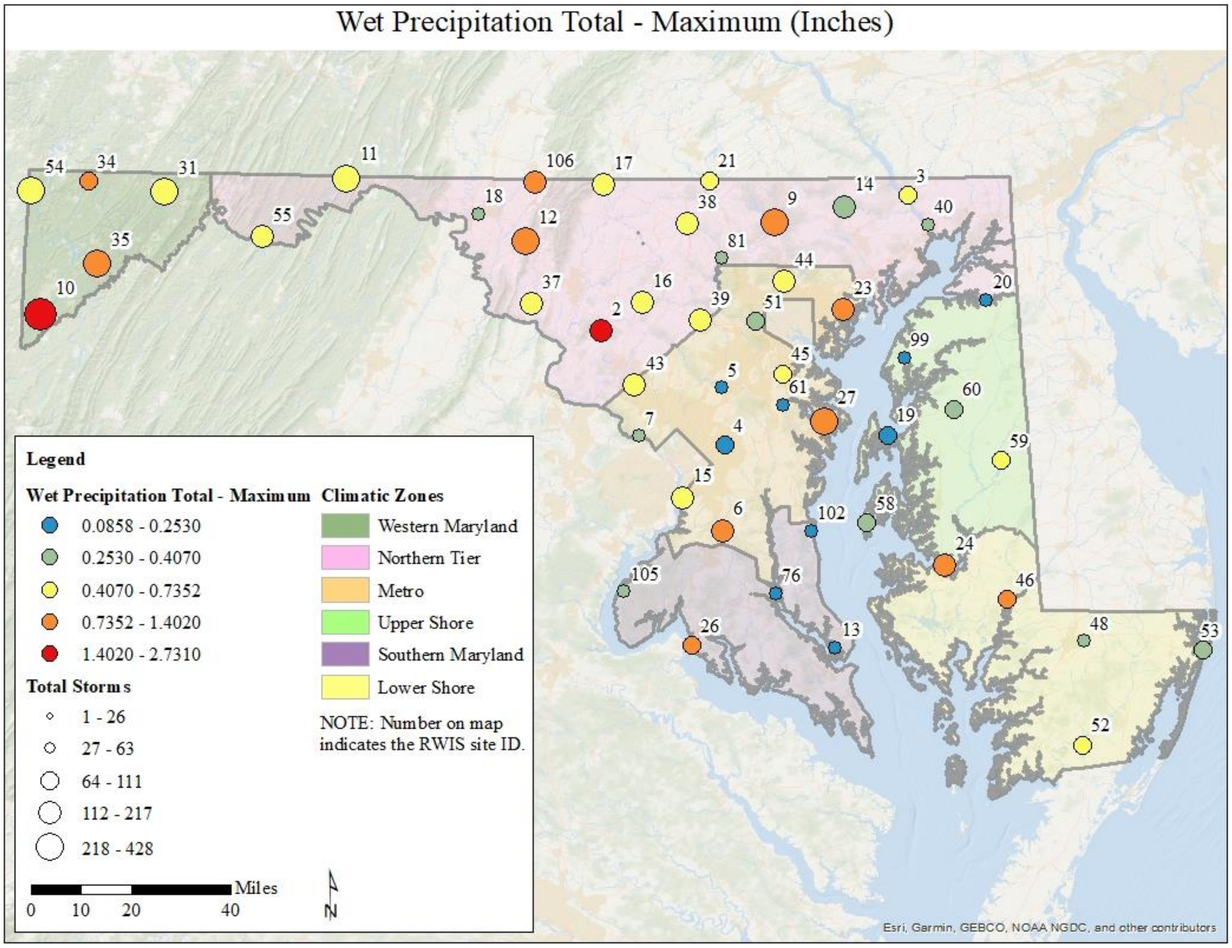


Figure 82. Shows the maximum wet precipitation total in inches for all storm events at each RWIS location in Maryland from 2012-2019.

Maximum

The maximum wet precipitation totals ranged from 0.0858 to 2.7310 inches (Figure 82). Most of the state has maximum wet precipitation total values toward the mid-range (0.404-1.402 inches). There is a cluster of lower maximum wet precipitation total values in the northern portion of the Southern Maryland climate zone and the southern portion of the Metro climate zone. Overall, the maximum wet precipitation totals are more highly variable across the state.

Wind Speed

Average Gust Speed (mph)

Average wind gust speed, in miles per hour, for each storm event from 2012-2019 for each RWIS site are shown as the mean (Figure 83), median (Figure 84), minimum (Figure 85), and maximum (Figure 86) values. Most of the state has average wind gust speeds in the moderate range but there is a band that moves from the south-west to north-east across the Metro and Northern Tier that has lower average gust speeds. Maximum average wind gust speeds overall appear to be higher across the central portion of the Northern Tier climate zone and at RWIS sites near the water in the Southern Maryland and Lower Shore climate zones.

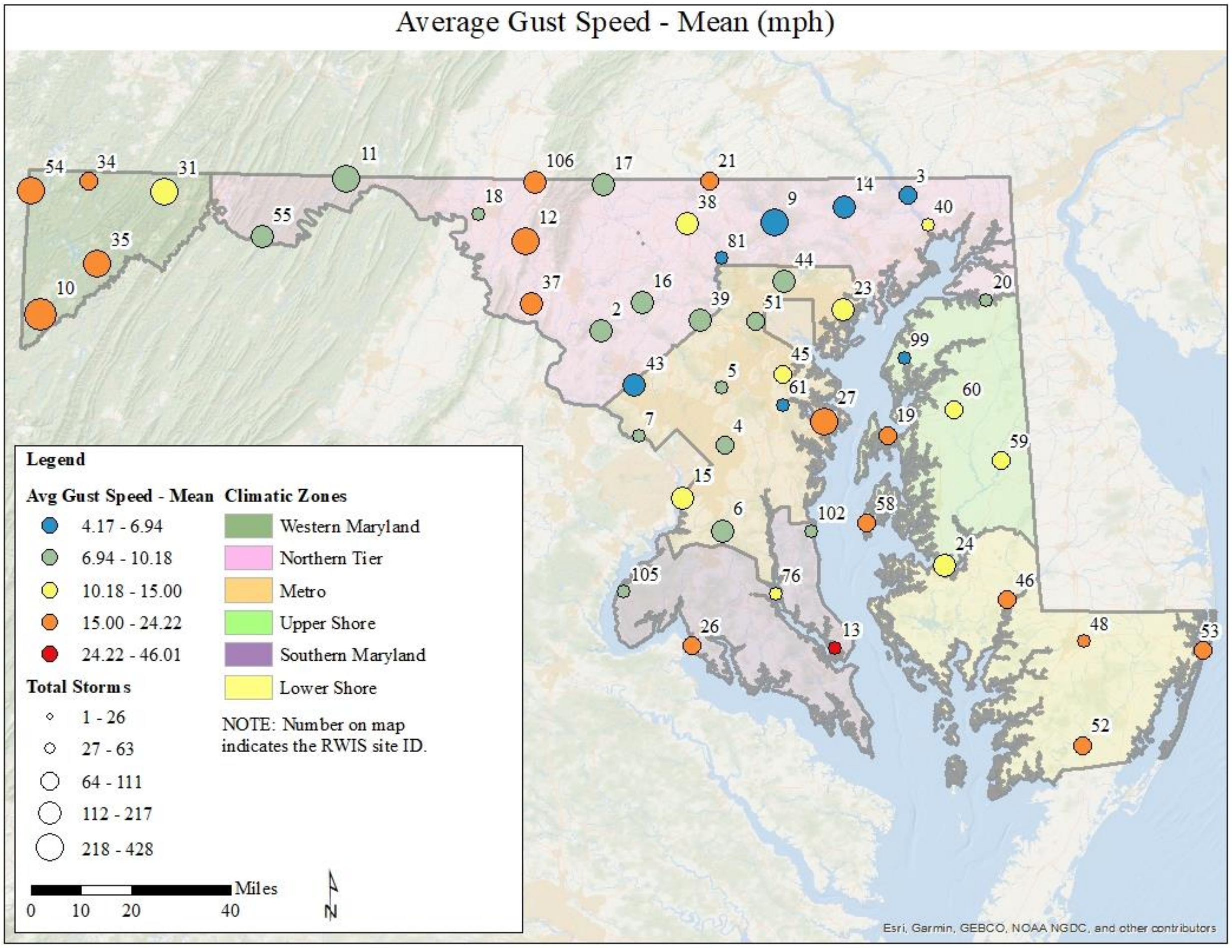


Figure 83. Shows the mean of the average wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland from 2012-2019.

Mean

The mean of the average wind gust speed values ranged from 4.17 to 46.01 mph (Figure 83). RWIS site 13 is skewing the data classifications because the high values reported at this RWIS site. If removed, values would range between 4.17 and 24.22 mph. Overall the mean of the average wind gust speed trend towards the upper end of mean values (orange dots), but there is a band that moves from the south-west to the north-east across the Metro and Northern Tier that has lower mean average wind gust speeds.

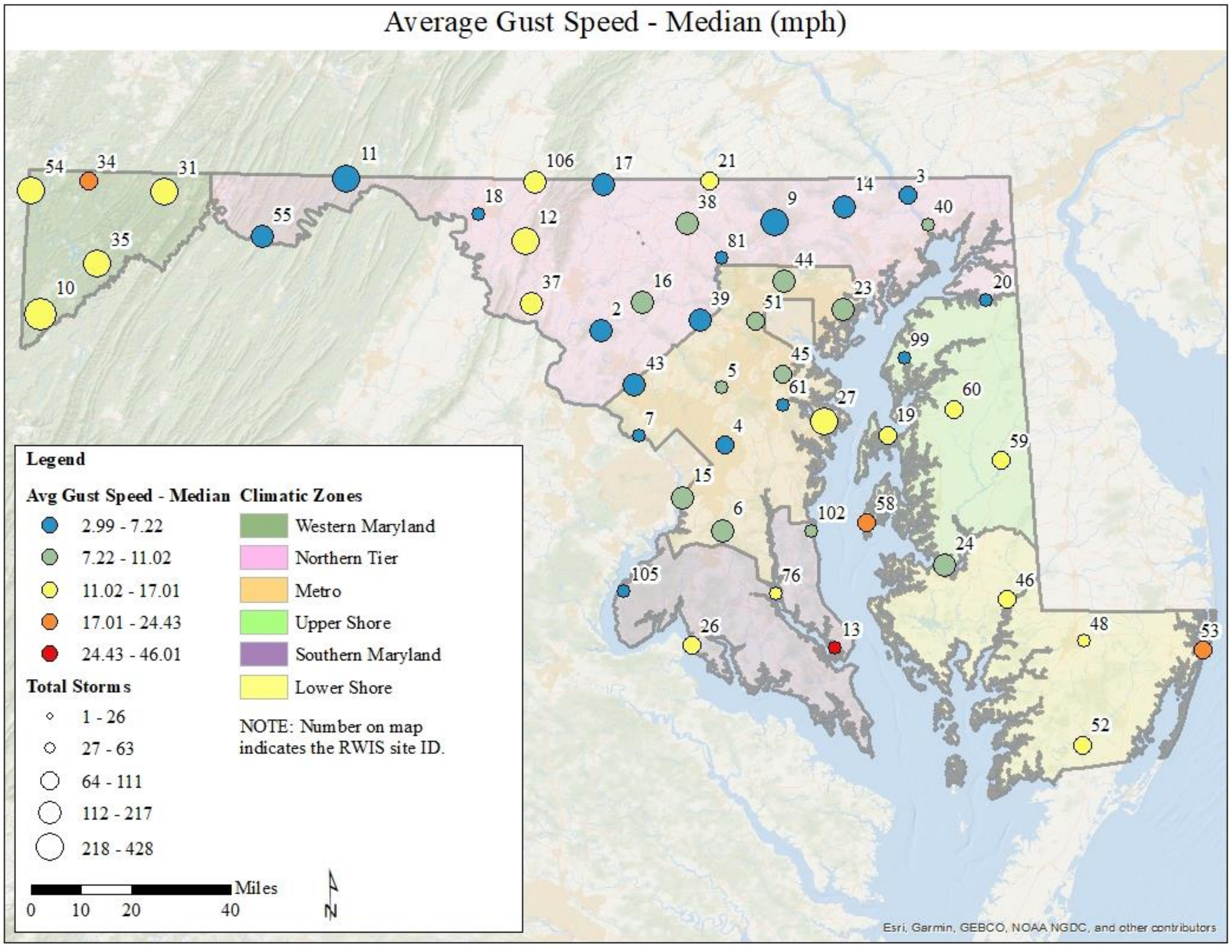


Figure 84. Shows the median of the average wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Median

The median of the average wind gust speeds ranged from 2.99 to 46.01 mph (Figure 84). Similar to Figure 83, RWIS site 13 is skewing the data classifications. If removed, the median of the average wind gust speeds would range between 2.99 and 24.43 mph. The Metro and Northern Tier climate zones have overall lower median average wind gust speeds.

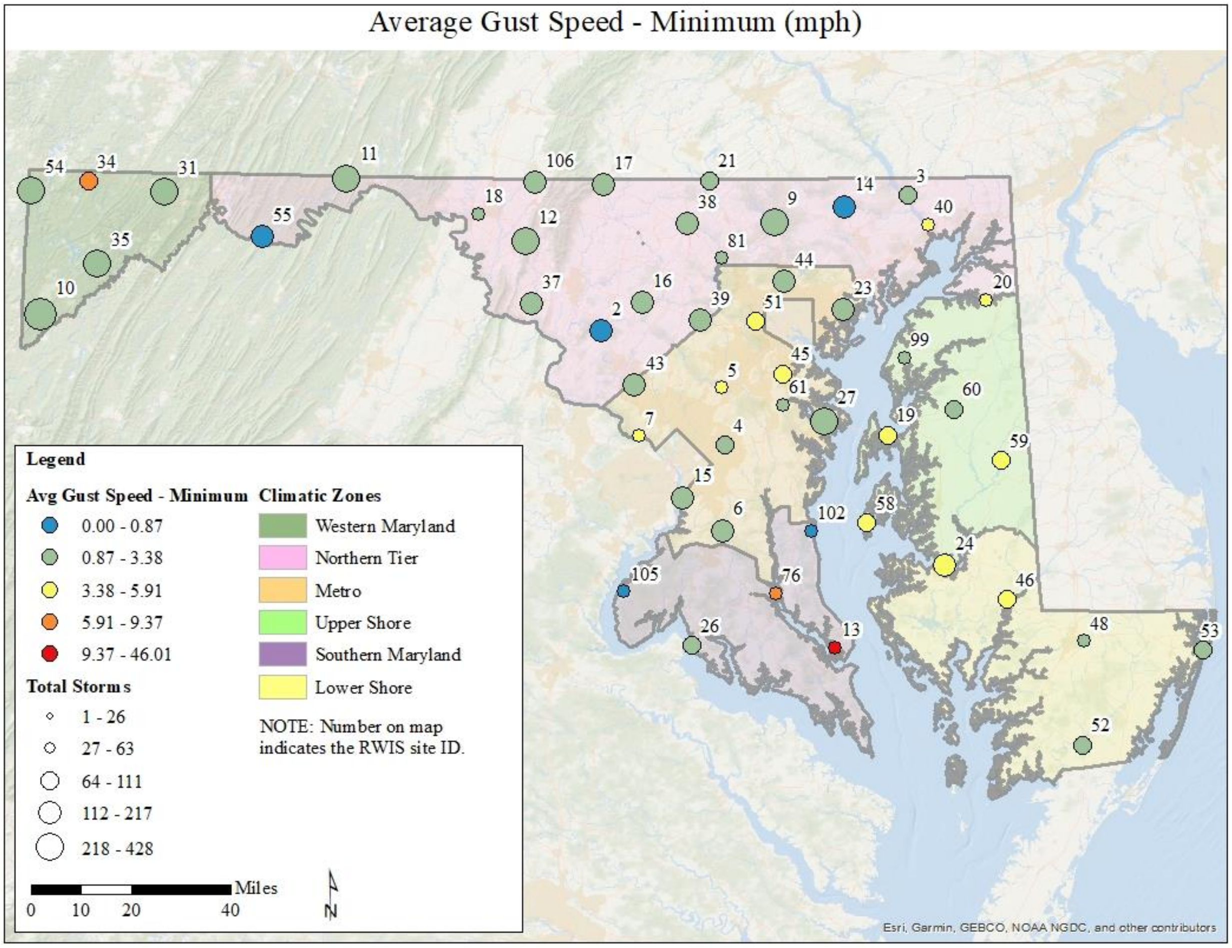


Figure 85. Shows the minimum of the average wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Minimum

The minimum of the average wind gust speed ranged from 0 to 46.01 mph (Figure 85). Again, RWIS site 13 is skewing the data classifications. If removed, the minimum of the average wind gust speed would range between 0 and 9.37 mph. Overall, the minimum of the average wind gust speed trends towards more moderate values, but there is a group of sites in the northern Metro climate zone and in the southern Upper Shore climate zone that had higher minimum average wind gust speeds. RWIS sites 34 and 76 had her minimum average wind gust speeds than other RWIS sites in the area.

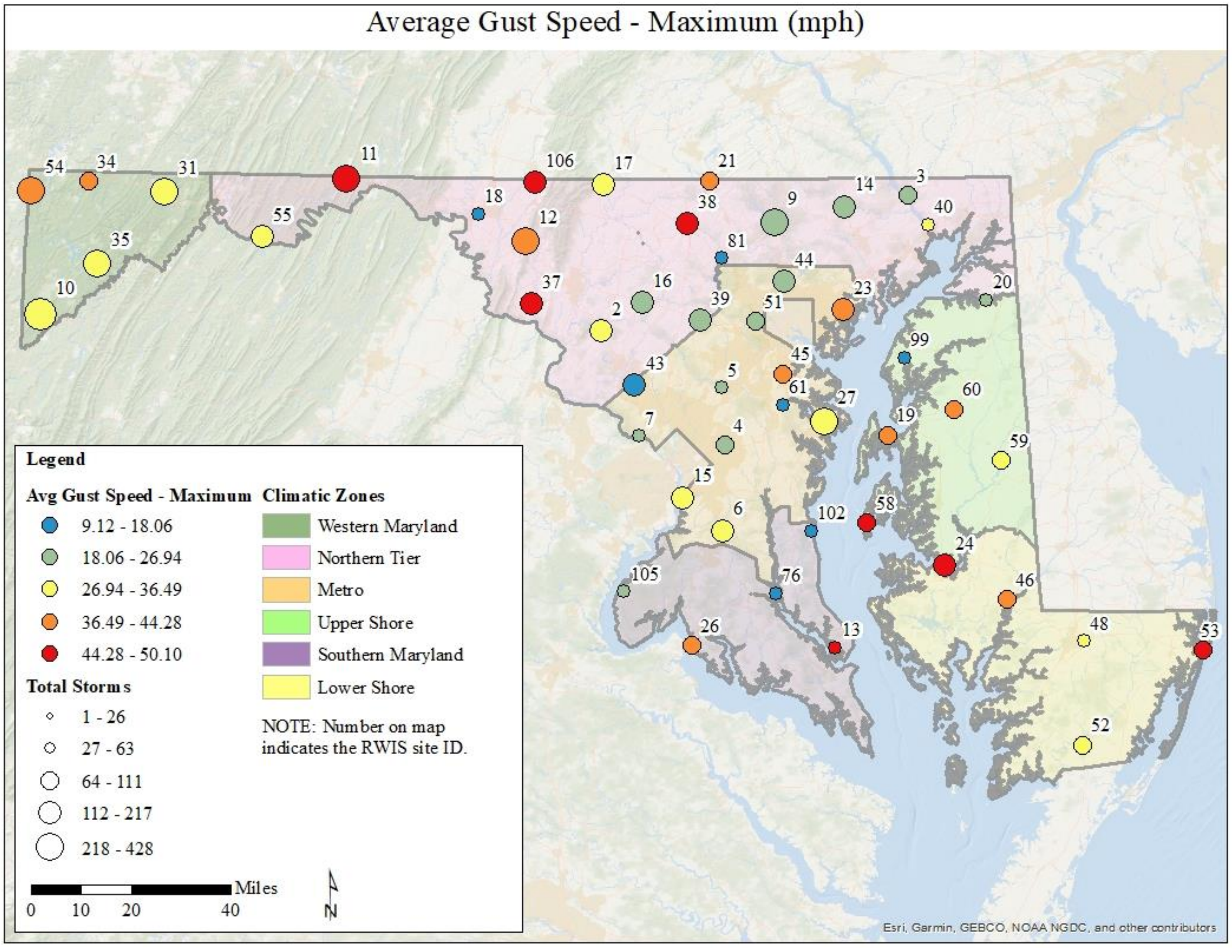


Figure 86. Shows the maximum of the average wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Maximum

The maximum of the average wind gust speed ranged from 9.12 to 50.10 mph (Figure 86). Similar to the mean and median maps, there is a band that moves from the south-west to the north-east across the Metro and Northern Tier that has lower maximum average wind gust speeds.

Maximum Gust Speed (mph)
Maximum wind gust speed in miles per hour was considered and is shown as the mean (Figure 87), median (Figure 88), minimum (Figure 89), and maximum (Figure 90) values.

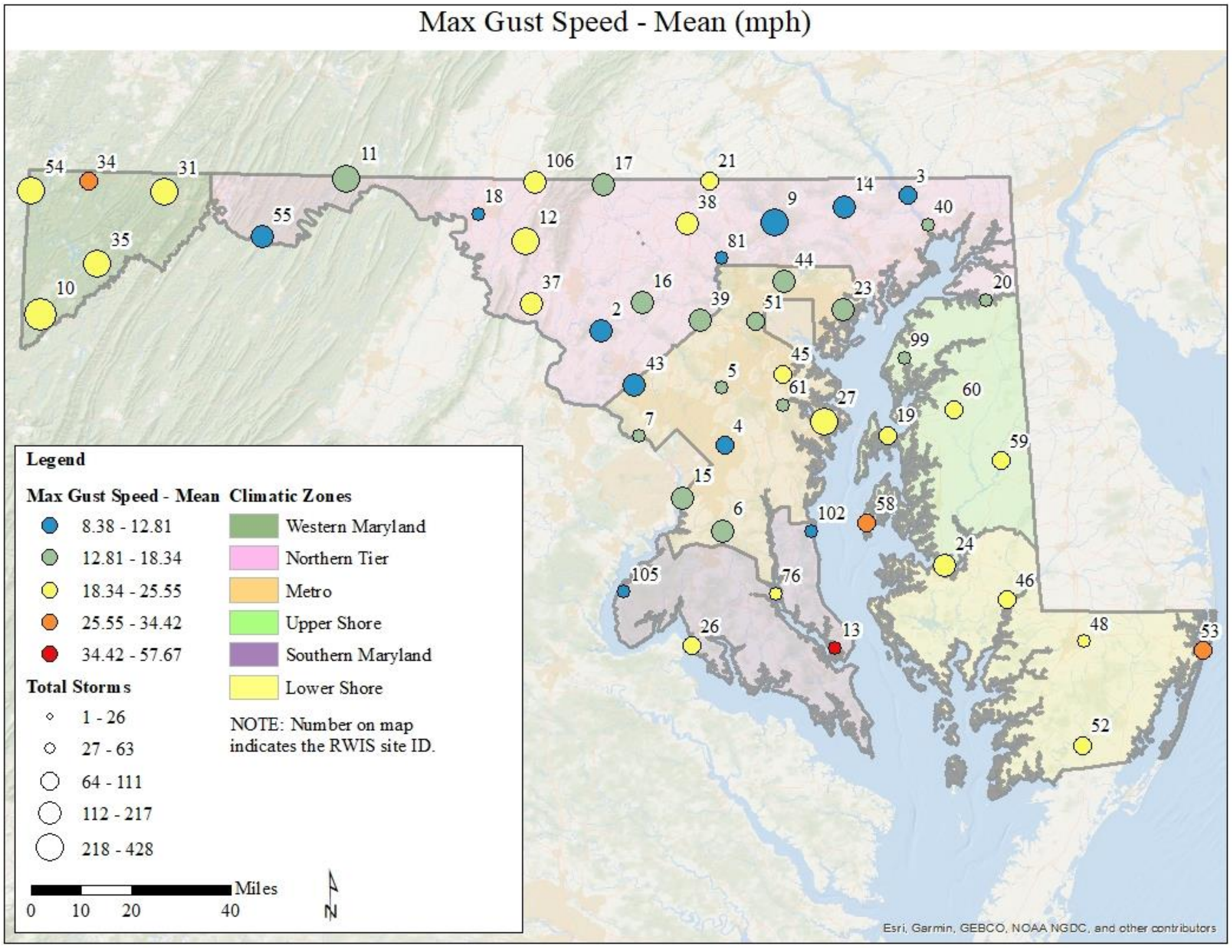


Figure 87. Shows the mean maximum wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Mean

Mean maximum wind gust speeds ranged from 8.38 to 57.7 mph (Figure 87). RWIS site 13 is skewing the mean maximum wind gust speed data classifications due unusually high values. If removed, mean maximum wind gust speeds would range between 8.38 and 34.42 mph. The Western Maryland climate zone and the Upper and Lower Shore climate zones all have values at the moderate to higher end of the mean maximum wind gust speeds. Similar to the average wind gust speeds, there is a band of lower mean maximum wind gust speeds from the south-west to the north-east through the Metro and the Northern Tier climate zones.

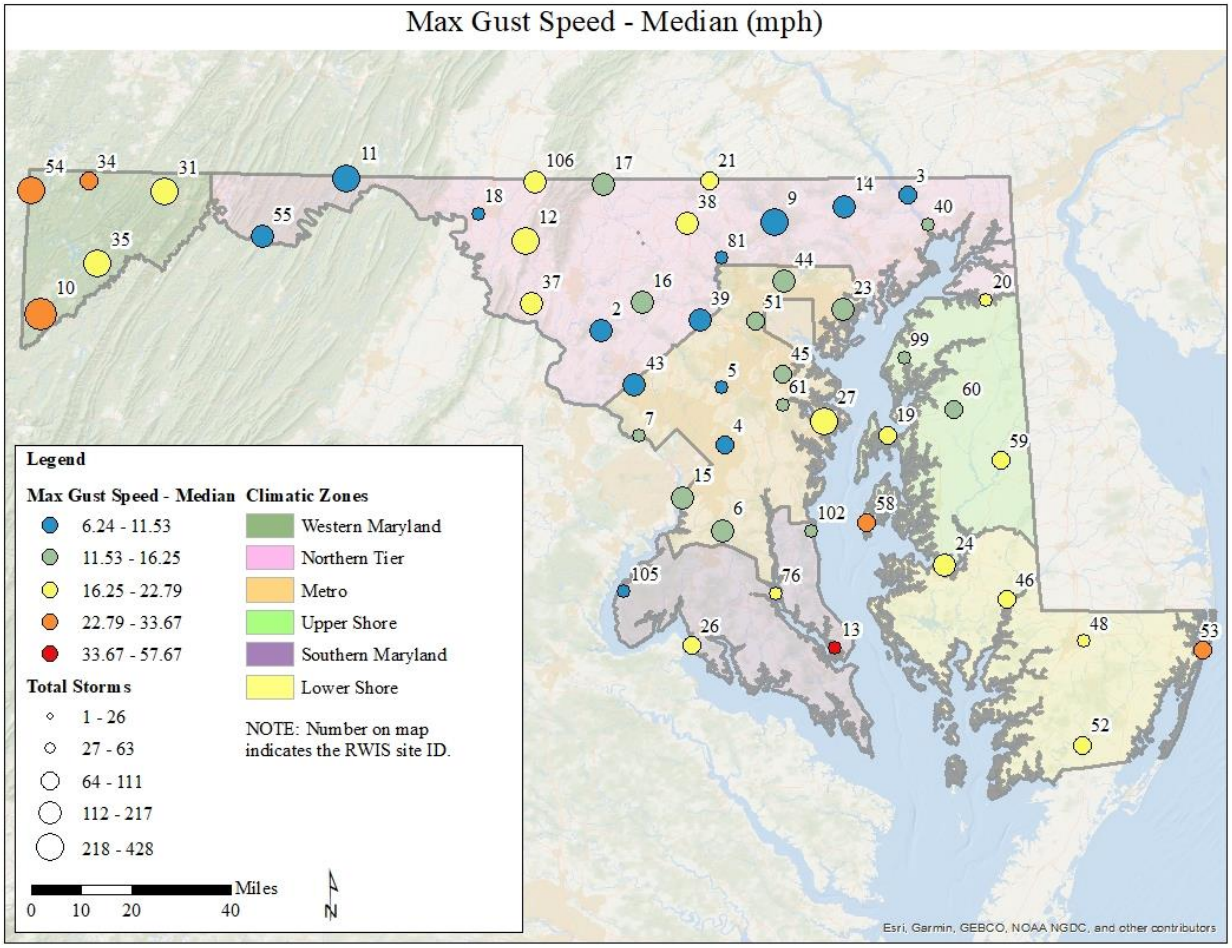


Figure 88. Shows the median of the maximum wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Median

The median of the maximum wind gust speeds ranged from 6.24 to 57.67 mph (Figure 88), and look very similar to the mean of the maximum wind gust speed from Figure 87. Again, RWIS site 13 is skewing the data classifications. If removed, the median of the maximum wind gust speeds would range between 6.24 and 33.67 mph.

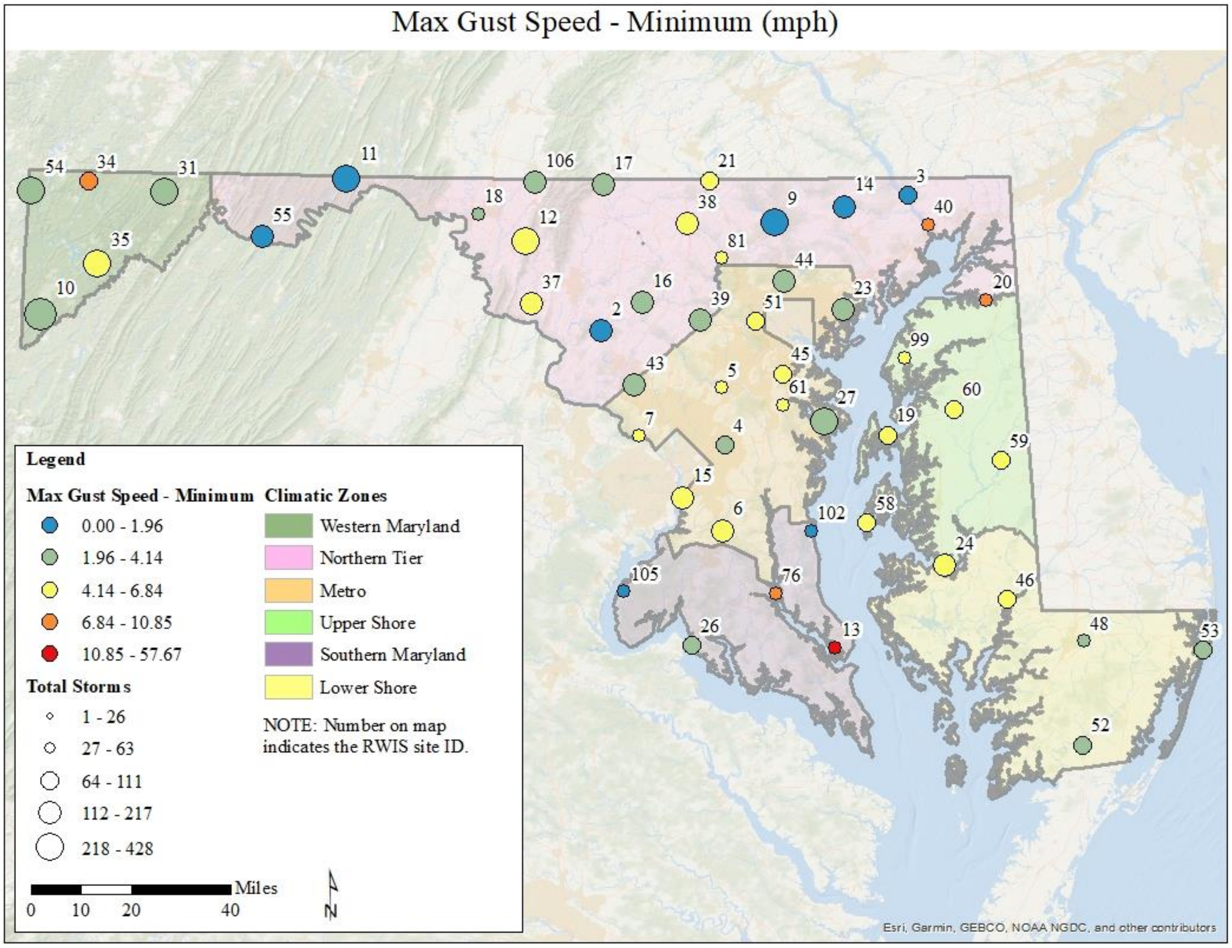


Figure 89. Shows the minimum of the maximum wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Minimum

The minimum of the maximum wind gust speeds ranged from 0 to 57.67 mph (Figure 89). Again, RWIS site 13 is skewing the data classifications and if removed, the minimum of the maximum wind gust speeds would range between 0 and 10.85 mph. There are two bands of RWIS sites moving from the south-west to the north-east through the Northern Tier that have lower minimum maximum wind gust speeds. RWIS sites 34 and 35 in the Western Maryland climate zone are interesting because the maximum wind gust speed trend higher than the other sites in the area. Also note, RWIS sites 40 and 20 in the Northern Tier climate zone and RWIS sites 76 and 13 in the Southern Maryland climate zone.

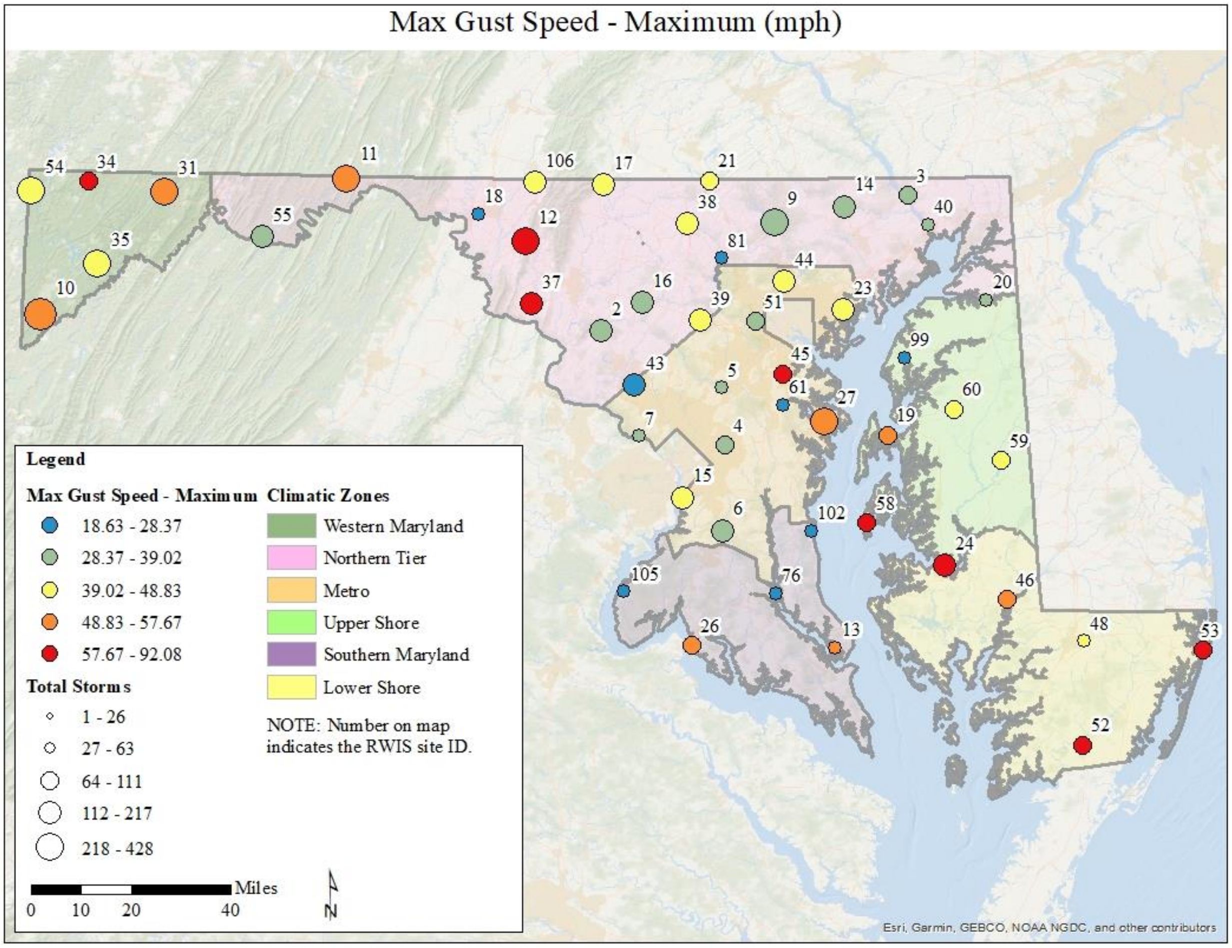


Figure 90. Shows the maximum wind gust speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Maximum

The maximum wind gust speeds ranged from 18.63 to 92.08 mph (Figure 90). Wind gust is a measure of the maximum wind reading recorded at a site over a five-minute period. (Wind gust differs from wind speed, which is an average of the wind speed data measured over a five-minute period at a site.) There appears to be a band of RWIS sites that moves across the entire state from the north-west to the south-east that have higher maximum wind gust speed values compared to the rest of the state.

Wind Speed (mph)
Overall wind speed values in miles per hour (mph) were considered and are shown as the mean (Figure 91), median (Figure 92), minimum (Figure 93), and maximum (Figure 94). Looking at the mean and median wind speed values, there is a band of lower wind speeds moving from south-west to north-east through the Metro and Northern Tier climate zones. The Upper Shore and Lower Shore have wind speed values in the mid-range and the Southern Maryland climate zone has wind speed values toward the higher end.

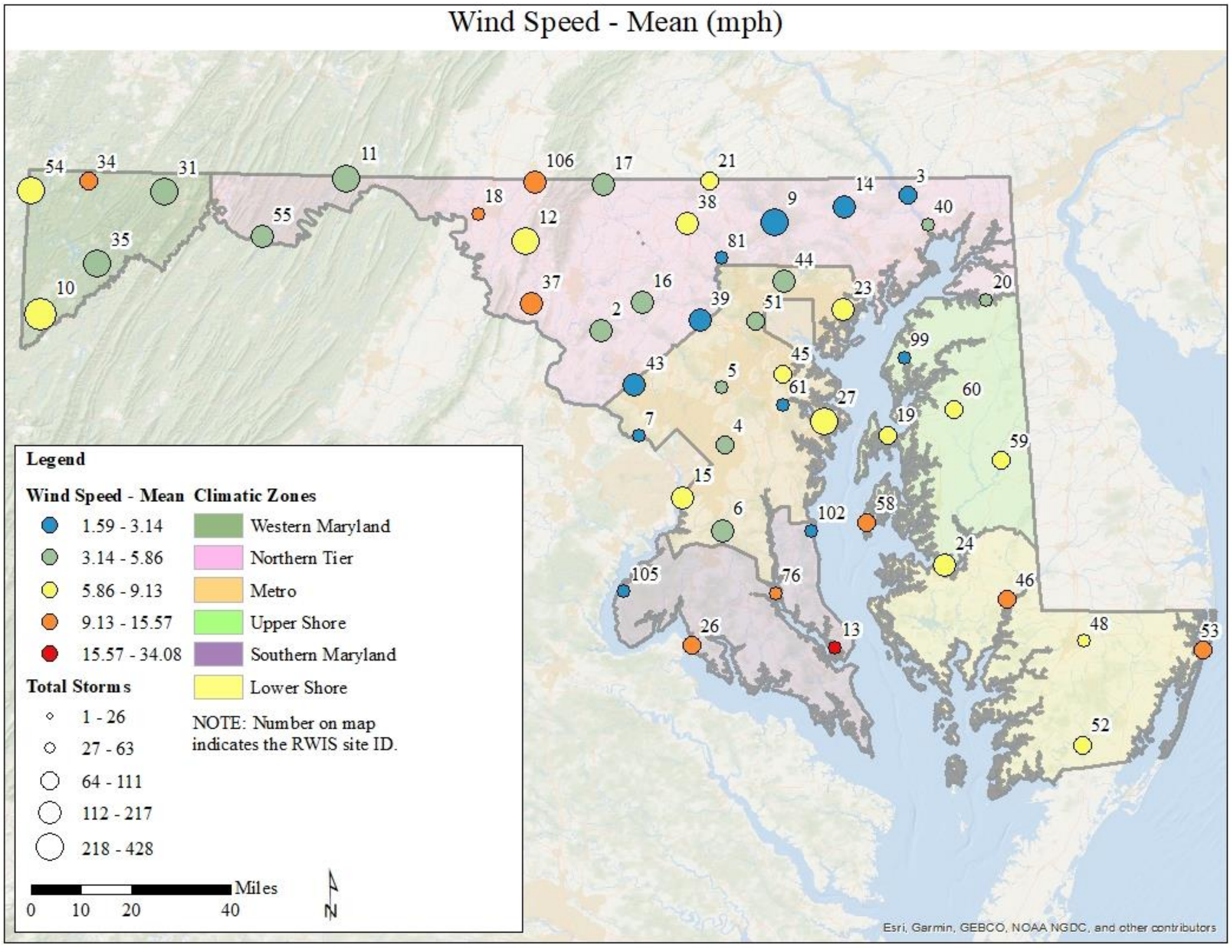


Figure 91. Shows the mean wind speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Mean

Mean wind speeds ranged from 1.59 to 34.08 mph (Figure 91). There is a band of lower wind speeds moving from the south-west to the north-east through the Metro and Northern Tier climate zones.

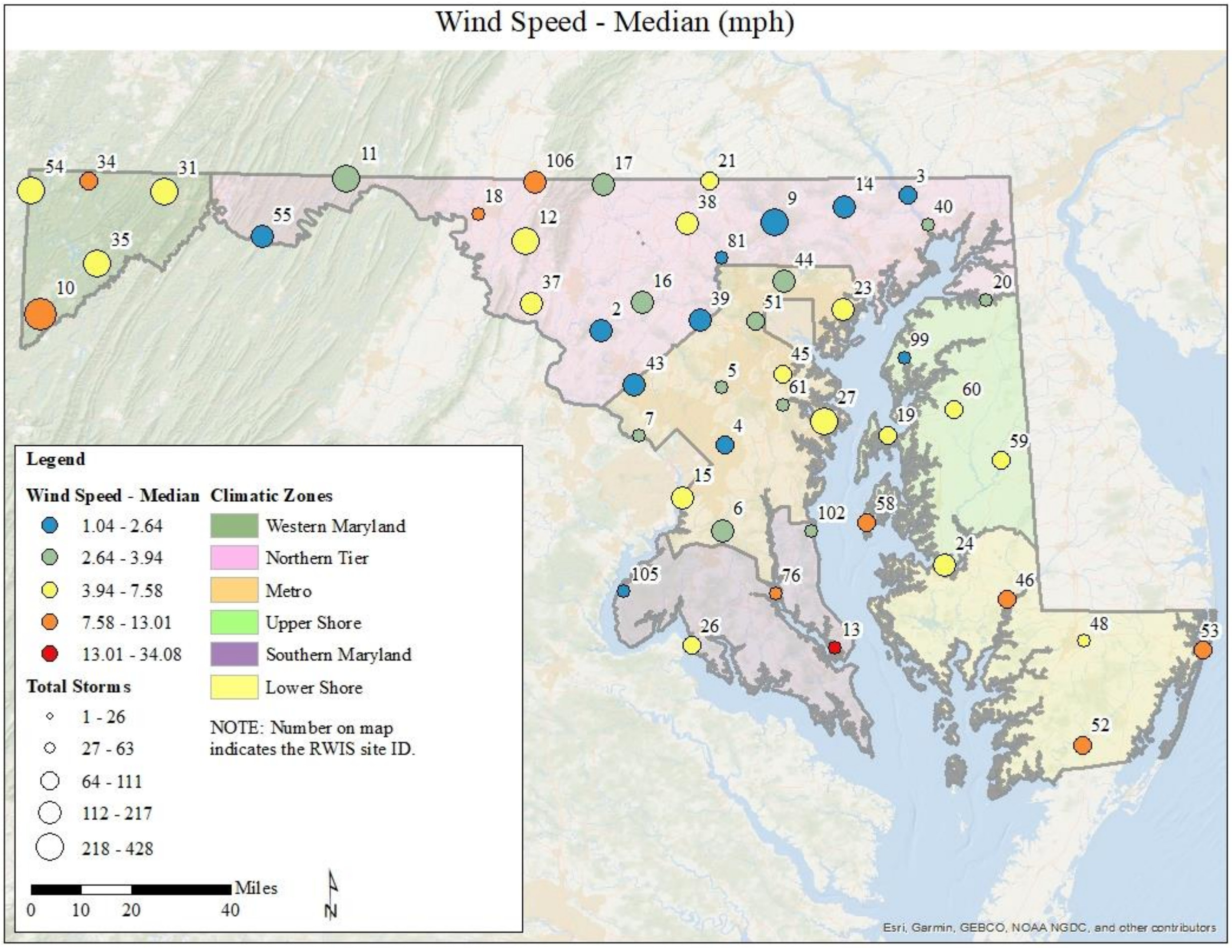


Figure 92. Shows the median wind speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Median

Median wind speeds ranged from 1.040 to 34.08 mph (Figure 92), which is similar to the map of mean wind speed values (Figure 91).

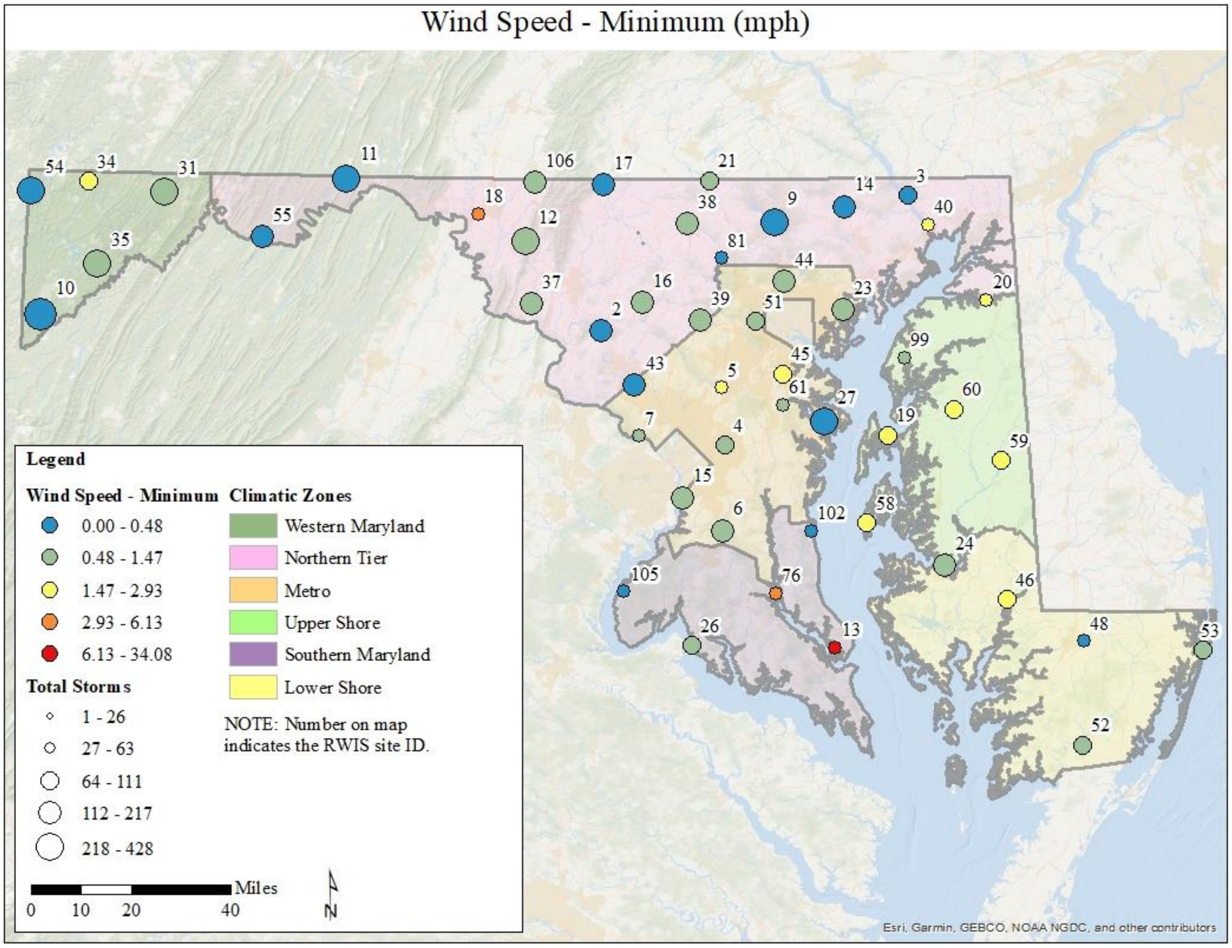


Figure 93. Shows the minimum wind speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Minimum

Minimum wind speeds ranged from 0 to 34.08 mph (Figure 93). Most of the state has low minimum wind speed values ranging from 0 to 1.47 mph. The Upper Shore and the eastern portion of the Northern Tier and Metro climate zones have slightly higher minimum values ranging from 1.47 to 2.93 mph. RWIS sites 18, 13, and 76 report notably high minimum wind speeds.

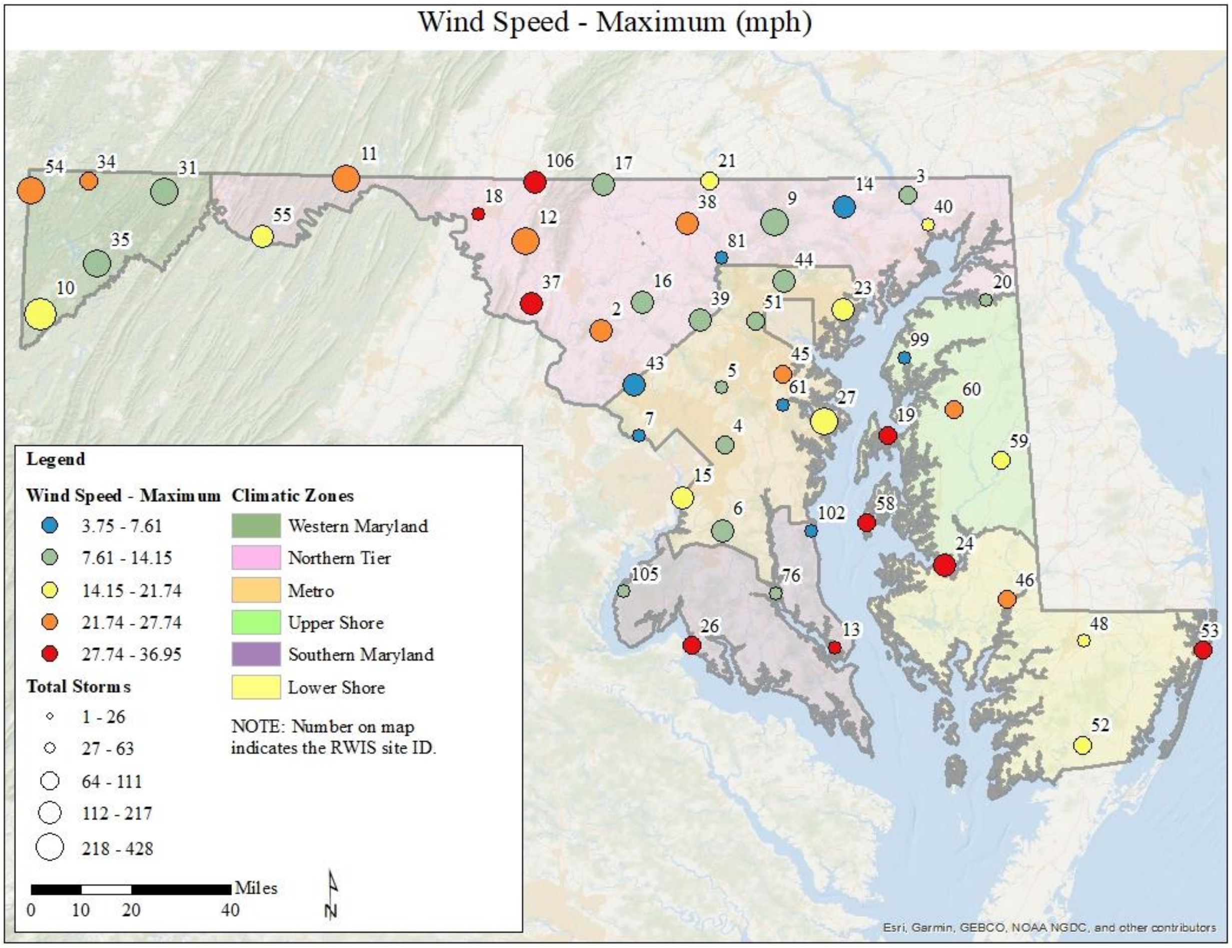


Figure 94. Shows the maximum wind speed in miles per hours (mph) for each storm event at each RWIS location in Maryland form 2012-2019.

Maximum

Maximum wind speeds ranged from 3.75 to 36.95 mph (Figure 94). Again, there is a band of lower maximum wind speeds moving from the south-west to the north-east through the Metro and Northern Tier climate zones. Higher maximum wind speeds are seen in the central portion of the Northern Tier and along the Upper and Lower Shore climate zones. The Western Maryland climate zone sees maximum wind speeds at the moderate range.

Storm Duration

The duration of storm events in total minutes was considered and is shown in as the mean (Figure 95), median (Figure 96), minimum (Figure 97), and maximum (Figure 98). Most of the state trends towards the moderate range for storm duration – around 170 to 232.5 minutes. There appears to be a cluster of RWIS sites around the central portion of the Northern Tier climate zone and the northern portion of the Metro climate zone that have longer median storm durations ranging from 232.5 to upwards of 607 minutes. Looking at the maximum storm duration values, in general, the Northern portion of the state seems to have much longer storm durations compared to the Southern portion of the state.

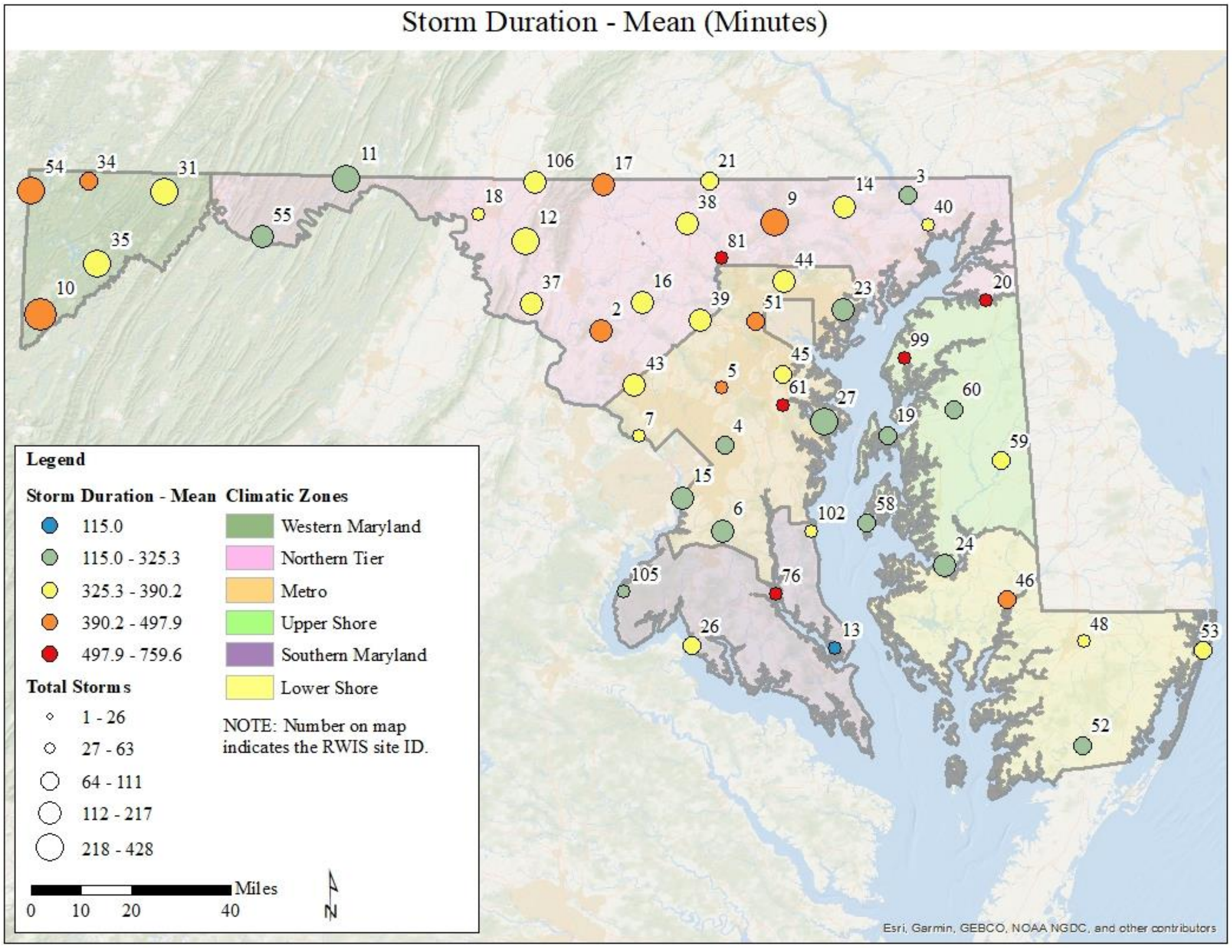


Figure 95. Shows the mean duration of storm events in minutes at each RWIS location in Maryland from 2012-2019.

Mean

Figure 95 shows the mean duration of storm events at each RWIS location in Maryland from 2012-2019. Mean storm duration ranged between 115 and 759 minutes. There is a band of lower mean storm duration values that moves from south-east to north-west through the southern portion of the Metro climate zone and across to the northern portion of the Upper Shore climate zone. Just north of this band there is a band, in Western Maryland and part of the North Tier Climate Zones, of higher mean storm duration values (or longer duration storms). This is supported by the larger size of the circles, which depicts a greater number of data points available to support this. The red circles that are smaller, RWIS sites 76, 61, 99, 20, and 81, many of these are RWIS sites located on bridges, are newer RWIS sites, or are RWIS sites that are missing some data, or a combination of these factors. The smaller sizes of the red circles indicate less data supports these findings, and therefore should be viewed critically until additional data can further support or refute these findings.

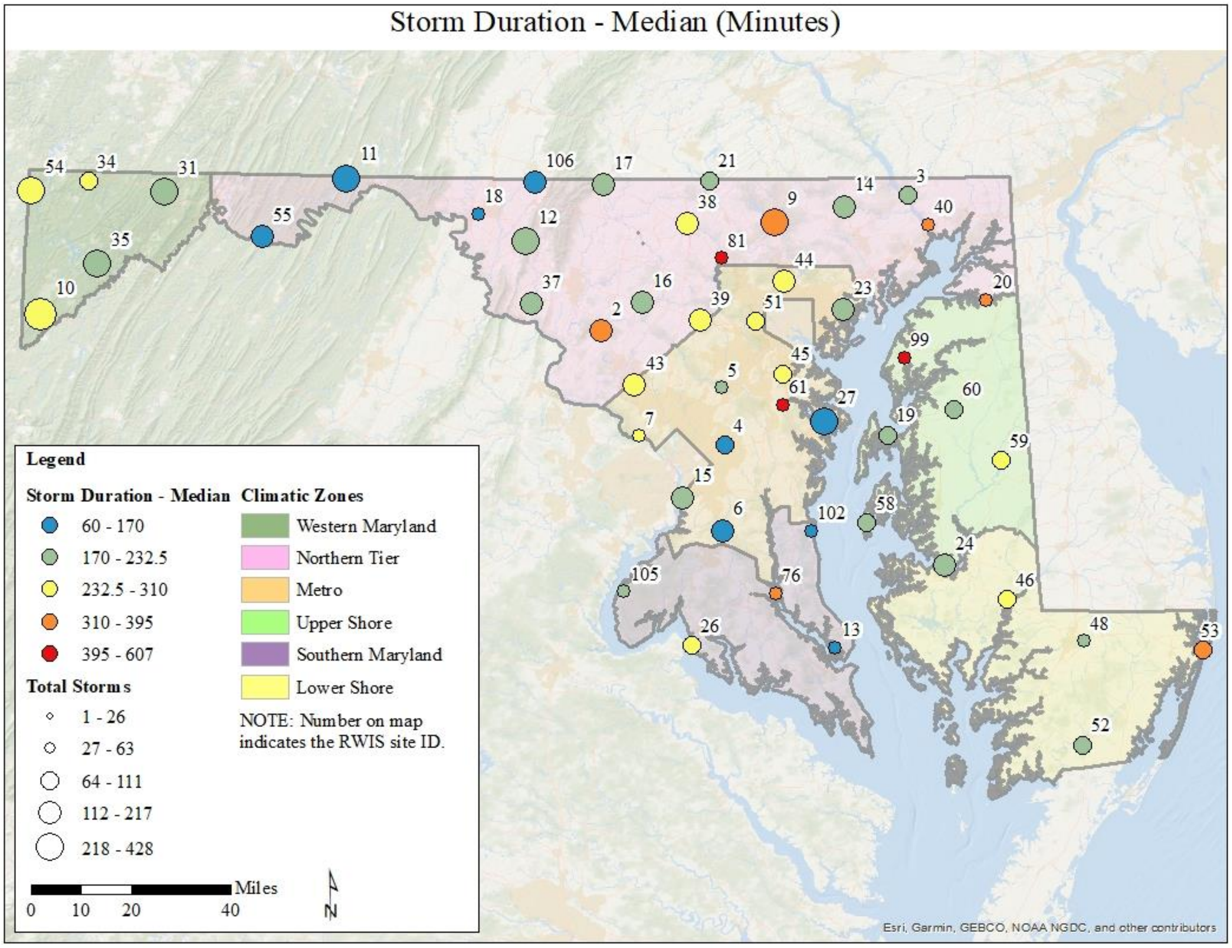


Figure 96. Shows the median duration of storm events in minutes at each RWIS location in Maryland from 2012-2019.

Median

Figure 96 shows the median values for storm durations across the RWIS in Maryland. Median storm duration ranged from 60 to 607 minutes. The western portion of the Northern Tier and the eastern portion of the Western Maryland climate zone have lower median storm durations.

When comparing mean storm duration in Figure 95 with median storm duration in Figure 96, it generally appears that the mean values are skewed slight higher, showing more severe storm duration. This is not true for all RWIS locations, for example RWIS site 53 in Lower Shore Climate Zone.

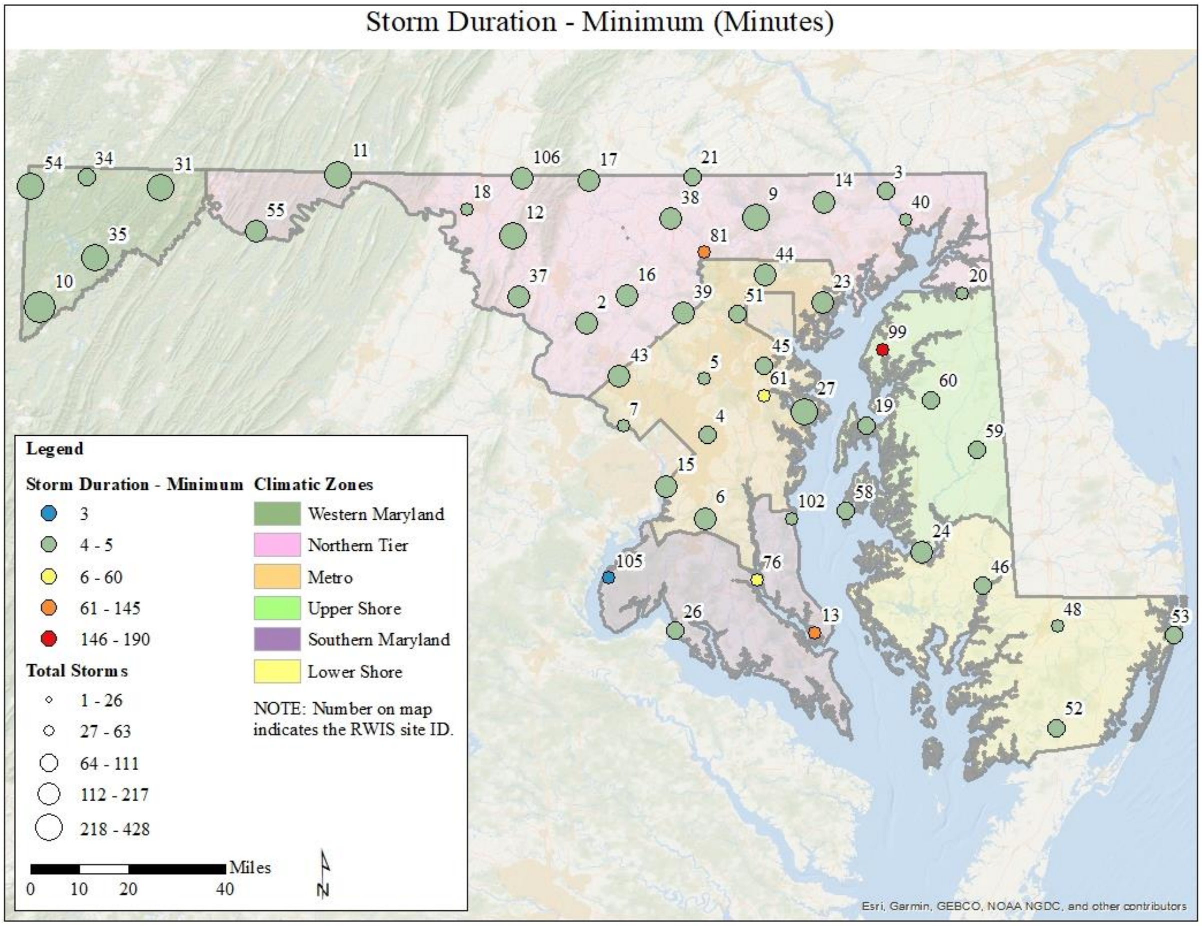


Figure 97. Shows the minimum duration of storm events in minutes at each RWIS location in Maryland from 2012-2019.

Minimum

Minimum storm duration ranged from 3 to 190 minutes (Figure 97). The majority of RWIS sites show a minimum storm duration of 4- to 5-minutes. RWIS sites 81, 99, 61, 76, 13, and 105 are the exceptions. The minimum storm duration is fairly consistent across the state may be an artifact of how storms were defined.

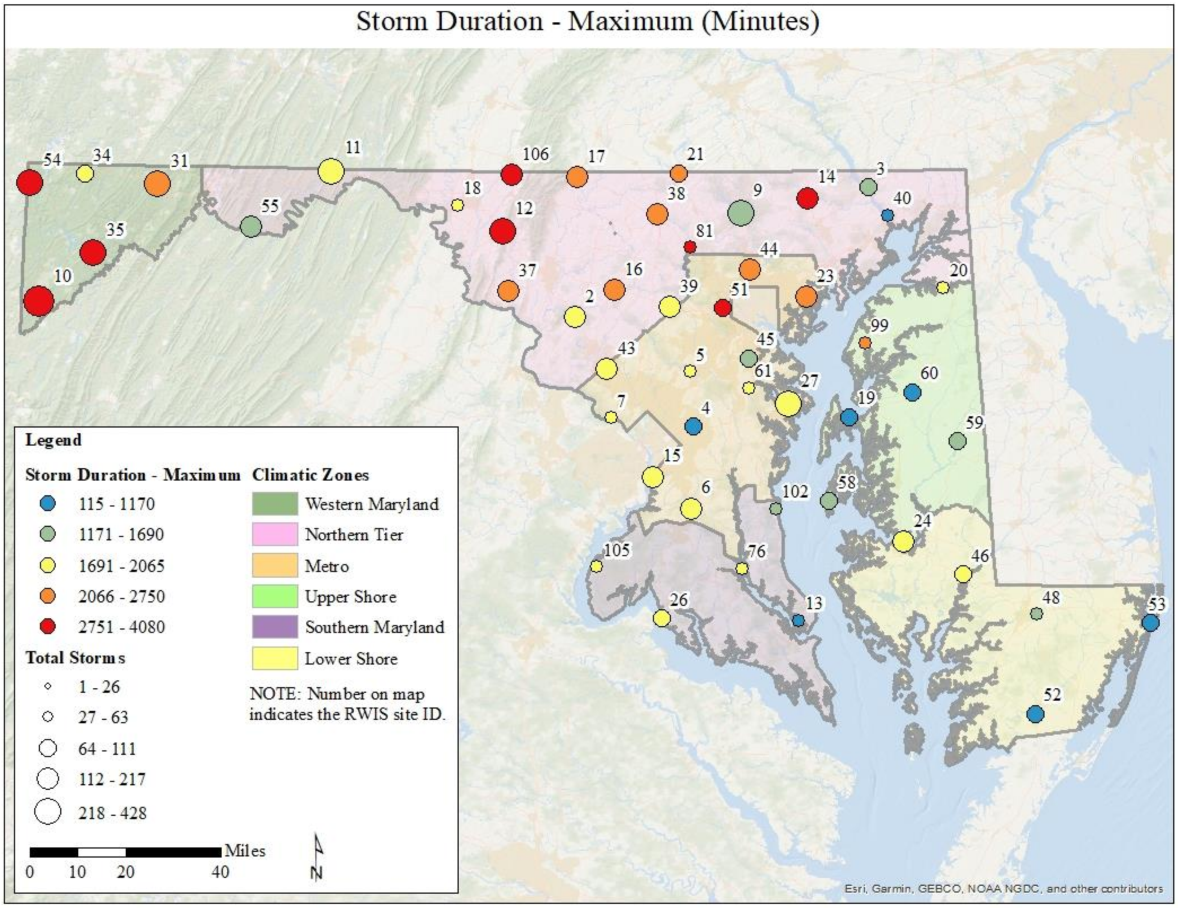


Figure 98. Shows the maximum duration of storm events in minutes at each RWIS location in Maryland from 2012-2019.

Maximum

Maximum storm duration ranged from 115 to 4080 minutes (Figure 98). The northern portion of the state appears to have higher storm duration values (or longer storm durations) overall with the exception of a few RWIS sites. The southern portion of the state has more moderate to lower storm duration values overall.

Storm Temperature

The temperature of storm events was considered for both air temperature (Figure 99, Figure 100, Figure 101, and Figure 102) and pavement or surface temperature (Figure 103, Figure 104, Figure 105, and Figure 106), and is shown as the mean, median, minimum, and maximum, respectively.

Storm Air Temperature (°F)

The western portion of the state and in particular the Western Maryland climate zone seems to have the lowest, coldest, storm temperatures. The Southern Maryland climate zone seems to have the "warmest" storm temperatures.

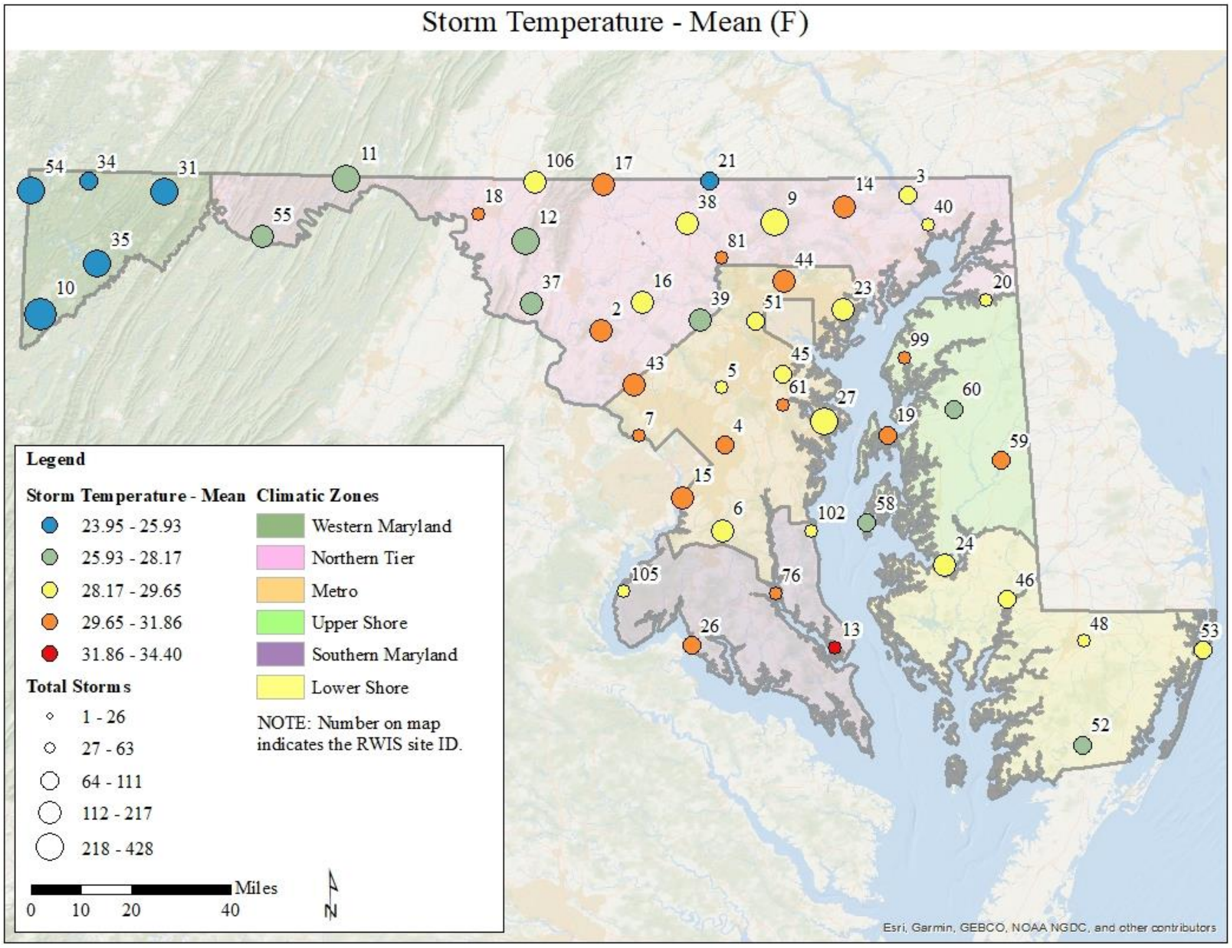


Figure 99. Shows the mean air temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Mean

Mean air temperature ranged from 23.95 to 34.40°F (Figure 99). The western portion of the state seems to have the lowest, or coldest, air temperature during storm events on average.

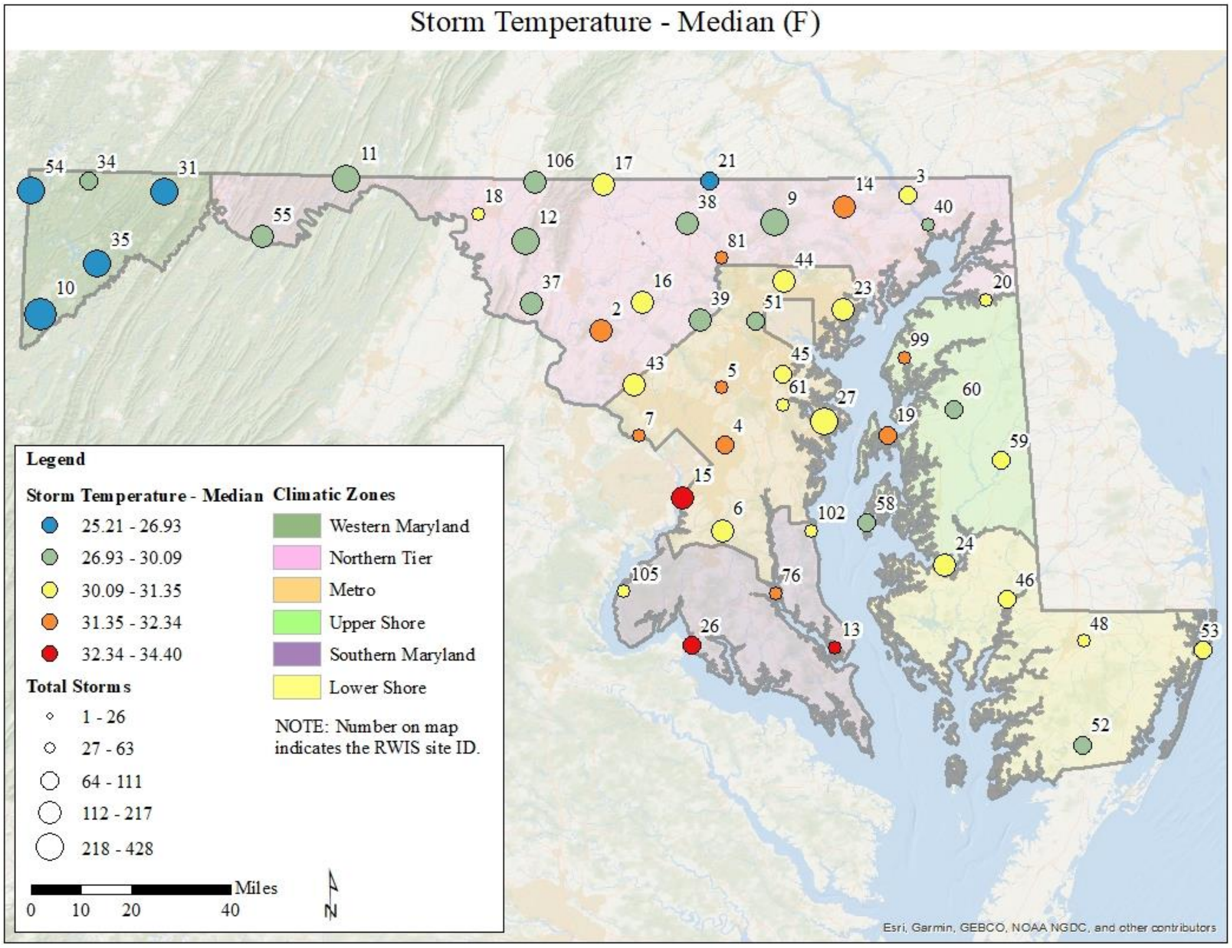


Figure 100. Shows the median air temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Median

Median air temperature ranged from 25.21 to 34.40°F (Figure 100). The western portion of the state seems to have the lowest, or coldest, air temperature during storm events. The Southern Maryland climate zone seems to have storms on the "warmer" end of the data range.

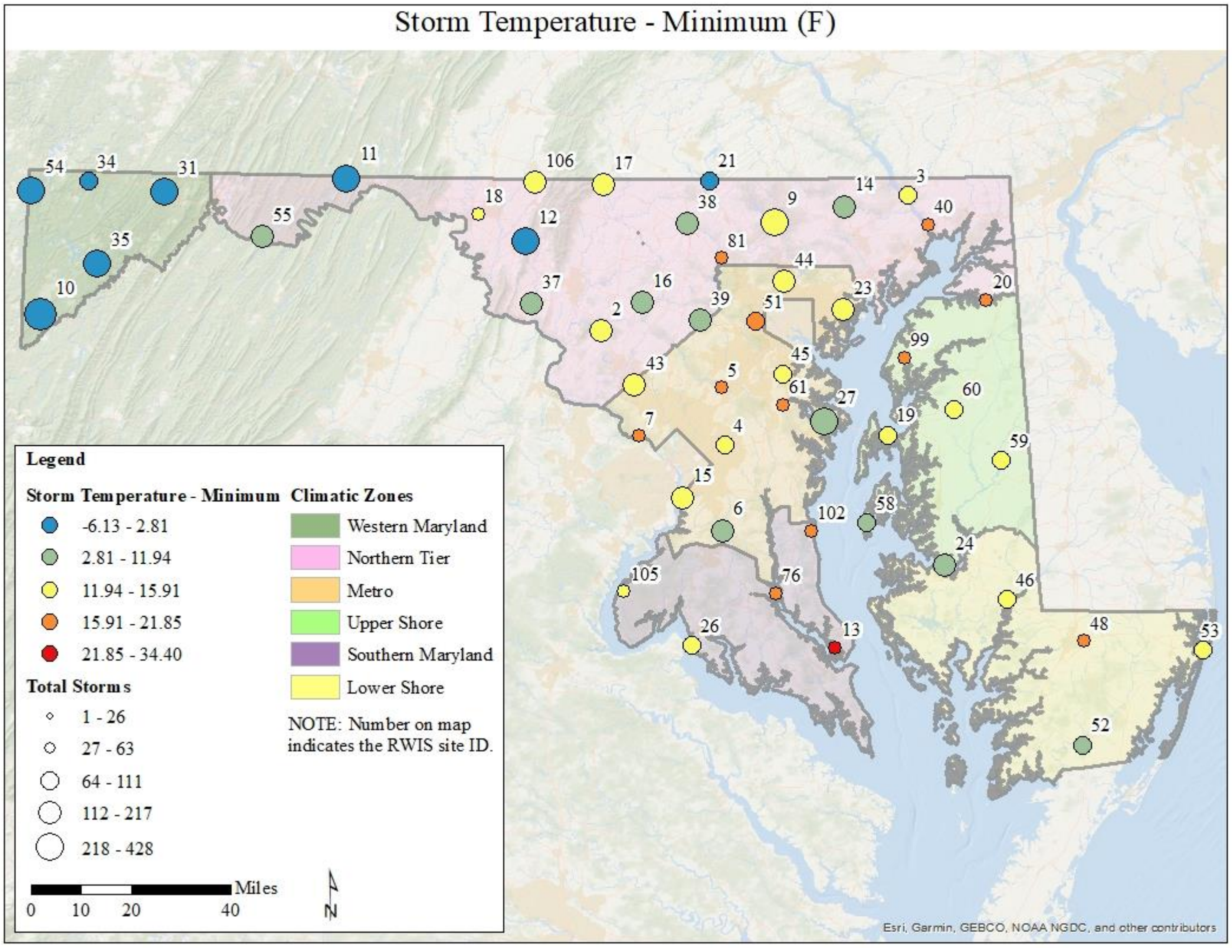


Figure 101. Shows the minimum air temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Minimum

Minimum air temperature ranged from -6.13 to 34.40°F (Figure 101). The western portion of the state seems to have the lowest minimum temperature values.

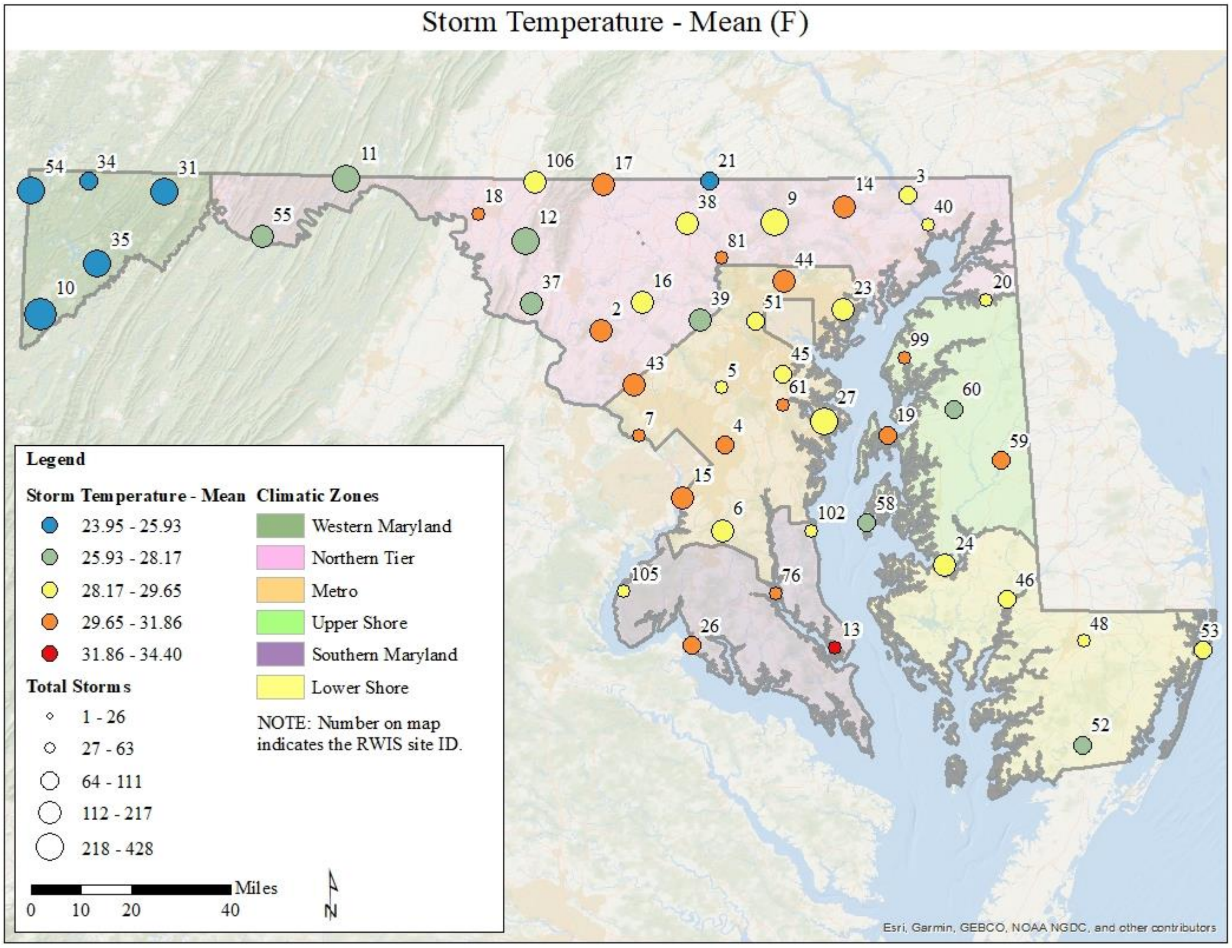


Figure 102. Shows the maximum air temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Maximum

Maximum air temperature ranged from 32.94 to 51.23°F (Figure 102). The Western Maryland climate zone had the lowest maximum air temperatures during storm events. The southern portion of the state sees a mix of low to moderate air temperature values.

Storm Road Surface Temperature

Road Surface Temperature (°F)

Similar to the air temperatures shown in the previous section, the western portion of the state and in particular the Western Maryland climate zone seems to have the lowest, or coldest, road surface temperatures. The Metro and Southern Maryland climate zones show to the “warmest” road surface temperatures.

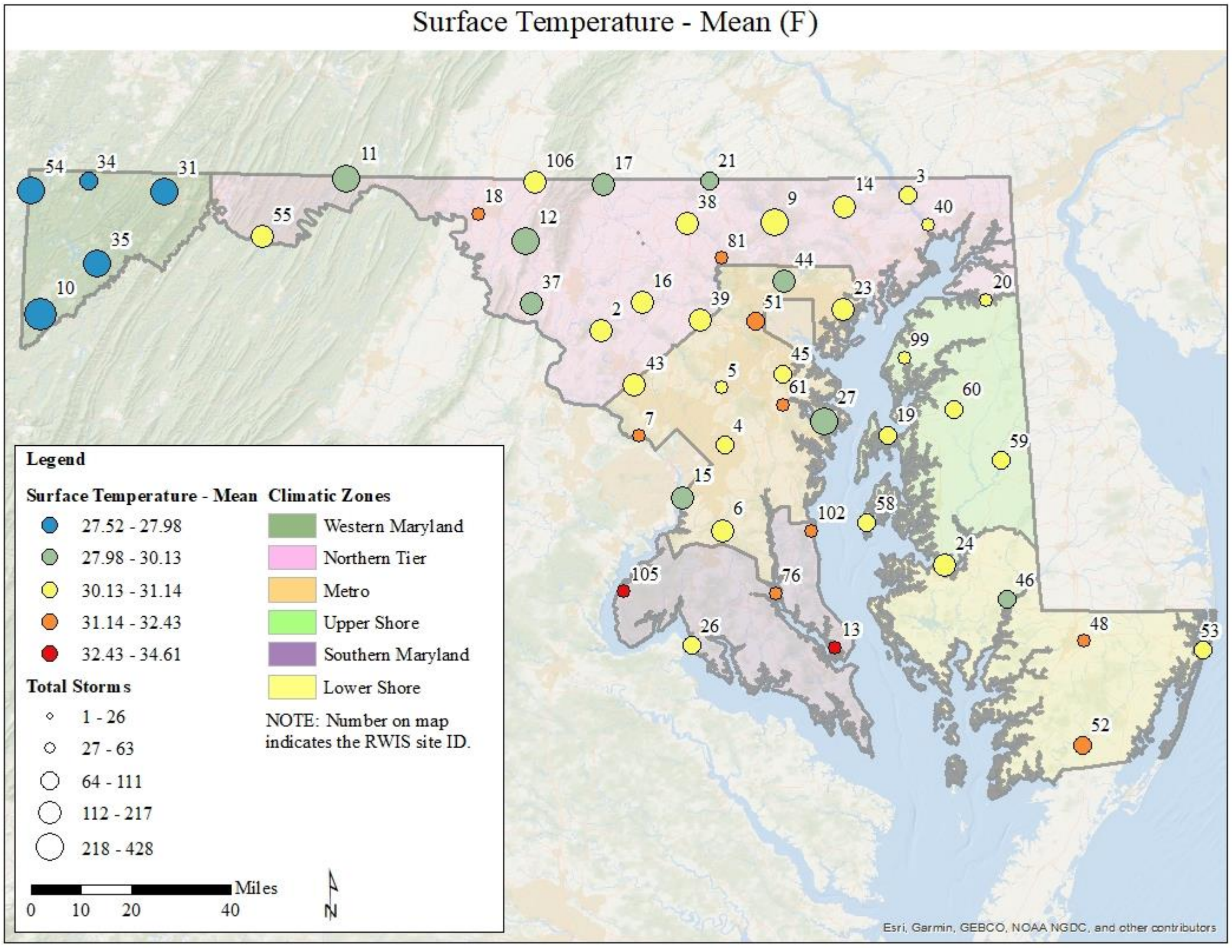


Figure 103. Shows the mean surface or road temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Mean

Mean road surface temperature ranged from 27.52 to 34.51°F (Figure 103). The western portion of the state appears to have much lower road surface temperatures. The rest of the state trends towards the moderate and higher road surface temperatures.

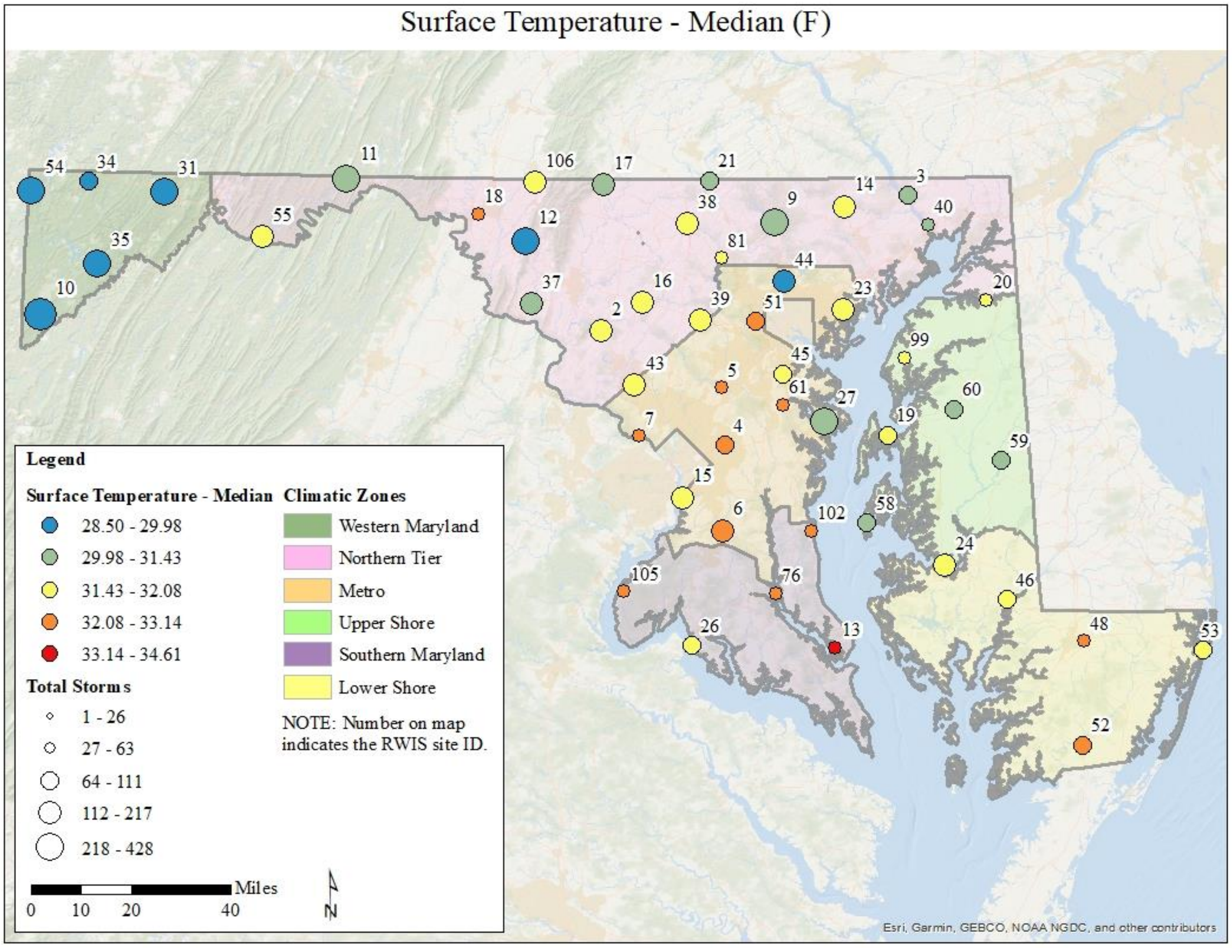


Figure 104. Shows the median surface, or road, temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Median

Median road surface temperatures ranged from 28.50 to 34.61°F (Figure 104), and is similar to mean road surface temperatures shown in Figure 103.

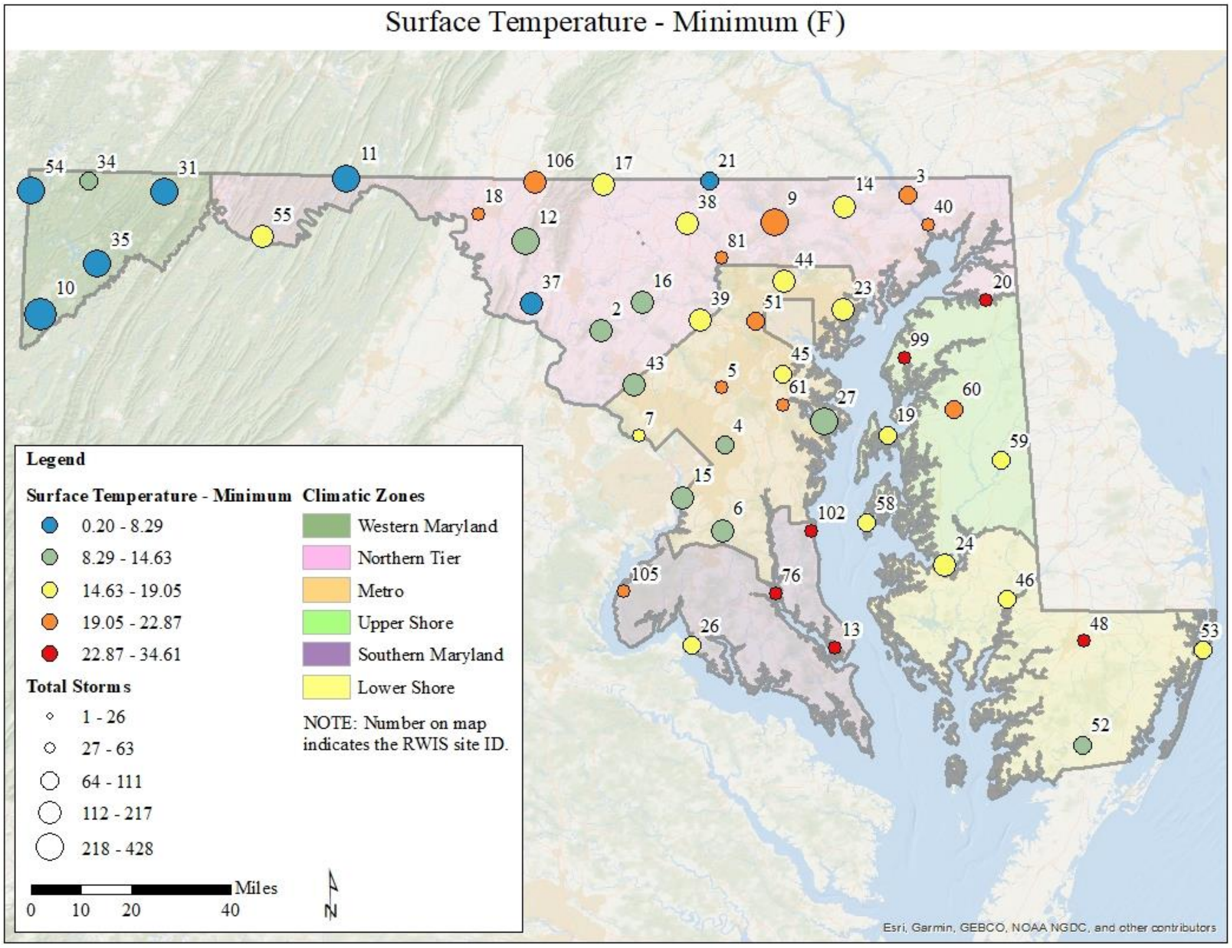


Figure 105. Shows the minimum surface or road temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Minimum

Minimum road surface temperatures ranged from 0.20 to 34.61 °F (Figure 105). The western portion of the state appears to have much lower road surface temperature values. The Southern Maryland climate zone, and overall southern and eastern parts of the state show storms on the “warmer” end of the data range.

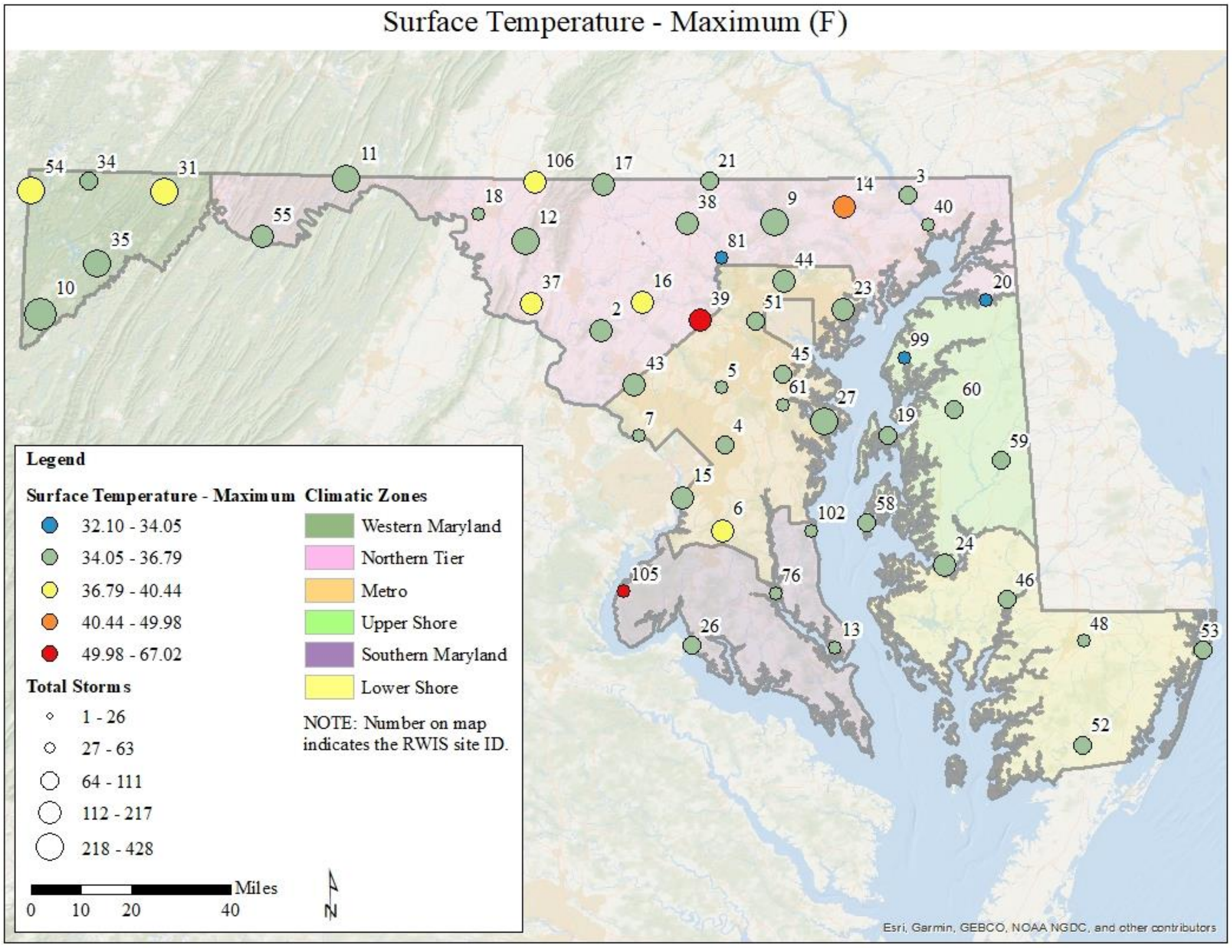


Figure 106. Shows the maximum surface, or road, temperature in degrees F during storm events at each RWIS site in Maryland from 2012-2019.

Maximum

Maximum road surface temperatures ranged from 32.10 to 67.02°F (Figure 106). The majority of RWIS sites across the state have road surface temperatures in the lower end of the temperature range (34.05 to 36.7 °F, green dot). Two RWIS sites, 39 in the Northern Tier and 105 in the Southern Maryland climate zone have a maximum road surface temperature values ranging between 49.98 to 67.02°F.

General Observations from Figures:

- The smaller dots, or RWIS sites that have less storm data, often show values that are outside of what is typically observed in the climate zone they are located in. This may be due in part to location, some of these sites are located in micro-climates or on bridges, and experience significantly different weather than adjacent RWIS sites. This also may speak to the power of historical data. When you have limited data you do not get full picture of changes in weather and climate over time. The RWIS sites with larger data sets of storm events (larger dots) have more central average and mean values, whereas the dots with less data sets of storm events have average and mean values that are more polarized.

The limited data from certain RWIS sites occurs for a few reasons:

- The RWIS site was installed at later date, or the sensor was added at a different time from the initial installation. This highlights the importance of having a record of when RWIS sites are installed or when sensors were added or changed.
- Data from RWIS site was not usable. This highlights the importance of viewing RWIS data to identify any issues and provide timely maintenance and calibration of RWIS sensors.

Appendix G - How to Guide for the SWI Use

Quick Reference Guide

How to Use the Maryland SWI

Purpose

The purpose of this document is to walk you step-by-step through how to use the developed Severe Weather Index (SWI) tool. This process shows you how to take raw data from MDOT SHA's Road Weather Information System (RWIS) to 1) Identify storms, 2) How to process the data to obtain the variables that will be used in the SWI calculation, and 3) How to apply the calculated SWI and methods to interpret the data.

This will require working with two spreadsheet files – the first is the raw data file that comes from the MDOT SHA vendor (Lufft) [See File: 40_I-95_at_Tydings_Bridge_Jan2019-Jan2020_EXAMPLE.xlsx or 99_MD_20_at_MD_21_Jan2019-Jan2020_EXAMPLE_ALTERNATIVE.xlsx]. This file will be used to create a Storm File.

Second, you will take the data you calculate in the Storm File and copy and paste that information into a Winter Severity File [See File: Winter_Severity_Values].

Data Needed

The primary data required for the SWI Calculation comes from MDOT SHA's RWIS network. The seasonal file, monthly files, or storm-by-storm event files for each RWIS site in the state can be downloaded from CHART or by the MDOT SHA RWIS vendor (Lufft) and provided to the analyst.

If you are processing seasonal files all at once, October 1 through March 31 is the defined winter season in the SWI model, and you can request files from this time period. If you are processing files by season or month these may also be crosschecked and compared to EORS event reports. EORS data is not required for calculating the SWI, but it serves as a good point of reference in knowing the dates and times that storms occurred. Note that the method used to identify storms in the SWI methodology may not identify the same storm events in EORS reports.

See Supplemental Information: Exporting Data RWIS Data from SmartView for information on how to export the RWIS data from vendor.

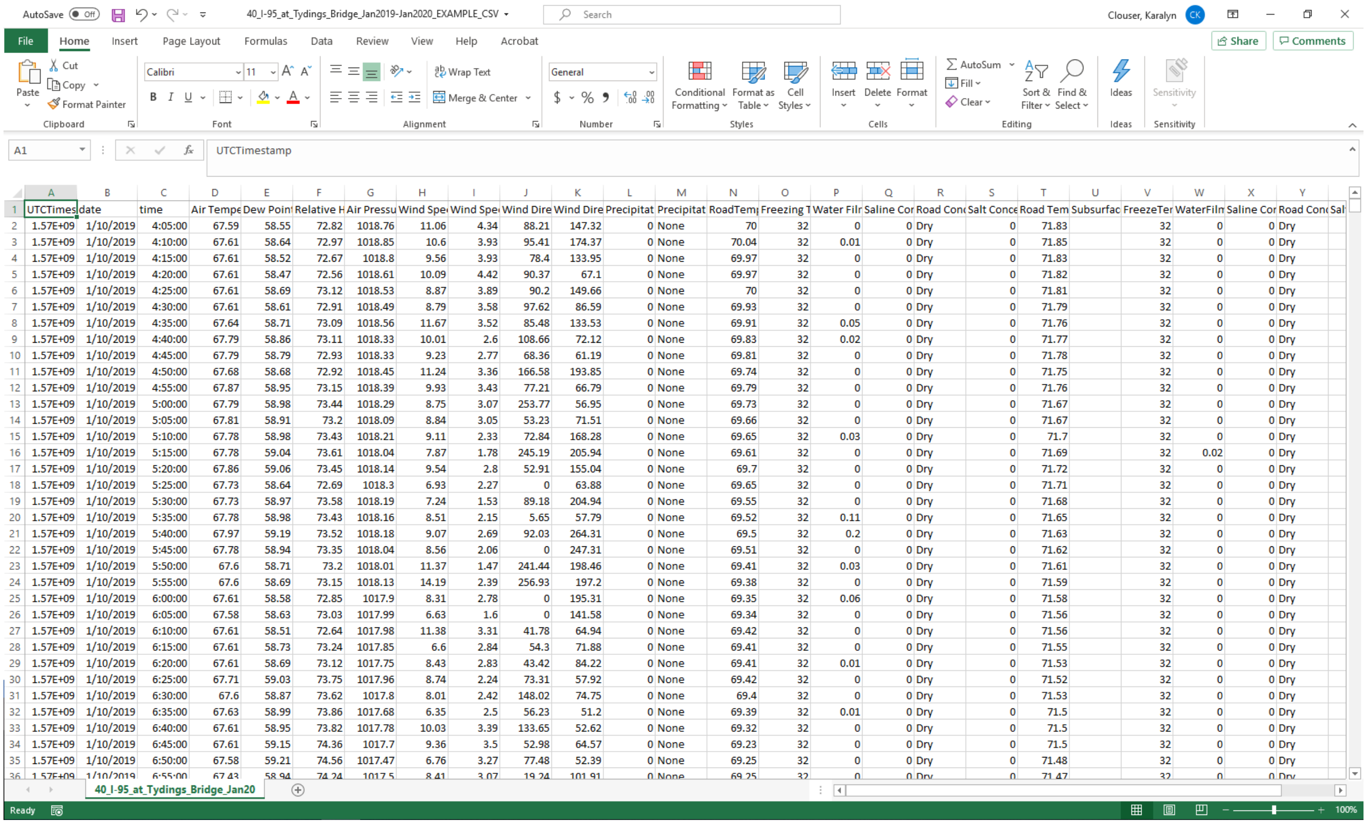
Vendor contact: Lufft, Laura Goodfellow, laura.goodfellow@lufftusainc.com, Phone (805)-335-8500, cell (80) 488-0979

How to Request the Data

Requests for data should include the RWIS site number as assigned by the RWIS vendor, as well as the name of the RWIS site used by MDOT SHA, for example: Site 40 - I-95 at Tydings Bridge [See file: MDSHA_Data_Dictionary.xlsx]. Ideally, to cut down on processing and download time, only data from October through March should be requested. The vendor will pull the data for the requested months and provide it to the analyst.

Files from the vendor include the data and sensor readings and are saved in five-minute intervals (Table 37).

Table 37. Example RWIS data file.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	
1	UTCTimes	date	time	Air Tempe	Dew Point	Relative H	Air Pressu	Wind Spe	Wind Spe	Wind Dire	Wind Dire	Precipitat	Precipitat	RoadTemp	Freezing T	Water Film	Saline Cor	Road Conc	Salt Conce	Road Tem	Subsurfac	FreezeTer	WaterFilm	Saline Cor	Road Conc	Sal
2	1.57E+09	1/10/2019	4:05:00	67.59	58.55	72.82	1018.76	11.06	4.34	88.21	147.32	0	None	70	32	0	0	Dry	0	71.83		32	0	0	Dry	
3	1.57E+09	1/10/2019	4:10:00	67.61	58.64	72.97	1018.85	10.6	3.93	95.41	174.37	0	None	70.04	32	0.01	0	Dry	0	71.85		32	0	0	Dry	
4	1.57E+09	1/10/2019	4:15:00	67.61	58.52	72.67	1018.8	9.56	3.93	78.4	133.95	0	None	69.97	32	0	0	Dry	0	71.83		32	0	0	Dry	
5	1.57E+09	1/10/2019	4:20:00	67.61	58.47	72.56	1018.61	10.09	4.42	90.37	67.1	0	None	69.97	32	0	0	Dry	0	71.82		32	0	0	Dry	
6	1.57E+09	1/10/2019	4:25:00	67.61	58.69	73.12	1018.53	8.87	3.89	90.2	149.66	0	None	70	32	0	0	Dry	0	71.81		32	0	0	Dry	
7	1.57E+09	1/10/2019	4:30:00	67.61	58.61	72.91	1018.49	8.79	3.58	97.62	86.59	0	None	69.93	32	0	0	Dry	0	71.79		32	0	0	Dry	
8	1.57E+09	1/10/2019	4:35:00	67.64	58.71	73.09	1018.56	11.67	3.52	85.48	133.53	0	None	69.91	32	0.05	0	Dry	0	71.76		32	0	0	Dry	
9	1.57E+09	1/10/2019	4:40:00	67.79	58.86	73.11	1018.33	10.01	2.6	108.66	72.12	0	None	69.83	32	0.02	0	Dry	0	71.77		32	0	0	Dry	
10	1.57E+09	1/10/2019	4:45:00	67.79	58.79	72.93	1018.33	9.23	2.77	68.36	61.19	0	None	69.81	32	0	0	Dry	0	71.78		32	0	0	Dry	
11	1.57E+09	1/10/2019	4:50:00	67.68	58.68	72.92	1018.45	11.24	3.36	166.58	193.85	0	None	69.74	32	0	0	Dry	0	71.75		32	0	0	Dry	
12	1.57E+09	1/10/2019	4:55:00	67.87	58.95	73.15	1018.39	9.93	3.43	77.21	66.79	0	None	69.79	32	0	0	Dry	0	71.76		32	0	0	Dry	
13	1.57E+09	1/10/2019	5:00:00	67.79	58.98	73.44	1018.29	8.75	3.07	253.77	56.95	0	None	69.73	32	0	0	Dry	0	71.67		32	0	0	Dry	
14	1.57E+09	1/10/2019	5:05:00	67.81	58.91	73.2	1018.09	8.84	3.05	53.23	71.51	0	None	69.66	32	0	0	Dry	0	71.67		32	0	0	Dry	
15	1.57E+09	1/10/2019	5:10:00	67.78	58.98	73.43	1018.21	9.11	2.33	72.84	168.28	0	None	69.65	32	0.03	0	Dry	0	71.7		32	0	0	Dry	
16	1.57E+09	1/10/2019	5:15:00	67.78	59.04	73.61	1018.04	7.87	1.78	245.19	205.94	0	None	69.61	32	0	0	Dry	0	71.69		32	0.02	0	Dry	
17	1.57E+09	1/10/2019	5:20:00	67.86	59.06	73.45	1018.14	9.54	2.8	52.91	155.04	0	None	69.7	32	0	0	Dry	0	71.72		32	0	0	Dry	
18	1.57E+09	1/10/2019	5:25:00	67.73	58.64	72.69	1018.3	6.93	2.27	0	63.88	0	None	69.65	32	0	0	Dry	0	71.71		32	0	0	Dry	
19	1.57E+09	1/10/2019	5:30:00	67.73	58.97	73.58	1018.19	7.24	1.53	89.18	204.94	0	None	69.55	32	0	0	Dry	0	71.68		32	0	0	Dry	
20	1.57E+09	1/10/2019	5:35:00	67.78	58.98	73.43	1018.16	8.51	2.15	5.65	57.79	0	None	69.52	32	0.11	0	Dry	0	71.65		32	0	0	Dry	
21	1.57E+09	1/10/2019	5:40:00	67.97	59.19	73.52	1018.18	9.07	2.69	92.03	264.31	0	None	69.5	32	0.2	0	Dry	0	71.63		32	0	0	Dry	
22	1.57E+09	1/10/2019	5:45:00	67.78	58.94	73.35	1018.04	8.56	2.06	0	247.31	0	None	69.51	32	0	0	Dry	0	71.62		32	0	0	Dry	
23	1.57E+09	1/10/2019	5:50:00	67.6	58.71	73.2	1018.01	11.37	1.47	241.44	198.46	0	None	69.41	32	0.03	0	Dry	0	71.61		32	0	0	Dry	
24	1.57E+09	1/10/2019	5:55:00	67.6	58.69	73.15	1018.13	14.19	2.39	256.93	197.2	0	None	69.38	32	0	0	Dry	0	71.59		32	0	0	Dry	
25	1.57E+09	1/10/2019	6:00:00	67.61	58.58	72.85	1017.9	8.31	2.78	0	195.31	0	None	69.35	32	0.06	0	Dry	0	71.58		32	0	0	Dry	
26	1.57E+09	1/10/2019	6:05:00	67.58	58.63	73.03	1017.99	6.63	1.6	0	141.58	0	None	69.34	32	0	0	Dry	0	71.56		32	0	0	Dry	
27	1.57E+09	1/10/2019	6:10:00	67.61	58.51	72.64	1017.98	11.38	3.31	41.78	64.94	0	None	69.42	32	0	0	Dry	0	71.56		32	0	0	Dry	
28	1.57E+09	1/10/2019	6:15:00	67.61	58.73	73.24	1017.85	6.6	2.84	54.3	71.88	0	None	69.41	32	0	0	Dry	0	71.55		32	0	0	Dry	
29	1.57E+09	1/10/2019	6:20:00	67.61	58.69	73.12	1017.75	8.43	2.83	43.42	84.22	0	None	69.41	32	0.01	0	Dry	0	71.53		32	0	0	Dry	
30	1.57E+09	1/10/2019	6:25:00	67.71	59.03	73.75	1017.96	8.74	2.24	73.31	57.92	0	None	69.42	32	0	0	Dry	0	71.52		32	0	0	Dry	
31	1.57E+09	1/10/2019	6:30:00	67.6	58.87	73.62	1017.8	8.01	2.42	148.02	74.75	0	None	69.4	32	0	0	Dry	0	71.53		32	0	0	Dry	
32	1.57E+09	1/10/2019	6:35:00	67.63	58.99	73.86	1017.68	6.35	2.5	56.23	51.2	0	None	69.39	32	0.01	0	Dry	0	71.5		32	0	0	Dry	
33	1.57E+09	1/10/2019	6:40:00	67.61	58.95	73.82	1017.78	10.03	3.39	133.65	52.62	0	None	69.32	32	0	0	Dry	0	71.5		32	0	0	Dry	
34	1.57E+09	1/10/2019	6:45:00	67.61	59.15	74.36	1017.7	9.36	3.5	52.98	64.57	0	None	69.23	32	0	0	Dry	0	71.5		32	0	0	Dry	
35	1.57E+09	1/10/2019	6:50:00	67.58	59.21	74.56	1017.47	6.76	3.27	77.48	52.39	0	None	69.25	32	0	0	Dry	0	71.48		32	0	0	Dry	
36	1.57E+09	1/10/2019	6:55:00	67.43	58.94	74.24	1017.5	8.41	3.07	19.24	101.91	0	None	69.25	32	0	0	Dry	0	71.47		32	0	0	Dry	

Step 1. Prior to this point, the analyst/MDOT SHA should set up a cloud folder where the vendor can upload the data files. We recommend having a folder for each winter season. For example: Primary Folder Name: SWI RWIS Data Files, Sub-Folder Name: 2020-2021 Winter Season RWIS Data Files, Sub-Folder Name: October 2020, Sub-Folder Name: October Storm [dates], etc.

(Cloud folder: SWI RWIS Data Files\2020-2021 Winter Season RWIS Data Files\October 2020\Storm [Dates]\ etc.)

*Keeping the files organized will greatly simplify the process.

Step 2. Data files are transferred by the vendor as comma separated value (.csv) format. **In order to save any formatting and formulas used to calculate the SWI re-save the file as an Excel worksheet (.xlxs).**

Step 3. For data management purposes, the analyst should ensure that the file name includes the site number as a prefix to the overall file name and that the file name includes the date range (2019-2020 or Oct2019-Mar2020). Example file name: 40__I-95_at_Tydings_Bridge_Jan2020.xlxs. This assists in quickly identifying the site by its number rather than having to scan through a series of sometimes similar file names.

Part 1. Creating the Storm File

Setting Up the Spreadsheet

Once the data for each RWIS site has been obtained from the vendor, it should then be processed to calculate the variables/inputs for the SWI.

Two Spreadsheets are available as example documents to give an idea of what the format and formulas can look like.

- 40_I-95_at_Tydings_Bridge_Jan2019-Jan2020_EXAMPLE
- 99_MD_20_at_21_Jan2019-Jan2020_EXAMPLE_ALTERNATIVE (example for what the file will look like if the surface temperature data is missing) *Note this is a special circumstance and should only be used when the pavement temperature data is not available.

Step 1. For ease while working with the data file, click on the "View" tab and select "Freeze Panes", click on "Freeze Top Row".

Step 2. Ensure that the data file includes the data fields necessary to complete the SWI calculation. These required fields are:

- Date (NOTE: this may sometimes be in day/month/year format)
- Time (military)
- Air Temperature (degrees F)
- Wind Speed Average (mph)
- Precipitation Differential (Diff.)[6]
- Surface Temperature (NOTE: if surface temperature data is not available, the analyst can use air temperature data)

NOTE: If the file is missing any of these fields the SWI calculations cannot be completed for this file. Please report any missing data field to the vendor and request the appropriate sensors be serviced by the RWIS maintenance contractor.

Step 3. Insert 3 columns to the right of the "Road Temperature" (Table 38). Label the first column "No Precip", the second column "Storm?", and the third column "Start/End". These will be used to calculate additional data fields within the data file that are necessary for the SWI calculation.

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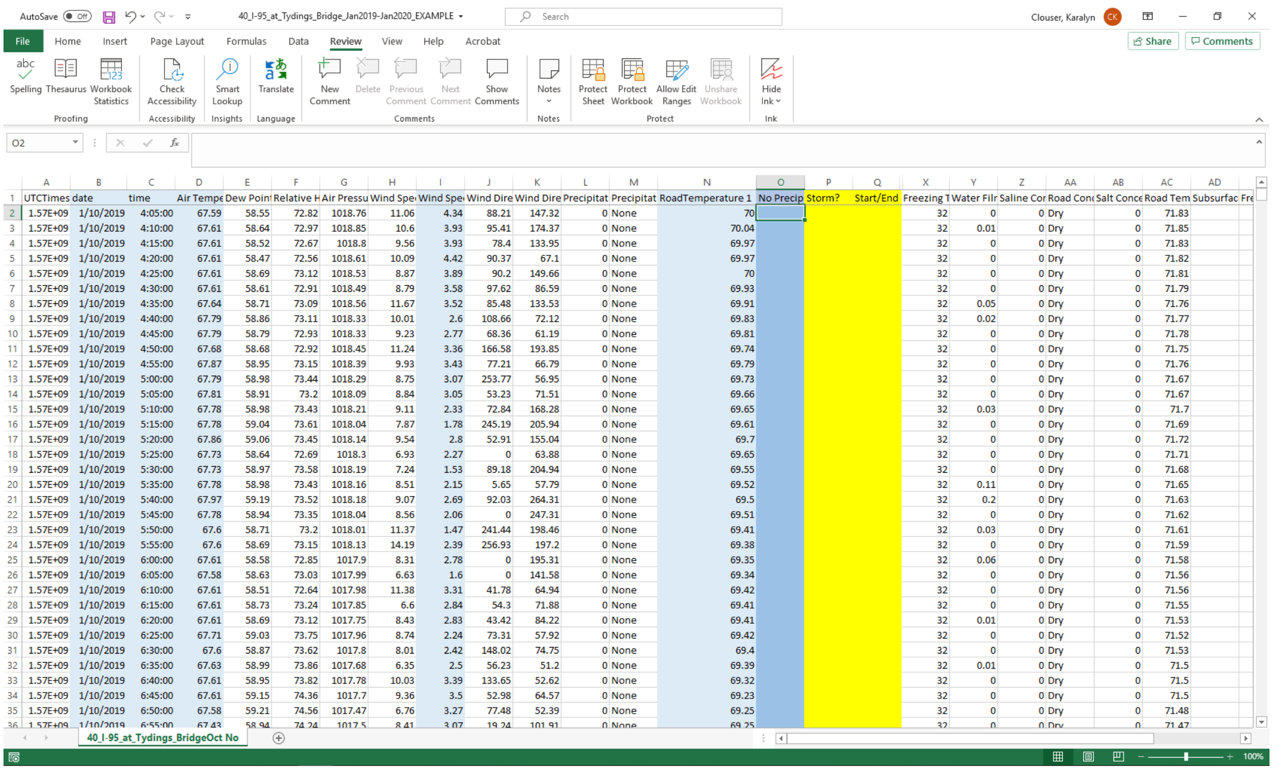
[6] Precipitation quantity is measured by the sensor for one minute out of a five-minute interval. Precipitation quantity is calculated by means of the correlation of raindrop size and speed by the sensor and measured in units of mils (thousands of an inch).

Table 38. RWIS data Excel file showing Part 1, Step 3 – inserting columns



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	X	Y	Z	AA	AB	AC	AD	
1	UTCTimes	date	time	Air Tempe	Dew Point	Relative H	Air Pressu	Wind Spe	Wind Spe	Wind Dire	Wind Dire	Precipitat	Precipitat	RoadTemperature 1	No Precip	Storm?	Start/End	Freezing T	Water Filr	Saline Cor	Road Con	Salt Conce	Road Tem	Subsurfac	Fre
2	1.57E+09	1/10/2019	4:05:00	67.59	58.55	72.82	1018.76	11.06	4.34	88.21	147.32	0	None	70				32	0	0	Dry	0	71.83		
3	1.57E+09	1/10/2019	4:10:00	67.61	58.64	72.97	1018.85	10.6	3.93	95.41	174.37	0	None	70.04				32	0.01	0	Dry	0	71.85		
4	1.57E+09	1/10/2019	4:15:00	67.61	58.52	72.67	1018.8	9.56	3.93	78.4	133.95	0	None	69.97				32	0	0	Dry	0	71.83		
5	1.57E+09	1/10/2019	4:20:00	67.61	58.47	72.56	1018.61	10.09	4.42	90.37	67.1	0	None	69.97				32	0	0	Dry	0	71.82		
6	1.57E+09	1/10/2019	4:25:00	67.61	58.69	73.12	1018.53	8.87	3.89	90.2	149.66	0	None	70				32	0	0	Dry	0	71.81		
7	1.57E+09	1/10/2019	4:30:00	67.61	58.61	72.91	1018.49	8.79	3.58	97.62	86.59	0	None	69.93				32	0	0	Dry	0	71.79		
8	1.57E+09	1/10/2019	4:35:00	67.64	58.71	73.09	1018.56	11.67	3.52	85.48	133.53	0	None	69.91				32	0.05	0	Dry	0	71.76		
9	1.57E+09	1/10/2019	4:40:00	67.79	58.86	73.11	1018.33	10.01	2.6	108.66	72.12	0	None	69.83				32	0.02	0	Dry	0	71.77		
10	1.57E+09	1/10/2019	4:45:00	67.79	58.79	72.93	1018.33	9.23	2.77	68.36	61.19	0	None	69.81				32	0	0	Dry	0	71.78		
11	1.57E+09	1/10/2019	4:50:00	67.68	58.68	72.92	1018.45	11.24	3.36	166.58	193.85	0	None	69.74				32	0	0	Dry	0	71.75		
12	1.57E+09	1/10/2019	4:55:00	67.87	58.95	73.15	1018.39	9.93	3.43	77.21	66.79	0	None	69.79				32	0	0	Dry	0	71.76		
13	1.57E+09	1/10/2019	5:00:00	67.79	58.98	73.44	1018.29	8.75	3.07	253.77	56.95	0	None	69.73				32	0	0	Dry	0	71.67		
14	1.57E+09	1/10/2019	5:05:00	67.81	58.91	73.2	1018.09	8.84	3.05	53.23	71.51	0	None	69.66				32	0	0	Dry	0	71.67		
15	1.57E+09	1/10/2019	5:10:00	67.78	58.98	73.43	1018.21	9.11	2.33	72.84	168.28	0	None	69.65				32	0.03	0	Dry	0	71.7		
16	1.57E+09	1/10/2019	5:15:00	67.78	59.04	73.61	1018.04	7.87	1.78	245.19	205.94	0	None	69.61				32	0	0	Dry	0	71.69		
17	1.57E+09	1/10/2019	5:20:00	67.86	59.06	73.45	1018.14	9.54	2.8	52.91	155.04	0	None	69.7				32	0	0	Dry	0	71.72		
18	1.57E+09	1/10/2019	5:25:00	67.73	58.64	72.69	1018.3	6.93	2.27	0	63.88	0	None	69.65				32	0	0	Dry	0	71.71		
19	1.57E+09	1/10/2019	5:30:00	67.73	58.97	73.58	1018.19	7.24	1.53	89.18	204.94	0	None	69.55				32	0	0	Dry	0	71.68		
20	1.57E+09	1/10/2019	5:35:00	67.78	58.98	73.43	1018.16	8.51	2.15	5.65	57.79	0	None	69.52				32	0.11	0	Dry	0	71.65		
21	1.57E+09	1/10/2019	5:40:00	67.97	59.19	73.52	1018.18	9.07	2.69	92.03	264.31	0	None	69.5				32	0.2	0	Dry	0	71.63		
22	1.57E+09	1/10/2019	5:45:00	67.78	58.94	73.35	1018.04	8.56	2.06	0	247.31	0	None	69.51				32	0	0	Dry	0	71.62		
23	1.57E+09	1/10/2019	5:50:00	67.6	58.71	73.2	1018.01	11.37	1.47	241.44	198.46	0	None	69.41				32	0.03	0	Dry	0	71.61		
24	1.57E+09	1/10/2019	5:55:00	67.6	58.69	73.15	1018.13	14.19	2.39	256.93	197.2	0	None	69.38				32	0	0	Dry	0	71.59		
25	1.57E+09	1/10/2019	6:00:00	67.61	58.58	72.85	1017.9	8.31	2.78	0	195.31	0	None	69.35				32	0.06	0	Dry	0	71.58		
26	1.57E+09	1/10/2019	6:05:00	67.58	58.63	73.03	1017.99	6.63	1.6	0	141.58	0	None	69.34				32	0	0	Dry	0	71.56		
27	1.57E+09	1/10/2019	6:10:00	67.61	58.51	72.64	1017.98	11.38	3.31	41.78	64.94	0	None	69.42				32	0	0	Dry	0	71.56		
28	1.57E+09	1/10/2019	6:15:00	67.61	58.73	73.24	1017.85	6.6	2.84	54.3	71.88	0	None	69.41				32	0	0	Dry	0	71.55		
29	1.57E+09	1/10/2019	6:20:00	67.61	58.69	73.12	1017.75	8.43	2.83	43.42	84.22	0	None	69.41				32	0.01	0	Dry	0	71.53		
30	1.57E+09	1/10/2019	6:25:00	67.71	59.03	73.75	1017.96	8.74	2.24	73.31	57.92	0	None	69.42				32	0	0	Dry	0	71.52		
31	1.57E+09	1/10/2019	6:30:00	67.6	58.87	73.62	1017.8	8.01	2.42	148.02	74.75	0	None	69.4				32	0	0	Dry	0	71.53		
32	1.57E+09	1/10/2019	6:35:00	67.63	58.99	73.86	1017.68	6.35	2.5	56.23	51.2	0	None	69.39				32	0.01	0	Dry	0	71.5		
33	1.57E+09	1/10/2019	6:40:00	67.61	58.95	73.82	1017.78	10.03	3.39	133.65	52.62	0	None	69.32				32	0	0	Dry	0	71.5		
34	1.57E+09	1/10/2019	6:45:00	67.61	59.15	74.36	1017.7	9.36	3.5	52.98	64.57	0	None	69.23				32	0	0	Dry	0	71.5		
35	1.57E+09	1/10/2019	6:50:00	67.58	59.21	74.56	1017.47	6.76	3.27	77.48	52.39	0	None	69.25				32	0	0	Dry	0	71.48		
36	1.57E+09	1/10/2019	6:55:00	67.43	58.94	74.24	1017.5	8.41	3.07	19.24	101.91	0	None	69.25				32	0	0	Dry	0	71.47		

The following information will be calculated in these columns. Note that the formula for each column is provided below as well as the formula that was used in the example spreadsheets. The **bolded text** refers to the column header but please be aware that these names may change slightly between files.

- No Precip – This column determines whether precipitation was present for that row of data. If precipitation differential > 0, assign a value of 1, else 0.
  - Formula
    - = IF (**Precipitation Diff**. = 0, 1, 0)
  - *Formula Used in Example Spreadsheet*
    - *=IF(L2=0,1,0)*
- Storm? – This field determines whether a storm is occurring, and the precipitation associated with it. If Surface Temperature < 35°F and Precipitation Differential >0, then assign the value of the Precipitation Differential for that time period, else 0. (NOTE: If surface temperature data is not available, use the alternative formula listed below.)
  - Formula
    - =IF (**RoadTemperature** < 35, IF (**Precipitation Diff**. > 0, **Precipitation Diff**., 0), 0)
  - *Formula Used in Example Spreadsheet*
    - *=IF(N2<35,IF(L2>0,L2,0),0)*
  - Formula Used Only if Surface Temperature Data is Not Available

        - If (**Air Temperature** < 35, IF (**Precipitation Diff**. > 0, **Precipitation Diff**., 0), 0)
    - *Formula Used in Example Alternative Spreadsheet (Use this formula only if surface temperature data is <u>not</u> available)*
        - *=IF(D2<35,IF(L2>0,L2,0),0)*
- Start/End – This field is a variable used to count the number of 5-minute periods of precipitation during a storm, as well as to flag the beginning and end of the storm. This field will be used below for the identification of storms.
    - Formula
        - IF (**Storm?** = 0, 0, 1)
    - *Formula Used in Example Spreadsheet*
        - *IF(P2=0,0,1)*

Step 4. Copy and paste these formulas into each row of the data file. To do this quickly, use your mouse to select the three cells, hit CTRL+C to copy, then CTRL+Shift+Down Arrow to highlight all the rows in the spreadsheet, then CTRL+V to paste. Once the equations have been pasted, the analyst should click in a few from each column to ensure that the copied formulas are referencing the correct cells and completing the expected calculations (Table 39).

Table 39. RWIS data Excel file with new columns populated with data following insertion of the equations.

R1 — Storm Total Precip

	J	K	L	M	N	O	P	Q	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1	Wind Dire	Wind Dire	Precipitat	Precipitat	RoadTemperature 1	No Precip	Storm?	Start/End	Freezing T	Water Filr	Saline Cor	Road Conc	Salt Conce	Road Tem	Subsurfac	FreezeTer	WaterFilm	Saline Cor	Road Conc	Salt Conc	Visibility	Visibilty feet
2	88.21	147.32	0	None	70	1	0	0	32	0	0	Dry	0	71.83		32	0	0	Dry	0		
3	95.41	174.37	0	None	70.04	1	0	0	32	0.01	0	Dry	0	71.85		32	0	0	Dry	0		
4	78.4	133.95	0	None	69.97	1	0	0	32	0	0	Dry	0	71.83		32	0	0	Dry	0		
5	90.37	67.1	0	None	69.97	1	0	0	32	0	0	Dry	0	71.82		32	0	0	Dry	0		
6	90.2	149.66	0	None	70	1	0	0	32	0	0	Dry	0	71.81		32	0	0	Dry	0		
7	97.62	86.59	0	None	69.93	1	0	0	32	0	0	Dry	0	71.79		32	0	0	Dry	0		
8	85.48	133.53	0	None	69.91	1	0	0	32	0.05	0	Dry	0	71.76		32	0	0	Dry	0		
9	108.66	72.12	0	None	69.83	1	0	0	32	0.02	0	Dry	0	71.77		32	0	0	Dry	0		
10	68.36	61.19	0	None	69.81	1	0	0	32	0	0	Dry	0	71.78		32	0	0	Dry	0		
11	166.58	193.85	0	None	69.74	1	0	0	32	0	0	Dry	0	71.75		32	0	0	Dry	0		
12	77.21	66.79	0	None	69.79	1	0	0	32	0	0	Dry	0	71.76		32	0	0	Dry	0		
13	253.77	56.95	0	None	69.73	1	0	0	32	0	0	Dry	0	71.67		32	0	0	Dry	0		
14	53.23	71.51	0	None	69.66	1	0	0	32	0	0	Dry	0	71.67		32	0	0	Dry	0		
15	72.84	168.28	0	None	69.65	1	0	0	32	0.03	0	Dry	0	71.7		32	0	0	Dry	0		
16	245.19	205.94	0	None	69.61	1	0	0	32	0	0	Dry	0	71.69		32	0.02	0	Dry	0		
17	52.91	155.04	0	None	69.7	1	0	0	32	0	0	Dry	0	71.72		32	0	0	Dry	0		
18	0	63.88	0	None	69.65	1	0	0	32	0	0	Dry	0	71.71		32	0	0	Dry	0		
19	89.18	204.94	0	None	69.55	1	0	0	32	0	0	Dry	0	71.68		32	0	0	Dry	0		
20	5.65	57.79	0	None	69.52	1	0	0	32	0.11	0	Dry	0	71.65		32	0	0	Dry	0		
21	92.03	264.31	0	None	69.5	1	0	0	32	0.2	0	Dry	0	71.63		32	0	0	Dry	0		
22	0	247.31	0	None	69.51	1	0	0	32	0	0	Dry	0	71.62		32	0	0	Dry	0		
23	241.44	198.46	0	None	69.41	1	0	0	32	0.03	0	Dry	0	71.61		32	0	0	Dry	0		
24	256.93	197.2	0	None	69.38	1	0	0	32	0	0	Dry	0	71.59		32	0	0	Dry	0		
25	0	195.31	0	None	69.35	1	0	0	32	0.06	0	Dry	0	71.58		32	0	0	Dry	0		
26	0	141.58	0	None	69.34	1	0	0	32	0	0	Dry	0	71.56		32	0	0	Dry	0		
27	41.78	64.94	0	None	69.42	1	0	0	32	0	0	Dry	0	71.56		32	0	0	Dry	0		
28	54.3	71.88	0	None	69.41	1	0	0	32	0	0	Dry	0	71.55		32	0	0	Dry	0		
29	43.42	84.22	0	None	69.41	1	0	0	32	0.01	0	Dry	0	71.53		32	0	0	Dry	0		
30	73.31	57.92	0	None	69.42	1	0	0	32	0	0	Dry	0	71.52		32	0	0	Dry	0		
31	148.02	74.75	0	None	69.4	1	0	0	32	0	0	Dry	0	71.53		32	0	0	Dry	0		
32	56.23	51.2	0	None	69.39	1	0	0	32	0.01	0	Dry	0	71.5		32	0	0	Dry	0		
33	133.65	52.62	0	None	69.32	1	0	0	32	0	0	Dry	0	71.5		32	0	0	Dry	0		
34	52.98	64.57	0	None	69.23	1	0	0	32	0	0	Dry	0	71.5		32	0	0	Dry	0		
35	77.48	52.39	0	None	69.25	1	0	0	32	0	0	Dry	0	71.48		32	0	0	Dry	0		
36	19.24	101.91	0	None	69.25	1	0	0	32	0	0	Dry	0	71.47		32	0	0	Dry	0		

40_I-95_at_Tydings_BridgeOct No — Average: 18.08352941 Count: 12 Sum: 108.5011765

Identifying Storms

With these three variables created in the previous section (1. No Precip, 2. Storm?, 3. Start/End) (Table 39), it is now possible to search through the data and identify where storms have occurred.

This is done by highlighting the Start/End column and performing a control-F function in Excel to search the Start/End column for values of 1 within the values of the column (Table 40).

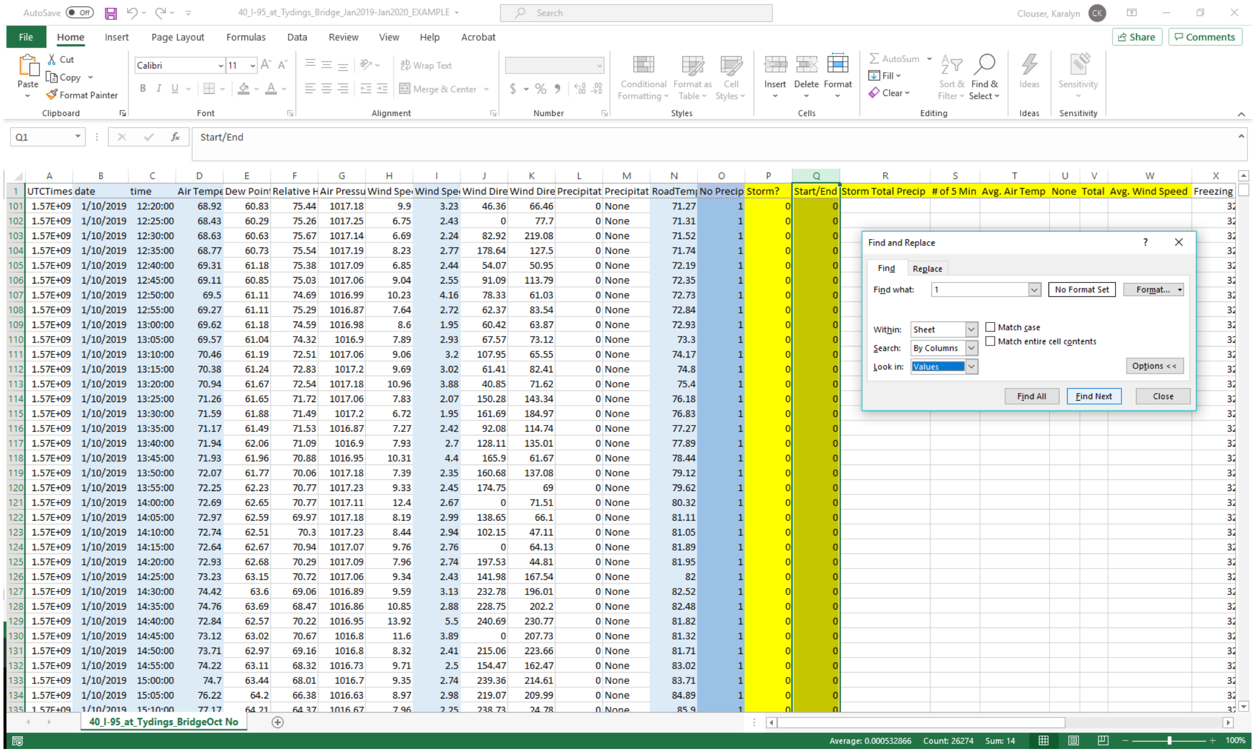
Step 1. Select the “Start/End” column and hit CTRL+F (Table 40).

Step 2. Click on “Options” in the “Find and Replace” box that pops up (Table 40).

- In the “Find What” box enter the number “1”
- In the “Search” drop-down select “By Columns”
- In the “Look In” drop-down select “Values”

NOTE: If an advanced search is not used to find values, the search for values of 1 will only look at the formula used in the column itself, not the actual results. Another option is to CTRL+C and CTRL+V the column so that it pastes the value that you see in each cell; the drawback to this approach is that you lose the formula.

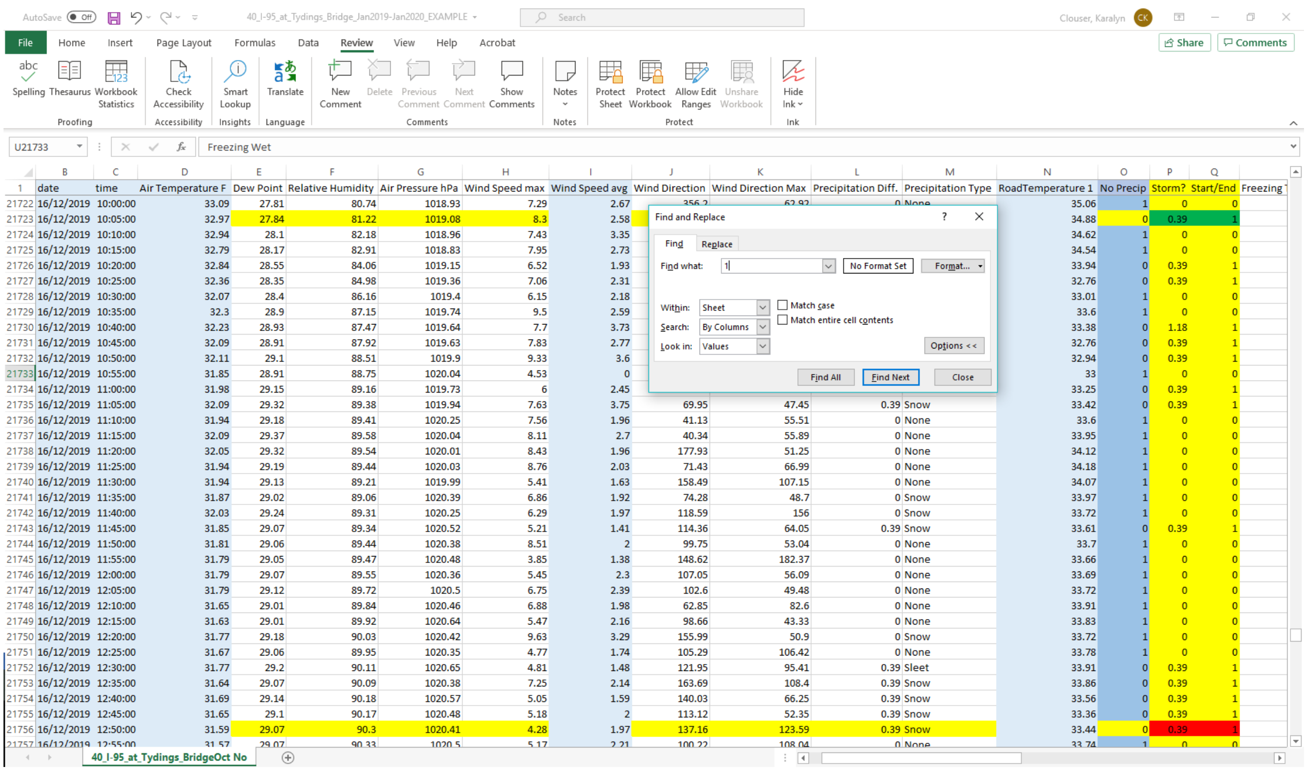
Table 40. RWIS data Excel file showing Identifying Storms, Steps 1 and 2.



Step 3. Click “Find Next” - when an initial value of 1 is identified (**start of a storm**), that cell should be colored **green** (Table 41). Then the analyst should scroll down the spreadsheet watching the values in the “Start/End” column. The analyst should look for a value of 1 followed

by a time period of 4 hours with 0 values is identified. This indicates the **end of a storm**, that cell should be colored **red**.

Table 41. RWIS data Excel file showing Identifying Storms, Steps 3 and 4.



1	date	time	Air Temperature F	Dew Point	Relative Humidity	Air Pressure hPa	Wind Speed max	Wind Speed avg	Wind Direction	Wind Direction Max	Precipitation Diff.	Precipitation Type	RoadTemperature 1	No Precip	Storm?	Start/End	Freezing
21722	16/12/2019	10:00:00	33.09	27.81	80.74	1018.93	7.29	2.67	356.2	62.92	0	None	35.06	1	0	0	
21723	16/12/2019	10:05:00	32.97	27.84	81.22	1019.08	8.3	2.58					34.88	0	0.39	1	
21724	16/12/2019	10:10:00	32.94	28.1	82.18	1018.96	7.43	3.35					34.62	1	0	0	
21725	16/12/2019	10:15:00	32.79	28.17	82.91	1018.83	7.95	2.73					34.54	1	0	0	
21726	16/12/2019	10:20:00	32.84	28.55	84.06	1019.15	6.52	1.93					33.94	0	0.39	1	
21727	16/12/2019	10:25:00	32.36	28.35	84.98	1019.36	7.06	2.31					32.76	0	0.39	1	
21728	16/12/2019	10:30:00	32.07	28.4	86.16	1019.4	6.15	2.18					33.01	1	0	0	
21729	16/12/2019	10:35:00	32.3	28.9	87.15	1019.74	9.5	2.59					33.6	1	0	0	
21730	16/12/2019	10:40:00	32.23	28.93	87.47	1019.64	7.7	3.73					33.38	0	1.18	1	
21731	16/12/2019	10:45:00	32.09	28.91	87.92	1019.63	7.83	2.77					32.76	0	0.39	1	
21732	16/12/2019	10:50:00	32.11	29.1	88.51	1019.9	9.33	3.6					32.94	0	0.39	1	
21733	16/12/2019	10:55:00	31.85	28.91	88.75	1020.04	4.53	0					33	1	0	0	
21734	16/12/2019	11:00:00	31.98	29.15	89.16	1019.73	6	2.45					33.25	0	0.39	1	
21735	16/12/2019	11:05:00	32.09	29.32	89.38	1019.94	7.63	3.75	69.95	47.45	0.39	Snow	33.42	0	0.39	1	
21736	16/12/2019	11:10:00	31.94	29.18	89.41	1020.25	7.56	1.96	41.13	55.51	0	None	33.6	1	0	0	
21737	16/12/2019	11:15:00	32.09	29.37	89.58	1020.04	8.11	2.7	40.34	55.89	0	None	33.95	1	0	0	
21738	16/12/2019	11:20:00	32.05	29.32	89.54	1020.01	8.43	1.96	177.93	51.25	0	None	34.12	1	0	0	
21739	16/12/2019	11:25:00	31.94	29.19	89.44	1020.03	8.76	2.03	71.43	66.99	0	None	34.18	1	0	0	
21740	16/12/2019	11:30:00	31.94	29.13	89.21	1019.99	5.41	1.63	158.49	107.15	0	None	34.07	1	0	0	
21741	16/12/2019	11:35:00	31.87	29.02	89.06	1020.39	6.86	1.92	74.28	48.7	0	Snow	33.97	1	0	0	
21742	16/12/2019	11:40:00	32.03	29.24	89.31	1020.25	6.29	1.97	118.59	156	0	Snow	33.72	1	0	0	
21743	16/12/2019	11:45:00	31.85	29.07	89.34	1020.52	5.21	1.41	114.36	64.05	0.39	Snow	33.61	0	0.39	1	
21744	16/12/2019	11:50:00	31.81	29.06	89.44	1020.38	8.51	2	99.75	53.04	0	None	33.7	1	0	0	
21745	16/12/2019	11:55:00	31.79	29.05	89.47	1020.48	3.85	1.38	148.62	182.37	0	None	33.66	1	0	0	
21746	16/12/2019	12:00:00	31.79	29.07	89.55	1020.36	5.45	2.3	107.05	56.09	0	None	33.69	1	0	0	
21747	16/12/2019	12:05:00	31.79	29.12	89.72	1020.5	6.75	2.39	102.6	49.48	0	None	33.72	1	0	0	
21748	16/12/2019	12:10:00	31.65	29.01	89.84	1020.46	6.88	1.98	62.85	82.6	0	None	33.91	1	0	0	
21749	16/12/2019	12:15:00	31.63	29.01	89.92	1020.64	5.47	2.16	98.66	43.33	0	None	33.83	1	0	0	
21750	16/12/2019	12:20:00	31.77	29.18	90.03	1020.42	9.63	3.29	155.99	50.9	0	Snow	33.72	1	0	0	
21751	16/12/2019	12:25:00	31.67	29.06	89.95	1020.35	4.77	1.74	105.29	106.42	0	None	33.78	1	0	0	
21752	16/12/2019	12:30:00	31.77	29.2	90.11	1020.65	4.81	1.48	121.95	95.41	0.39	Sleet	33.91	0	0.39	1	
21753	16/12/2019	12:35:00	31.64	29.07	90.09	1020.38	7.25	2.14	163.69	108.4	0.39	Snow	33.86	0	0.39	1	
21754	16/12/2019	12:40:00	31.69	29.14	90.18	1020.57	5.05	1.59	140.03	66.25	0.39	Snow	33.56	0	0.39	1	
21755	16/12/2019	12:45:00	31.65	29.1	90.17	1020.48	5.18	2	113.12	52.35	0.39	Snow	33.36	0	0.39	1	
21756	16/12/2019	12:50:00	31.59	29.07	90.3	1020.41	4.28	1.97	137.16	123.59	0.39	Snow	33.44	0	0.39	1	
21757	16/12/2019	12:55:00	31.57	29.07	90.33	1020.5	5.17	2.21	100.22	108.04	0	None	33.74	1	0	0	

NOTE: Some storms may just be a single line (5-minute storm).

Step 4. Then the CTRL+F search can be used once again to find the start of the next storm (Table 41).

Step 5. Follow this procedure until you reach the end of 1 values in the "Start/End" column (Table 41).

Once reaching the end of the file, you have completed identifying all of the storms for the selected file.

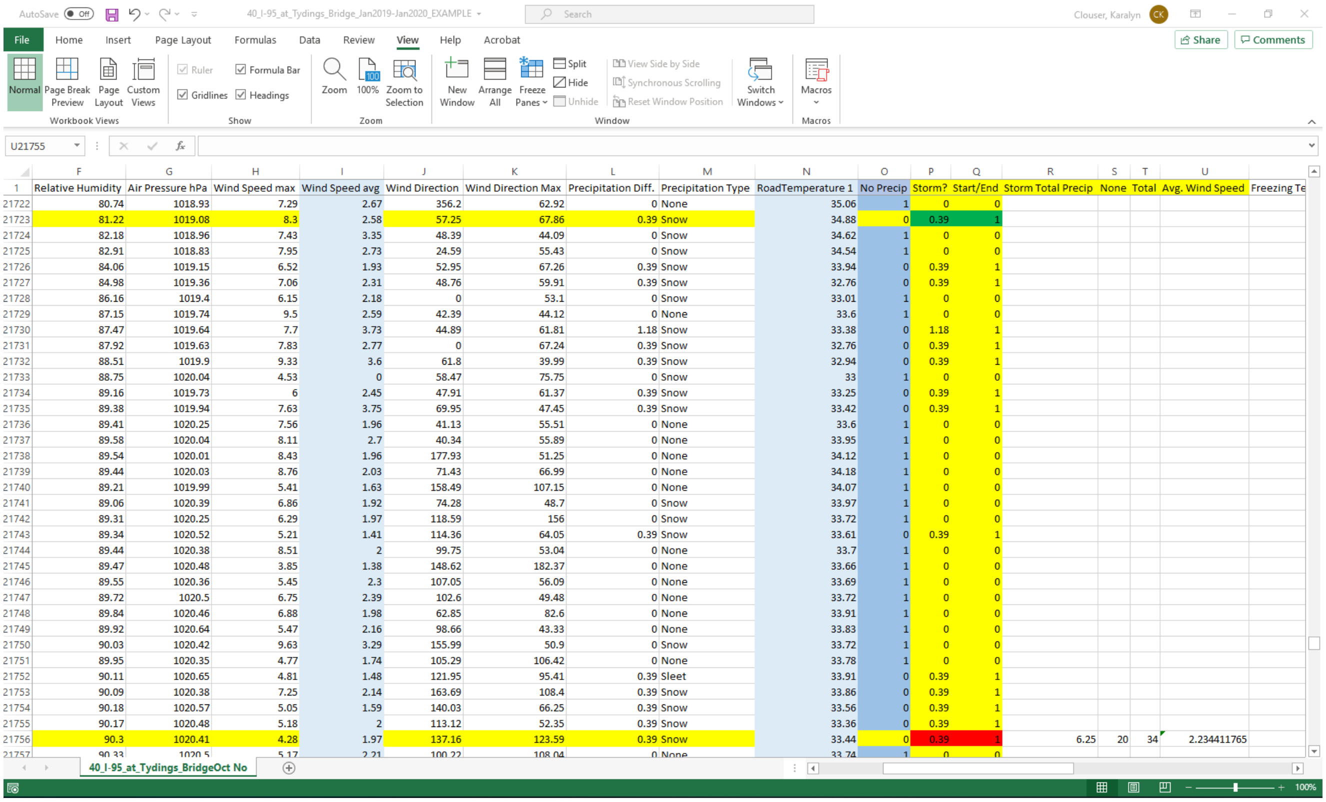
Calculating Storm Data

Once all storms have been identified for a site, additional calculations will be made for each storm (shown as columns R-W in Table 41 and Table 42).

Step 1. Insert 4 columns to the right of the "Start/End" column. These columns will be used to calculate data for each storm identified. Note that the formula for each column is provided below as well as the formula that was used in the example spreadsheets. The **bolded text** refers to the column header but please be aware that these names may change slightly between files.

- Storm Total Precip – This column will be used to calculate the sum of all precipitation associated with each storm. This is calculated by summing the "Storm?" cells during a storm event. This will provide the measured precipitation during the storm in mils (thousands of an inch).
    - Formula
        - =SUM (**Storm?start**: **Storm?end**)
    - *Formula Used in Example Spreadsheet*
        - *=SUM(P**start**:P**end**)*
- None – This column will be used to calculate the sum of all 5-minute periods without precipitation that occurred during the storm.
    - Formula
        - =COUNTIF (**No Precip start**: **No Precip end**, 1)
    - Formula Used in Example Spreadsheet
        - =COUNTIF(O**start**:O**end**,1)
- Total – This column will be used to calculate the sum of all 5-minute periods within the storm.
    - Formula
        - =COUNTIF (**No Precip start**: **No Precip end**)
    - Formula Used in Example Spreadsheet
        - =COUNT(O**start**:O**end**)
- Avg Wind Speed – This column will be used to calculate the average wind speed for the storm.
    - Formula
        - =AVERAGE(**Wind Speed start**: **Wind Speed end**)
    - Formula Used in Example Spreadsheet
        - =AVERAGE(I**start**:I**end**)

Table 42. RWIS data Excel file showing Calculating Storm Data steps.



	Relative Humidity	Air Pressure hPa	Wind Speed max	Wind Speed avg	Wind Direction	Wind Direction Max	Precipitation Diff.	Precipitation Type	RoadTemperature 1	No Precip	Storm?	Start/End	Storm Total Precip	None	Total	Avg. Wind Speed	Freezing Te
21722	80.74	1018.93	7.29	2.67	356.2	62.92	0	None	35.06	1	0	0					
21723	81.22	1019.08	8.3	2.58	57.25	67.86	0.39	Snow	34.88	0	0.39	1					
21724	82.18	1018.96	7.43	3.35	48.39	44.09	0	Snow	34.62	1	0	0					
21725	82.91	1018.83	7.95	2.73	24.59	55.43	0	Snow	34.54	1	0	0					
21726	84.06	1019.15	6.52	1.93	52.95	67.26	0.39	Snow	33.94	0	0.39	1					
21727	84.98	1019.36	7.06	2.31	48.76	59.91	0.39	Snow	32.76	0	0.39	1					
21728	86.16	1019.4	6.15	2.18	0	53.1	0	Snow	33.01	1	0	0					
21729	87.15	1019.74	9.5	2.59	42.39	44.12	0	None	33.6	1	0	0					
21730	87.47	1019.64	7.7	3.73	44.89	61.81	1.18	Snow	33.38	0	1.18	1					
21731	87.92	1019.63	7.83	2.77	0	67.24	0.39	Snow	32.76	0	0.39	1					
21732	88.51	1019.9	9.33	3.6	61.8	39.99	0.39	Snow	32.94	0	0.39	1					
21733	88.75	1020.04	4.53	0	58.47	75.75	0	Snow	33	1	0	0					
21734	89.16	1019.73	6	2.45	47.91	61.37	0.39	Snow	33.25	0	0.39	1					
21735	89.38	1019.94	7.63	3.75	69.95	47.45	0.39	Snow	33.42	0	0.39	1					
21736	89.41	1020.25	7.56	1.96	41.13	55.51	0	None	33.6	1	0	0					
21737	89.58	1020.04	8.11	2.7	40.34	55.89	0	None	33.95	1	0	0					
21738	89.54	1020.01	8.43	1.96	177.93	51.25	0	None	34.12	1	0	0					
21739	89.44	1020.03	8.76	2.03	71.43	66.99	0	None	34.18	1	0	0					
21740	89.21	1019.99	5.41	1.63	158.49	107.15	0	None	34.07	1	0	0					
21741	89.06	1020.39	6.86	1.92	74.28	48.7	0	Snow	33.97	1	0	0					
21742	89.31	1020.25	6.29	1.97	118.59	156	0	Snow	33.72	1	0	0					
21743	89.34	1020.52	5.21	1.41	114.36	64.05	0.39	Snow	33.61	0	0.39	1					
21744	89.44	1020.38	8.51	2	99.75	53.04	0	None	33.7	1	0	0					
21745	89.47	1020.48	3.85	1.38	148.62	182.37	0	None	33.66	1	0	0					
21746	89.55	1020.36	5.45	2.3	107.05	56.09	0	None	33.69	1	0	0					
21747	89.72	1020.5	6.75	2.39	102.6	49.48	0	None	33.72	1	0	0					
21748	89.84	1020.46	6.88	1.98	62.85	82.6	0	None	33.91	1	0	0					
21749	89.92	1020.64	5.47	2.16	98.66	43.33	0	None	33.83	1	0	0					
21750	90.03	1020.42	9.63	3.29	155.99	50.9	0	Snow	33.72	1	0	0					
21751	89.95	1020.35	4.77	1.74	105.29	106.42	0	None	33.78	1	0	0					
21752	90.11	1020.65	4.81	1.48	121.95	95.41	0.39	Sleet	33.91	0	0.39	1					
21753	90.09	1020.38	7.25	2.14	163.69	108.4	0.39	Snow	33.86	0	0.39	1					
21754	90.18	1020.57	5.05	1.59	140.03	66.25	0.39	Snow	33.56	0	0.39	1					
21755	90.17	1020.48	5.18	2	113.12	52.35	0.39	Snow	33.36	0	0.39	1					
21756	90.3	1020.41	4.28	1.97	137.16	123.59	0.39	Snow	33.44	0	0.39	1	6.25	20	34	2.234411765	
21757	90.33	1020.5	5.17	2.21	100.22	108.04	0	None	33.74	1	0	0					

Step 2. Copy and paste these formulas into each row of the data file. To do this quickly, use your mouse to select the four cells, hit CTRL+C to copy, then CTRL+Shift+Down Arrow to highlight all the rows in the spreadsheet, then CTRL+V to paste. Once the equations have been pasted, the analyst should click in a few from each column to ensure that the copied formulas are referencing the correct cells and completing the expected calculations

Once these calculations have been completed for each storm identified in the data file, the storm file for that site is complete. The next step is to copy storm-related calculations into the Winter Severity file.

Part 2. Creating the Winter Severity File

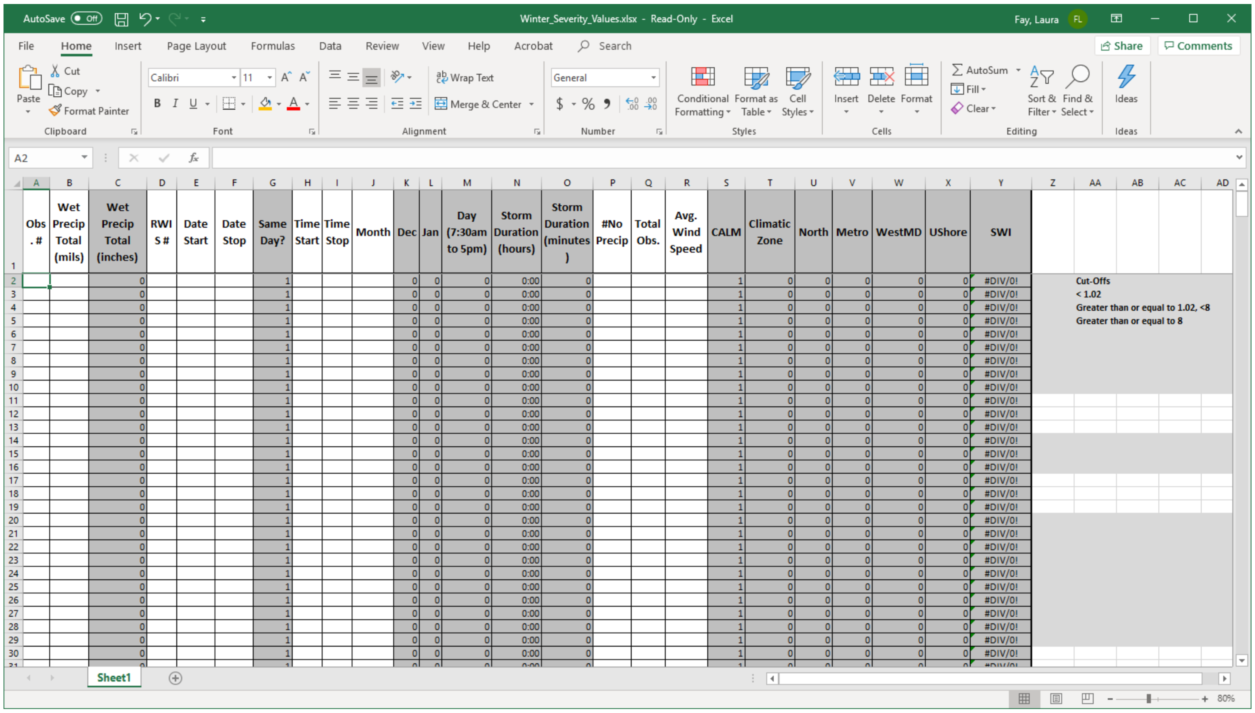
The Winter Severity file ("Winter_Severity_Values") will summarize all of the storms during a time period identified by the user and use the inputted data to calculate the SWI.

Step 1. Copy and paste or enter the following information for each storm identified into the Winter Severity file (Table 43) (Note: not all of the data that needs to be entered is shaded):

- Obs # - the analyst assigns this number; assigning a number to each storm may help with discussing any concerns or findings by reviewing the spreadsheet
- Wet Precip Total (mils) – the sum over the entire storm duration [Column R in the example storm data spreadsheet]

- RWIS # - number (should not have any alphabetic characters) for the RWIS that is used consistently by vendor and MDOT SHA [See file: MDSHA_Data_Dictionary.xlsx]
- Date Start – date storm began on – identified from Storm File [Column B in the example storm data spreadsheet]
- Date Stop – date storm ended – identified from Storm File [Column B in the example storm data spreadsheet]
- Time Start – military time that the storm began – identified from Storm File [Column C in the example storm data spreadsheet]
- Time Stop – military time that the storm ended – identified from Storm File [Column C in the example storm data spreadsheet]
- Month – numeric value for month (e.g. 10 = October; 11 = November; 12 = December; 1 = January; 2 = February) – identified from Storm File
- #No Precip – total number of periods with no/none precipitation during the storm – Previously calculated in Step 1 [Column S in the example storm data spreadsheet]
- Total Obs. – total number of observation periods (includes those with and without precipitation) during the storm – Previously calculated in Calculating Storm Data, Step 1 [Column T in the example storm data spreadsheet]
- Avg. Wind Speed – average of average wind speeds during the storm – Previously calculated in Step 1 [Column U in the example storm data spreadsheet]

Table 43. Winter Severity Values Excel file showing all variables to be calculated including the SWI [Column Y].



	Obs. #	Wet Precip Total (mils)	Wet Precip Total (inches)	RWIS #	Date Start	Date Stop	Same Day?	Time Start	Time Stop	Month	Dec	Jan	Day (7:30am to 5pm)	Storm Duration (hours)	Storm Duration (minutes)	#No Precip	Total Obs.	Avg. Wind Speed	CALM	Climatic Zone	North	Metro	WestMD	UShore	SWI	
2			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	Cut-Offs
3			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	< 1.02
4			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	Greater than or equal to 1.02, <8
5			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	Greater than or equal to 8
6			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
7			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
8			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
9			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
10			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
11			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
12			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
13			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
14			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
15			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
16			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
17			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
18			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
19			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
20			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
21			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
22			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
23			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
24			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
25			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
26			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
27			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
28			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
29			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	
30			0				1				0	0	0	0:00	0				1	0	0	0	0	0	#DIV/0!	

The Winter Severity spreadsheet will calculate the following data fields for you (which are shaded) (Table 43):

- Wet Precip Total (inches) – the spreadsheet will convert the precipitation value entered into the file that was in mils into inches by multiplying by 1,000 [Column C in Table 43]
- Same Day? – the spreadsheet will check to determine if the start and end date of the storm was the same [Column G in Table 43]
- Dec – the spreadsheet is creating an indicator variable, assigning 1 if the storm occurred in December [Column K in Table 43]
- Jan – the spreadsheet is creating an indicator variable, assigning 1 if the storm occurred in January [Column L in Table 43]
- Day – variable to establish whether the storm occurred during daylight hours, between 7:30am and 5pm (no exceptions) (value of 1) or it did not (value of 0) – entered based on information from time fields [Column M in Table 43]
- Storm Duration (hours) – the spreadsheet will calculate, based on the times that the analyst entered, the duration of the storm in hours [Column N in Table 43]
- Storm Duration (mins) – the spreadsheet will convert the storm duration from hours into minutes [Column O in Table 43]
- CALM – if the Avg. Wind Speed is less than 6, a 1 will be assigned, else 0 [Column S in Table 43]
- Climatic Zone – based on the RWIS number that you entered, the climatic zone will be assigned (Column T in Table 43)
- North – if the climatic zone where the RWIS is located is the Northern Tier, a 1 will be assigned; else 0 [Column U in Table 43]
- Metro – if the climatic zone where the RWIS is located is Metro, a 1 will be assigned; else 0 [Column V in Table 43]
- WestMD – if the climatic zone where the RWIS is located is Western Maryland, a 1 will be assigned; else 0 [Column W in Table 43]
- UShore – if the climatic zone where the RWIS is located is the Upper Shore, a 1 will be assigned; else 0 [Column X in Table 43]
- SWI – the model will calculate the SWI and concurrently assign the severity category (green, yellow, or red) [Column Y in Table 43]

Part 3. QA/QC data

Once all of the data is inserted into the spreadsheet, the data analyst should determine the minimum, average, and maximum for each variable for the storms identified for the new winter season. It should be confirmed that these data are within the minimums, maximums used in the model (see Table 44 for data ranges, and Data Summary File for all data ranges). If they are outside of the model's minimums and maximums and not similar to the averages, then the model cannot be expected to provide a reliable output.

Table 44. Summary of data ranges, minimum, average, and maximum for variables used in the SWI model.

Variable	Minimum	Mean	Maximum	Std Dev.
WET_PRECIP	0.0003900	0.07080	2.731	0.1550
DAY	0	0.2525	1.000	0.4345
STORM_DURATION	3.000	368.6	4080	431.3
OCT	0	0.004402	1.000	0.06621
NOV	0	0.06823	1.000	0.2522
DEC	0	0.1593	1.000	0.3660
JAN	0	0.3117	1.000	0.4632
FEB	0	0.2663	1.000	0.4421
MAR	0	0.1895	1.000	0.3920
APR	0	0.0005500	1.000	0.02345
NO_PRECIP_RATIO	0	0.2183	1.000	0.2601
NUM_NO_PRECIP	0	20.58	478.0	36.06
TOTAL_NUM	1	74.74	1089	87.82
CALM	0	0.5827	1.000	0.4932
NORTH	0	0.3865	1.000	0.4870
METRO	0	0.2036	1.000	0.4027
WESTMD	0	0.2746	1.000	0.4464
USHORE	0	0.07263	1.000	0.2596
LOWER	0	0.03714	1.000	0.1891
SOUTHMD	0	0.02559	1.000	0.1579
Maryland Index Number	0	16.83	108.2	30.65

Table 45 provides an example of wind speed data shown as minimum, average, and maximum values, with excessively high values highlight in yellow. The highlighted yellow values were flagged for additional QA/QC. This may suggest that either there are some errors in the data computation, or it may suggest that there winter is unlike any of the previous years.

Table 45. Example summary data file showing wind gust speeds (mph) as the minimum, average, and maximum values. Excessively high or low values are highlighted in yellow.

	Day		Month	Time			Wind Gust		
File Name	Start	Stop		Start	Stop	Wind Speed Avg.	Min.	Avg.	Max.
US 15 at MD 140	11/27/2012	11/27/2012	November	11:31	14:46	6.03124	0.9208	12.76891	38.7887
US 15 at MD 140	12/24/2012	12/25/2012	December	19:30	0:50	2.176275	0	72.06027	276.0098
US 15 at MD 140	12/26/2012	12/27/2012	December	13:50	6:50	11.49189	0	28.49136	284.8725
US 15 at MD 140	12/29/2012	12/29/2012	December	9:15	18:55	3.434147	0	108.9309	276.9306
US 15 at MD 140	1/25/2013	1/25/2013	January	19:30	20:45	5.438475	140.0767	168.1971	194.4039
US 15 at MD 140	1/28/2013	1/28/2013	January	9:45	16:00	8.915707	179.2107	211.1449	241.8251
US 15 at MD 140	2/1/2013	2/1/2013	February	10:50	10:50	6.4456	-1000	-1000	-1000
US 15 at MD 140	2/5/2013	2/5/2013	February	20:50	21:10	4.35078	209.8273	220.0021	228.0131
US 15 at MD 140	2/11/2013	2/11/2013	February	9:25	10:30	1.562071	0	95.69606	258.5146
US 15 at MD 140	2/14/2013	2/14/2013	February	0:25	3:00	2.712044	0	24.171	284.9876
US 15 at MD 140	2/16/2013	2/16/2013	February	8:50	12:25	2.799023	0	33.9824	226.747
US 15 at MD 140	2/19/2013	2/19/2013	February	13:45	15:35	11.59507	204.3025	216.4481	228.8188
US 15 at MD 140	3/6/2013	3/6/2013	March	7:10	14:30	8.086745	0	43.31291	131.6744
US 15 at MD 140	3/18/2013	3/19/2013	March	19:50	1:25	3.158646	0	56.36642	267.6075
US 15 at MD 140	3/25/2013	3/25/2013	March	8:00	11:55	2.333173	0	23.34931	194.1737
US 15 at MD 140	11/26/2013	11/26/2013	November	14:04	16:44	4.164527	176.7936	215.6172	275.3192
US 15 at MD 140	11/26/2013	11/27/2013	November	22:24	3:09	7.749405	0	17.06064	55.1329

Part 4. SWI Calculation

In the Winter Severity file [Column Y in Table 43], SWI is the calculated. The equation for the SWI is as follows:

Severity Index = 113.7*(WET_PRECIP)+

-2.233*(DAY)+

0.0241*(STORM_DURATION)+

-1.62*(DEC)+

-3.058*(JAN)+

-17.254*(NO_PRECIP_RATIO)+

-1.331*(CALM)+

-3.408*(NORTH)+

-3.183*(METRO)+

-5.938*(WESTMD)+

-5.912*(USHORE)+

10.224

Where:

WET_PRECIP – the total wet precipitation during a storm (in inches)

DAY – “1” if the storm occurred within the 7:30am and 5:00pm time period; “0” if the storm occurred outside of this time period (e.g. even if it started at 7:25am and ended by 5pm, it would receive a “0”; similarly, even if it started at 7:30am and ended at 5:05pm, it would receive a “0”)

STORM_DURATION – length of the storm in minutes

DEC – 1 if the storm occurred in the month of December; 0 if during another month

JAN – 1 if the storm occurred in the month of January; 0 if during another month

NO_PRECIP_RATIO – the ratio of 5-minute intervals without precipitation/total number of 5-minute intervals over the course of the storm

CALM – 1 if the average wind speed is less than 6mph; 0 if it is greater than or equal to 6mph

NORTH – 1 if the storm occurred in the Northern Tier Climatic Zone; 0 if in another climatic zone (Figure 107)

METRO – 1 if the storm occurred in the Metro Climatic Zone; 0 if in another climatic zone (Figure 107)

WESTMD – 1 if the storm occurred in the Western Maryland Climatic Zone; 0 if in another climatic zone (Figure 107)

USHORE – 1 if the storm occurred in the Upper Shore Climatic Zone; 0 if in another climatic zone (Figure 107)

10.224 is the constant. This accounts for error unexplained by the model.

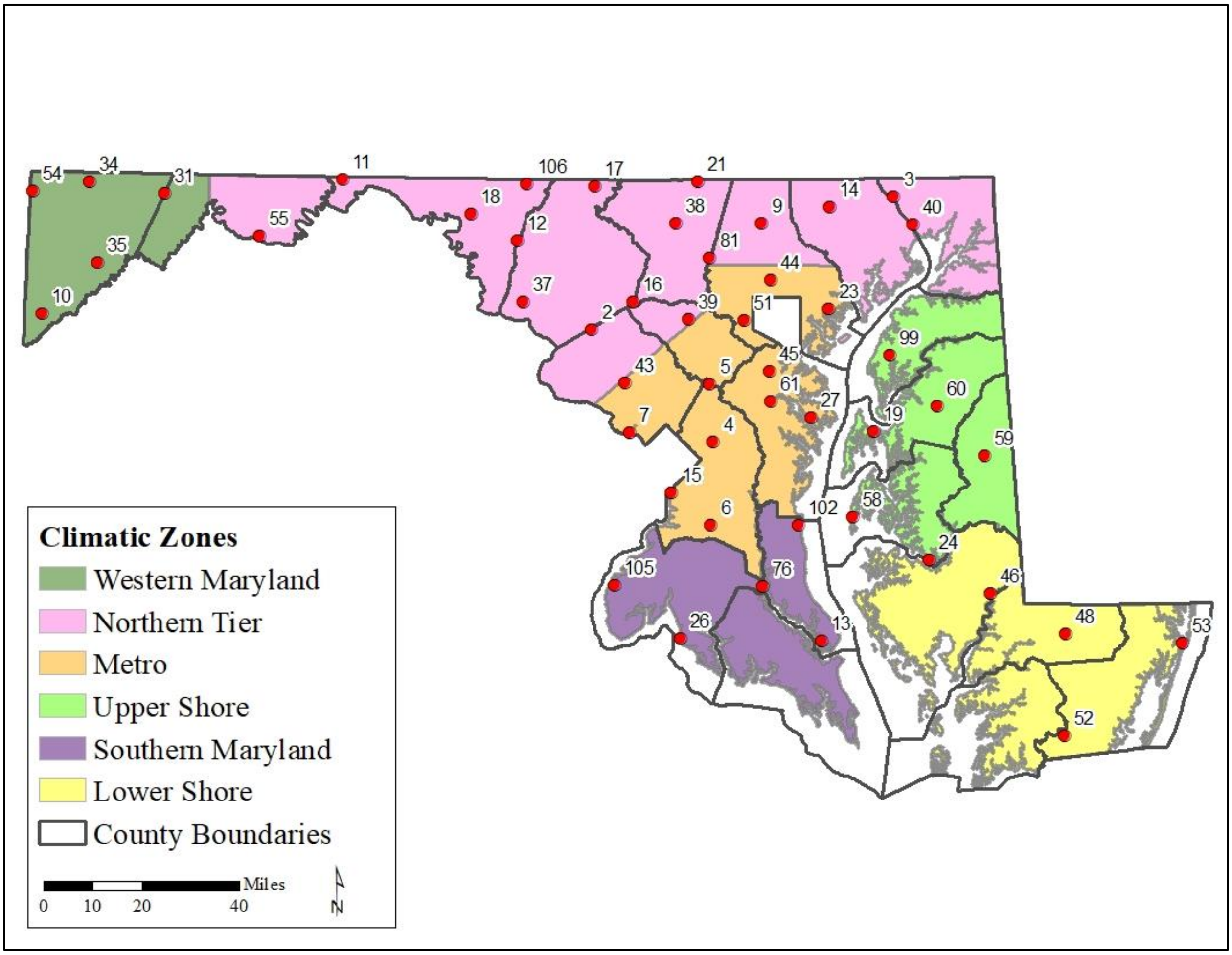


Figure 107. Maryland climate zone map with red dots showing numbered RWIS sites.

Part 5. How to Apply the Calculated SWI

In the Winter Severity file, the SWI will be calculated in Column Y Table 43, and will be green if the SWI value is from 0 to less than 1.02 designating the storm as mild, yellow if the SWI value is from 1.02 to less than 8 designating the storm as moderate, and red if the SWI value is greater than 8 designating the storm as severe.

Storm Severity Categories
Less than 1.02
≥1.02 and <8
Greater than or equal to than 8

These bounds were defined based on the quartiles of the data file used to develop the model. [See SWI Final Report for additional details]

Part 6. Add on Values for Blowing and Drifting Snow

After the SWI is calculated in the Winter Severity file, another column can be added [Column Z to Table 43] to incorporate Add-on points associated with specific conditions – such as blowing and drifting snow. MDOT SHA should work to determine the appropriate amount of added points to each storm event based on the magnitude of the blowing and drifting snow event and resources required to treat the event. [See SWI Final Report, 5.7.1 Blow and Drifting Snow for additional information]

Supplemental Information: Exporting Data RWIS Data from SmartView

To get each export file, you must login to SmartView, go to Edit > Import/Export.

In the Export jobs screen (Figure 108), I setup a job for each station. The export job is titled Full RWIS and starts at Job 00744. Currently, all the jobs are inactive. To activate, double click on the desired job number, this allows you to edit the job. See Figure 109 for the view. Click the "Is Active" button, and then change the data start and data interval to the desired dates. If desired, you could also change the export folder to avoid confusion.

Key items are not to run more than one job at a time as this can slow the system. Before logging out, it is imperative that the exports are all running smoothly. This can be checked by going to Modules> Show SmartCom (See Figure 110) and verifying that the last run is not out of date. Make sure that the SmartCom module stays running (don't exit the program).

To change the export sensors, just click export sensors in the Export Edit window (see Figure 111) and delete any sensors they don't want coming through. This would significantly reduce the amount of time per export job.

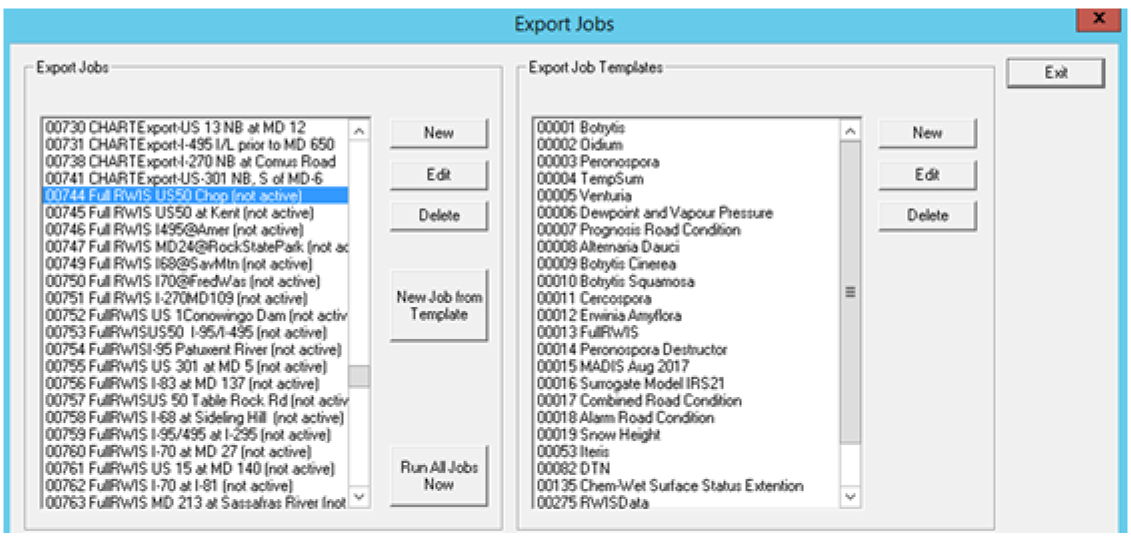


Figure 108. Main menu for export jobs

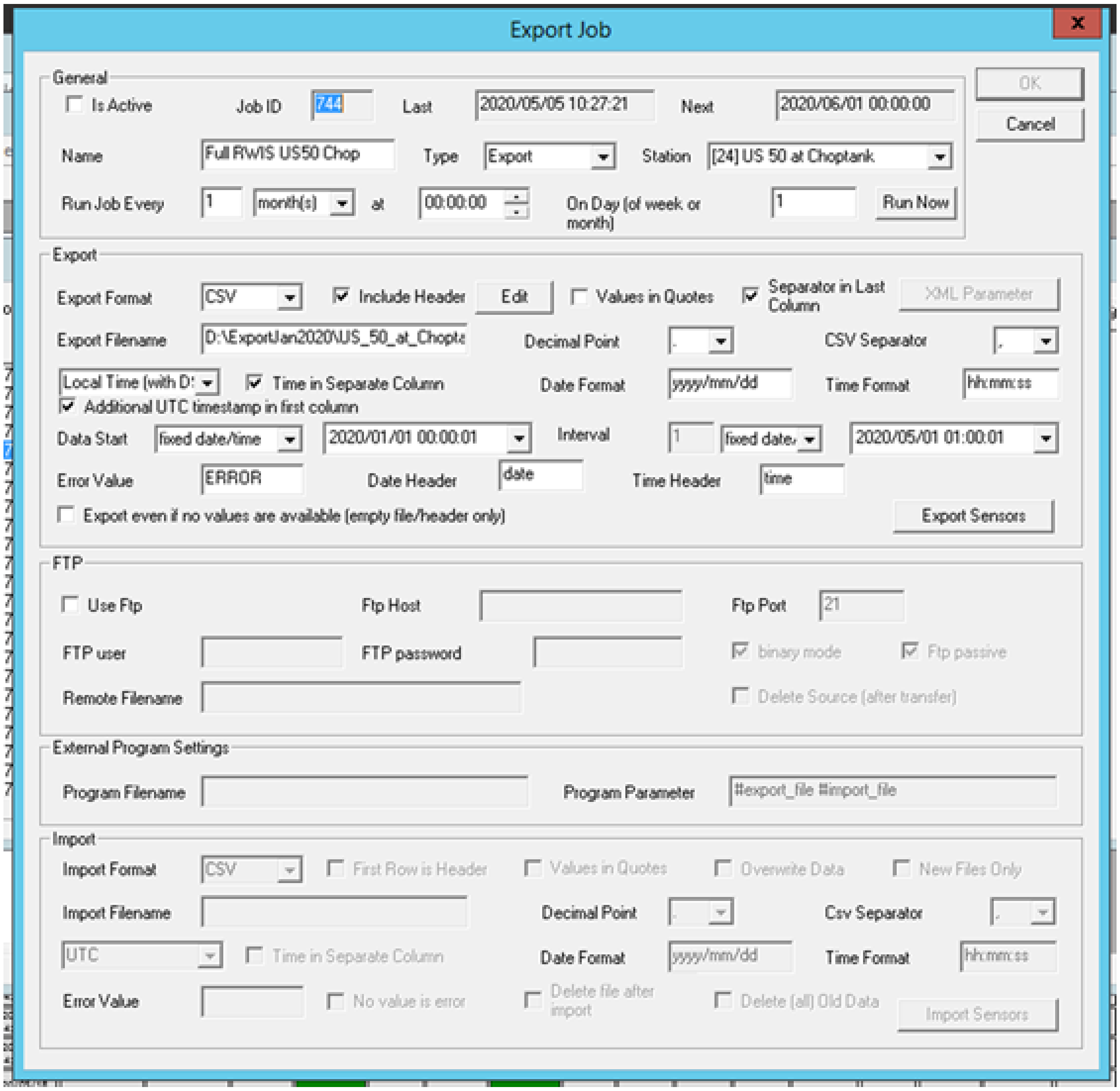


Figure 109. Export job Edit screen. “Is active” button at top left

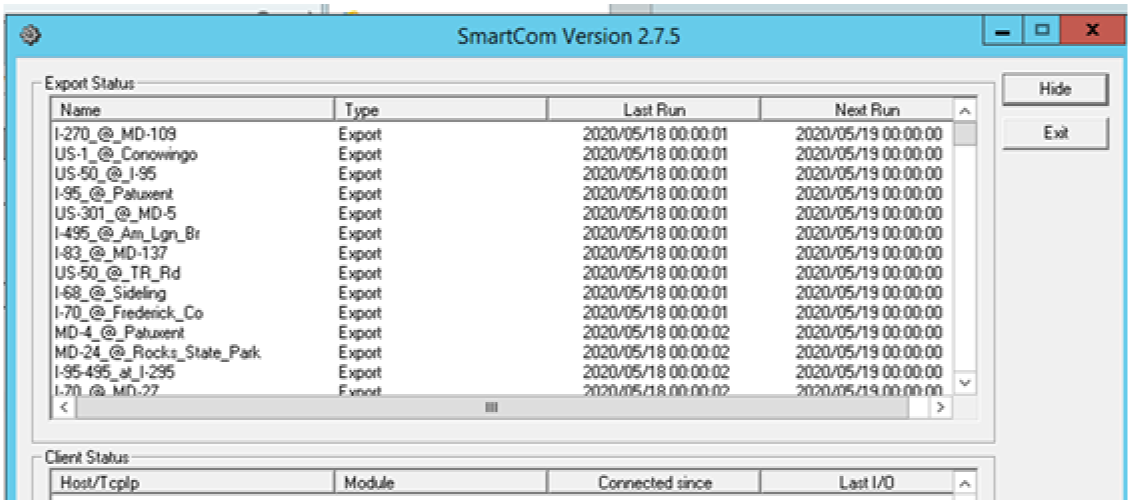


Figure 110. SmartCom – showing all the jobs that are running. This should be current before you hide the screen.

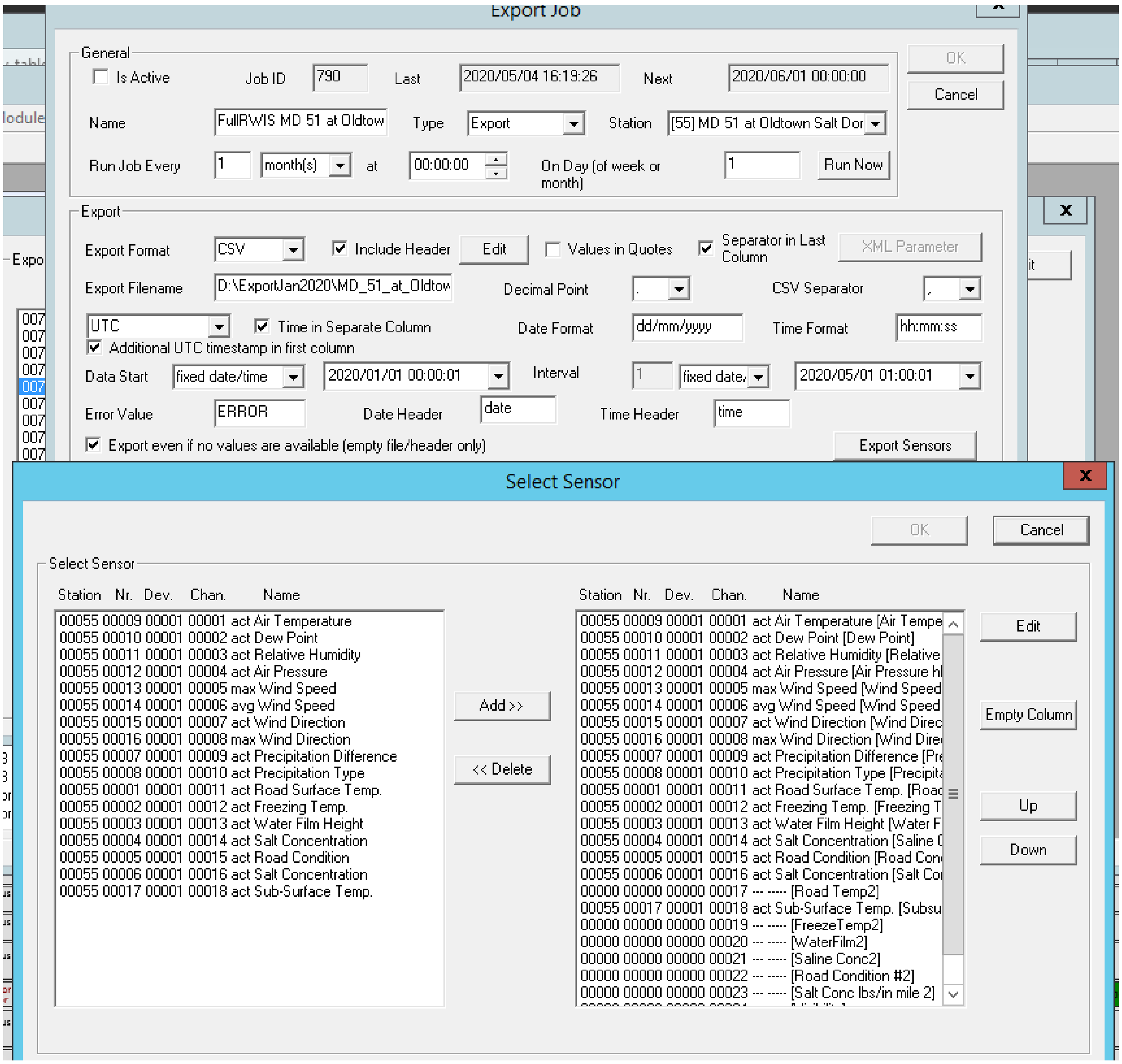


Figure 111. Export Job Edit screen is at the top. Once you hit the “Export Sensors” button to the middle right of the screen, the select sensor window is opened where you can select which sensors you want to include in your export.

Appendix H – Two Page Project Summary