MODELS FOR PREDICTING
RWIS SENSOR MISALIGNMENTS
AND
THEIR CAUSES

FINAL REPORT

**Northland Advanced Transportation Systems
Research Laboratories**

Fiscal Year 2007

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MODELS FOR PREDICTING RWIS SENSOR MISALIGNMENTS AND THEIR CAUSES

PROJECT OVERVIEW

SCAN Web is a user interface Internet tool that displays RWIS data in tabular and graphical form. Users can choose various levels of detail, including summary information, RWIS raw data, or historical views of sensor data. Each SCAN Web image contains navigational links to additional informational items related to the exhibited data, such as forecasts and maps. Mn/DOT technicians periodically monitor RWIS sensors in their assigned districts to determine if they are malfunctioning. They depend heavily on data available through Scan Web to make decisions. The process is time consuming, based on years of experience, and typically involves analyses of the relationships between various sensors.

In this project we developed an Internet-based, pilot software tool that allows a site engineer to automatically assess a group of RWIS sites to determine when malfunctions occur. We focused on 10 sites from Districts 3, 4, and 7, and 19 sites from District 8 (all these sites fall under the engineer assigned to District 8). We identified the decision rules employed by this engineer and created a software tool that enables him to automatically assess a group of sites to detect malfunctions. For clarification, we briefly describe first the manual process currently followed to identify suspect sensors and then the new interface we developed, as follows.

The data tags corresponding to sensors on the Scan Web display which are of primary interest are air temperature, barometric pressure, dew point, precipitation type, surface status, relative humidity, subsurface temperature, wind direction, wind speed, and visibility. (Site characteristics are very important and contribute to the diversity of sensor values for various seasons and weather conditions.) The District 8 engineer recognizes malfunctioning sensors by following a procedure and rules he has developed through years of experience and expert knowledge of the sensors. For example, he may bring up a set of 5 sensors corresponding to air temperature. A sensor shown in black on the display image indicates that the sensor has not reported data for some time. He notes any non-reporting sensor that he was previously unaware of and then examines its history to see how long it has failed to report. If the time frame is significant and he is not already aware of the cause of failure (e.g., the sensor being replaced), he records this as a likely failure.

The engineer then examines the sensor set to see if any value shown differs significantly from those of its neighbors when there is no weather-related explanation for the difference. For example, if most sensors display values in the high 30 to low 40 range while one sensor is registering, say, 52, this case might require further analysis. When a sensor malfunctions, it does not necessarily register that it is malfunctioning. It often simply reports its last reading. Such cases can be detected by determining that the sensor is registering differently from its neighbors and then confirmed by examining its history. (Our software can identify such cases but improves on the process by noting, for example, cases where a sensor has reported the same value for an extended period of time even if that value is similar to the values reported by its neighbors.) The engineer then repeats this procedure, for various sensors over a variety of values, while taking into account the likely variation among the sensors. Our system performs similarly but extends the analysis described above and incorporates a larger set of information to determine which sensors are malfunctioning.

Our system permits an engineer to define a *profile* containing sites and rules associated with various sensors at these sites. A user may create as many profiles as desired and modify them as warranted. Thre are three basic types of rules used to recognize sensor failure. For a given site, one or more rules may be applied to selected sensors within the profile or to all sensors as a group; for each rule, user-selected colors are assigned to the various sensors. This allows one to quickly observe the results of applying a given profile to the sensor data. The rules are as follows:

1. Type A rules are triggered if the selected sensors are not reporting at the current time.

2. Type B rules are triggered if the selected sensors have reported identical values for the preceding x hours, where the value of x is specified by the user.

3. Rules of Type C are triggered if the selected sensors deviate by y amount from other sensors at sites within a radius of z miles for w hours, where the values of y, z and w are specified by the user.

The system utilizes a map/parameter screen which can be used to display a sensor site, specific parameters, or to initiate a change in profiles. The map can display all sites within the state or those associated only with a given profile. Clicking a given site on the map yields a list of the site's sensors, including current values and colors that reflect triggered rules. The user may also scroll backwards in time to see dynamic changes to the profile as a result of the rules being applied to historical data. Our system employs a set of user-friendly screens to facilitate the creation and modification of rules and profiles.

This project is fully described in the attached copy of a thesis culminating from this research and directed by the three co-principal investigators.

A WEB-BASED SYSTEM TO ASSIST IN
DETECTING RWIS SENSOR MALFUNCTIONS

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

AUGUST 2008

Abstract

The Minnesota Department of Transportation (MnDOT) uses the Road Weather Information System (RWIS) for monitoring the current weather and surface conditions of its highways. The real-time data received from these sensors reduces the need for road patrolling in specific locations by providing timely and accurate information to those responsible for directing winter maintenance operations. Most of the road maintenance decisions, weather forecasts and severe weather warnings are explicitly dependent on the reliability and accuracy of the RWIS weather sensors' data. Hence it is important for these sensors to report accurate weather data.

In this thesis, we help to automate the process of identifying a malfunctioning weather sensor in real time. We analyze the weather data reported by these sensors to detect possible anomalies. Our system allows users to define rules. The rules cover cases such as a simple detectable situation where the sensor itself is reporting an error as well as the other situations in which the sensor is likely to be malfunctioning. For example, if a sensor reports the same value for a long period of time or when some deviation is expected. Other features include notification messages when a sensor may be malfunctioning and the ability to analyze proposed rules.

The software performs reasonably accurately in detecting malfunctioning sensor. Based on the rules set by the user, it analyzes the weather sensor data in real-time to notify of malfunctions with a reasonable accuracy. Rule parameters set by the user can result in a false indication of a sensor malfunction. But if the user sets up the optimal rule parameters as per the suggestions from the software, the accuracy of the software to detect a malfunctioning sensor increases.

We believe that the analysis of the weather sensor data as per the rules to detect the situations that indicate a possible malfunctioning of a sensor can be used effectively for detecting sensor malfunctions. The accuracy of this analysis can be improved by choosing appropriate parameters.

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Chapter 1

Introduction

Road Weather Information System (RWIS) stations are deployed throughout the United States. RWIS is a system of surface and atmospheric sensors integrated with prediction and monitoring functions that employs real-time sensor data, historical weather patterns, and computer models to make useful prediction such as specific adverse pavement conditions. RWIS networks have been used for many years as a highway winter maintenance tool to improve snow removal and ice prevention efficiency. They are increasingly being viewed as tool for intelligent transportation systems and as a means to improve communication of weather and road conditions to travelers. The real-time data can reduce the need for road patrolling in specific locations by providing timely and accurate information to those responsible for directing winter maintenance operations. Winter maintenance practices largely involve the operations of road patrolling, plowing for snow removal, and the spreading of sand or salt. The RWIS weather sensor data can be tracked and associated modeling can predict when moisture is likely to freeze on the pavement, facilitating timely and effective deployment of staff and equipment. As road maintenance decisions, weather forecasts and severe weather warnings are explicitly dependent on the reliability and accuracy of the RWIS weather sensors' data, it is very important for these sensors to remain active and report an accurate weather data. Generally, routine maintenance checks are needed to ensure the proper working of these sensors.

RWIS sensors generally include some basic error checking capabilities, but for many types of malfunctions, the sensor will not directly indicate that an error has occurred. Instead the human user has to examine the data. Each individual uses RWIS information in conjunction with field and operational experiences to decide if, when, and what types of maintenance activities should be deployed. But the process is complex and time consuming, so it would be beneficial to have an automated system that could detect malfunctions in real time and alert the user.

In order to detect a malfunctioning sensor, we propose to analyze the RWIS weather sensors' data in real-time to identify any anomalies and notify the maintenance personnel. We provide a suite of tools that the maintenance manager can use to make decisions about malfunctions of the RWIS sensors.

1.1 Analyzing the Sensor Data

In RWIS system of weather sensors, detecting a failure of a weather sensor could be as simple as a sensor itself reporting an error or could be very difficult if the sensor is reporting some value which seems to be correct but for some reason is not. In such cases, it is important for the user (in our case MNDOT personnel) to analyze the data and detect if the sensor is reporting a wrong data. This process can be automated by analyzing the weather sensors' data programmatically by applying rules defined by the user (and perhaps MNDOT). A rule is a detectable situation that suggests the malfunctioning of a sensor. Examples of situations that might indicate malfunction would include (1) that the sensor is reporting the same value for a long period of time (this is especially useful for sensors whose values are expected to vary such as temperature sensors) and (2) that a sensor is reporting a value that is significantly different from its neighbors.

In this thesis, we implemented a software tool which allows the user to detect potential malfunctions for specific RWIS sites of their interest with a user-defined set of parameters. The sets of parameters include the time period, the radius within which the neighboring sensors should be and the amount by which the sensor deviates from the nearby sensors. The system can analyze the historical weather data to suggest appropriate values for these parameters. Once the user sets up the parameters for the rules, these rules are used to detect a malfunctioning sensor. A popup window notification or an email notification is sent to the user when a rule's conditions are met, which allow them to take decisions about the maintenance activity for these sensors.

One of the critical difficulties in making use of rules is that the user will likely want the rules to catch as many of the malfunctions as possible, but also will want to avoid getting a lot of "false alarms" from the rules. False alarms here would be cases where an alarm is raised but no malfunction is occurring. One tool that may help in dealing with this issue is the analysis of the rule. Analysis can give a user some idea of the percentage of sensor sites that could be triggered by the rule and helps the user to setup the optimal parameters to get an efficient and accurate rule.

1.2 Thesis Statement

In this thesis, we automate the process of identifying a malfunctioning weather sensor in real time. We analyze the weather data reported by these sensors to detect possible anomalies. The rules cover cases such as a simple detectable situation where the sensor itself is reporting an error as well as the other situations in which the sensor is reporting the same value for a long period of time (e.g. The 'Air Temperature' sensor reporting 20 degree celsius for 24 hrs) or the sensor value deviates from the nearby sensors by a significant amount (e.g. The 'Air Temperature' sensor reporting a value that deviates by 10 degree celsius from other sensors within the radius of 40 miles). A pop-up window or an email notification is sent to the user about the malfunctioning sensor. We also implemented a feature that allows the user to verify the quality of the rule that is the percentage of sensor sites covered by this rule.

1.3 Thesis Outline

This thesis is organized as follows. Chapter 2 presents the background for the thesis with a detailed description of the road weather information system and the weather sensors they use. It describes the sensor failure conditions and examples of reasons for those failures. Chapter 3 describes our approach to detect a malfunctioning sensor in real time. It describes the implemented software and the various features of the software. Chapter 4 presents our conclusions and summarizes the work done in this thesis. Chapter 5 covers the feedback received for the fielded software and the future work for this thesis.

Chapter 2

Background

2.1 Description of Sensors: RWIS

As weather affects all modes of transportation, it is very important to have a system which is capable of sensing a variety of weather conditions in order to increase safety on roadways and runways. An RWIS (Road and Runway Weather Information System) Network is a system consisting of several meteorological stations strategically located along major highways. It is a combination of sensors used to detect current weather conditions and methods to forecast future weather conditions. An RWIS system can consist of multiple sites, each containing a suite of sensors that gather weather and pavement data and then report the same to a central location where authorized personnel can view the information. RWIS technology provides vital information on pavement and weather conditions needed for both highway and airport maintenance operations.

RWIS systems enable maintenance and operations personnel to monitor changing weather conditions and to identify hazardous driving conditions in real time and make informed and timely decisions. Ice or water on the pavement, low visibility, and high winds are all examples of hazardous conditions that RWIS can bring to the attention of transportation personnel and the public.

An RWIS network consists of three main elements: 1) a set of weather sensors which is a collection of meteorological sensors to report various weather conditions; 2) a processing system that helps to develop forecasts and convert information into an easily understood format; and 3) a display system which displays the tailored information. Figure 2.1 shows the typical RWIS site and its interface with the data collection and user interface system.

An RWIS system's sensor array has a variety of standard sensors providing basic information such as air temperature, wind speed, wind direction, ground temperature, and subsurface temperature(s), and it can also measure more complex parameters such as visibility.
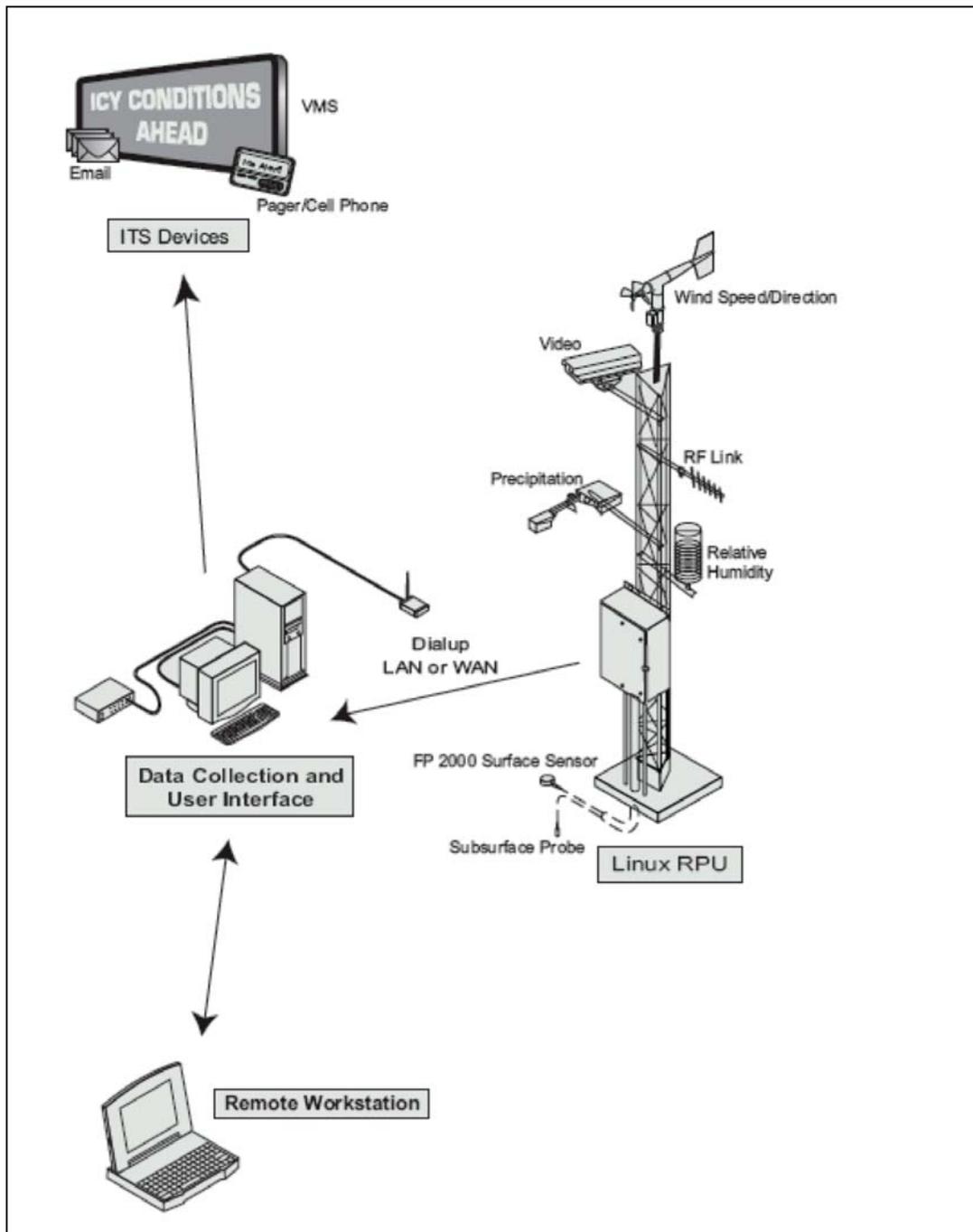
Figure 2.1: RWIS Site and Interface

(Source: http://www.qttinc.com/pdf/SSI/RWIS.pdf)

Remote processing units (RPUs) (refer Linux RPU in Figure 2.1) placed along the roadway connect the road and weather sensors to a central location. The sensors linked to remote processing units can be one of the two following types: 1) atmospheric and weather sensors report the atmospheric conditions such as Wind Speed and Direction, Air Temperature, Precipitation, Relative Humidity etc., and 2) surface and subsurface sensors report the surface conditions such as surface and subsurface temperatures. Video cameras are also added for viewing weather and traffic conditions at the site.

As these processing units have limited processing abilities, the data measured by them is transmitted via LAN or WAN network to a central data collection server having a user interface located in the highway maintenance facility. These sensors report their observed values every 10 minutes, resulting in 6 records per hour. Servers help in communication, collection, distribution, analysis and archiving of the weather data received from sensors. The raw data received can be used to detect site-specific current weather and surface conditions and forecast the site-specific weather and pavement conditions. Remote workstations can connect to these servers to access the weather information. ITS (Intelligent Transportation System) devices such as animated displays on the highways are integrated with the RWIS system to inform travelers about the weather and road surface conditions. ITS helps to improve the transportation safety and mobility.

During severe weather events, RWIS information helps in the cost-effective application of labor, equipments and materials. RWIS systems help monitor conditions and enable users to plan the operations, schedule personnel, select material and deploy the equipments efficiently and effectively. This information also assists wide range of transportation users and operators in their decision making for trips and travel times.

The Minnesota Department of Transportation maintains 93 RWIS sites across the state. Each site has some or all of the weather and surface sensors. Figure 2.2 displays the Minnesota state map along with the RWIS sites on it. It displays 79 sites out of 93 sites available with Minnesota department of transportation. Information for the remaining 14 sites added recently is not available. The exact location of each site is shown in Appendix A.
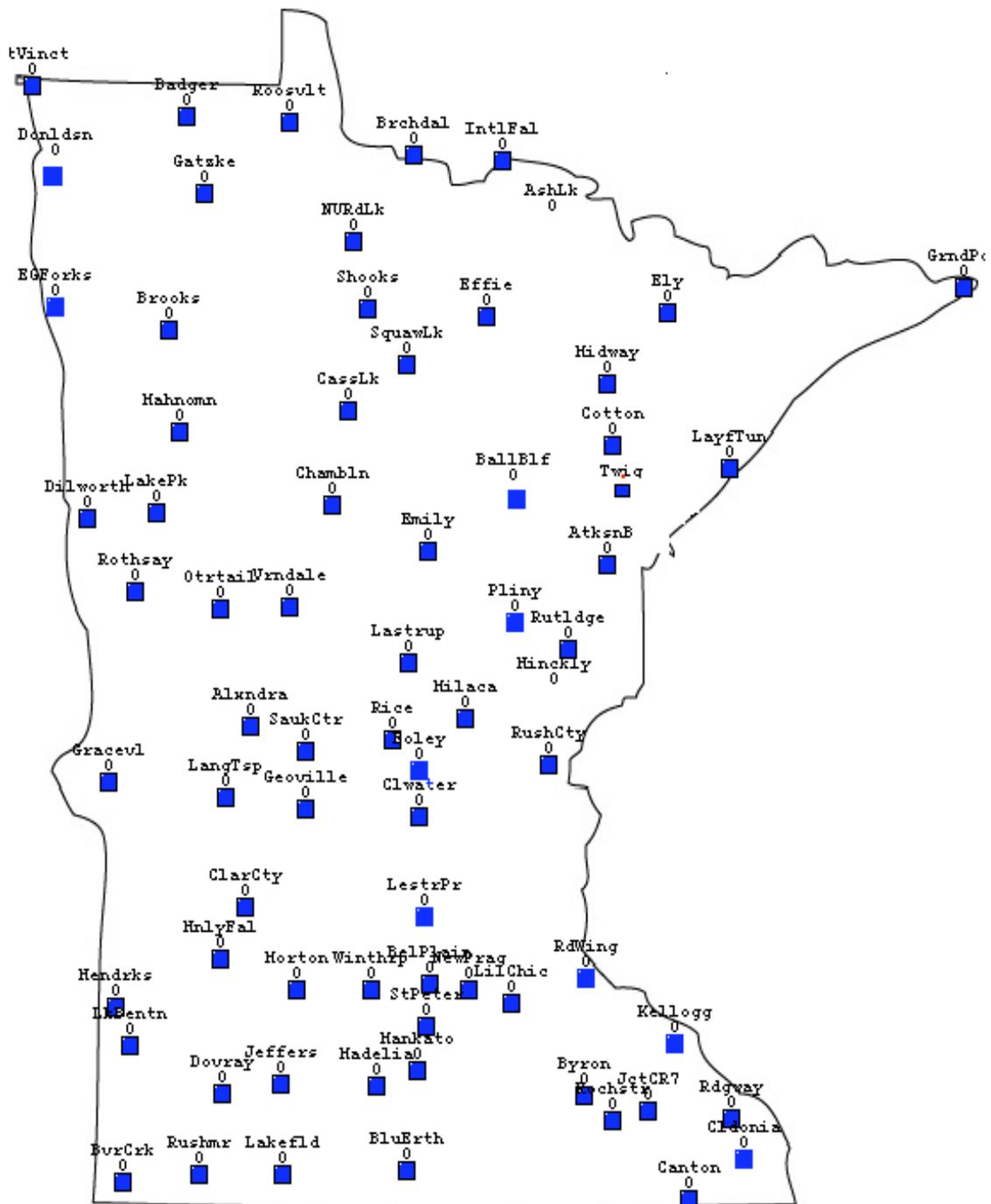
Figure 2.2: Minnesota Map with Sensor Site

(**Source: Our Software at http://www.d.umn.edu/~bhale001/deploy/appletapr22.html**)

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2.2 Types of RWIS Sensors

RWIS systems will nearly always include sensors to measure wind speed and wind direction, either in the form of combination sensors that can measure both speed and direction, or as individual wind speed and direction sensors.

A mechanical wind speed sensor is the three-cup anemometer, which uses an arrangement of horizontally-mounted cups to sense wind speeds. As the wind turns the cups, this movement is converted to an electrical signal that can be read and converted to wind speed by the RWIS computer.

There are many different types of anemometers, which can be different in appearance, but the basic principles of operation, reporting and converting wind movement to an electrical signal are the same. Figure 2.3 shows a mechanical wind sensor. If for any reason, the cups of this sensor cannot perform a smooth rotation, it will report an erroneous value of the wind speed.

Figure 2.3: Mechanical Wind Sensor

(Source: www.ftsinc.com/Sensors)

Ultrasonic wind sensors are becoming a more popular choice for measuring wind speed and direction because of their advantage of no moving parts, which means less maintenance and continuous operation during freezing rain events. Figure 2.4 shows an ultrasonic wind sensor.

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Figure 2.4: Ultrasonic Wind Sensor

(Source: www.rainwise.com)

Other nearly universal RWIS sensors are the air temperature, relative humidity and dew temperature sensors. These sensors are critical for predicting or detecting conditions where frost may appear on the road surfaces. Typically, a single sensor provides both air temperature and relative humidity measurements. To minimize temperature measurement errors induced by solar heating, the sensor is typically mounted in a solar radiation shield. If for any reason, the shield exposes the sensor to solar heating; it will report an incorrect value of these parameters. The temperature measurements are done with a simple thermometer type device; a thermo liner component, housed in a radiation shield. The relative humidity sensor uses capacitance to determine relative humidity. Dew point is calculated from the air temperature and relative humidity measurements. Figure 2.5 shows the typical RWIS sensor used to measure the air temperature and relative humidity.

Figure 2.5: Air Temperature and Relative Humidity Sensor

(Source: http://www.qttinc.com/images/AirTemp-RHSensor.jpg)

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Visibility sensors measure meteorological optical range, and can be extremely useful in low-visibility, fog-prone areas. Knowledge of low-visibility conditions allows drivers to evaluate and possibly change their travel plans in order to avoid stressful and potentially hazardous driving situations. Visibility sensors used for RWIS typically use infrared forward-scatter technology. One limitation of these sensors is that anything in the optical path that attenuates or scatters the infrared light beam--such as dirt, spider webs, and so on--may cause erroneous readings. Figure 2.6 shows an example of visibility sensor.

Figure 2.6: Visibility Sensor

(Source: www.geneq.com/catalog)

Surface sensors are used to determine the road condition, a critical function of RWIS systems. Surface sensors report the road surface as wet, dry, or frozen, and normally report road surface temperature as well. A common approach used in these sensors is monitoring road surface conductivity, which changes as road surface conditions change. When anti-icing chemicals are in use, surface conductivity is also an indication of the concentration of anti-icing material on the roadway. The presence and concentration of anti-icing material is vital information, since it will affect the actual freezing temperature of the road surface. Figure 2.7 shows the Surface sensor. These are normally placed just outside the wheel path of vehicles, at a location that is known to freeze early.

The surface temperature of a pavement is strongly affected by the pavement and soil temperatures below the surface. The sub-surface temperature probe typically measures temperature 17 inches below the

roadway surface. Sub-surface probes are used to determine frost-depth, assist in predicting the pavement surface temperature and can be utilized in pavement forecasting.

Figure 2.7: Surface Sensor

(Source: http://www.campbellsci.co.uk)

A typical RWIS site holds various types of sensors which can be grouped in the two sets as atmospheric and surface sensors. Table 2.8 lists the possible atmospheric sensors and describes the meaning of the parameters being reported by the sensors. It also lists the reporting units of these parameters. As wind direction is reported in degrees, it needs to be mapped to cardinal format by using a standard mapping used by the RWIS system. Table 2.9 shows this mapping of degrees to the cardinal format.

Table 2.10 lists the surface sensors and describes the meaning of the parameters being reported by the sensors. It also lists the reporting units of these parameters.

The sensor data corresponding to these sensors can be read from the files received from the ftp server rwis.dot.state.mn.us. As sensor data is reported every 10 minutes, a new file with current sensor data is uploaded on the server and is available for download approximately every ten minutes.

Each file contains the time-stamped weather data for every site. A typical record for a site contains the meta data which is the information about the weather data being reported and the actual weather sensors' data. The meta data contains the System ID in the RWIS System, the Site ID and the timestamp when the data was reported in the RWIS system. The actual weather data reports the values received from the weather sensors such as air temperature, dew temperature and relative humidity. Table 2.11 lists the fields in the typical weather record. These records can be parsed to accumulate the weather and surface

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sensor data needed for the application. Once the data is available, it could be used for display and analysis in the application.

2.3 Sensor Malfunctions

The atmospheric, surface and subsurface sensors in RWIS system report the data about the current weather conditions every ten minutes. A sensor is said to be malfunctioning when the values reported by it deviate from the actual weather conditions present. This could be a result of an internal mechanical problem with the sensor or some external objects/conditions which prevent the sensor from reporting the accurate data.

Sensor / Parameter	Description	Reporting Unit
Air Temperature	The measure of the heat content of the air.	Celsius / Fahrenheit
Dew Temperature	Temperature at which air becomes saturated as it cools.	Celsius / Fahrenheit
Relative Humidity	The percent of moisture present in the air.	Percentage
Wind Speed	The rate at which air is moving horizontally past a given point.	Km / hr or Mph
Wind Direction	The direction from which the wind is blowing depicted in degrees from 0 to 360.	Degrees
Air Pressure	The pressure exerted by the atmosphere.	Millibars / Inch of Mercury
Precipitation Intensity	Precipitation rate is used to derive the precipitation intensity	None, light, slight, moderate, heavy, other and unknown
Precipitation Accumulation	The rainfall amount or snowfall liquid equivalent for a particular period	Cm / Inch
Precipitation Type	The type of precipitation is detected by a precipitation sensor	Yes, No, Rain , Snow, Moderate Snow, Heavy Snow
Visibility	The average distance that you can see, both day and night, computed every three minutes.	Meters / Feet

Table 2.8: Atmospheric Sensors

Direction	Cardinal Format	Degree Range
North	N	338 – 22
Northeast	NE	23 – 68
East	E	69 – 112
Southeast	SE	113 – 158
South	S	159 – 202
Southwest	SW	203 – 248
West	W	249 – 292
Northwest	NW	293 - 337

Table 2.9: Wind Direction Cardinal Format and Degree Range

Sensor / Parameter	Description	Reporting Unit
Surface Temperature	The temperature of the pavement sensor roughly 3 mm (1/8 inch) below the surface of the sensor.	Celsius / Fahrenheit
Freezing Temperature	The freezing point of the moisture on the pavement sensor based upon the specific chemical in use.	Celsius / Fahrenheit
Subsurface Temperature	The temperature approximately 43 cm (17 inches) below the top of the pavement.	Celsius / Fahrenheit

Table 2.10: Surface and Subsurface Sensors and Corresponding Units

The reported sensor values when the sensor is malfunctioning could be an invalid value, a constant value or even more difficult, it may report a value that on the surface appears accurate but is not. Some of the sensors such as air temperature might not be expected to report a constant value, as the temperature does vary in the considered time span. If it does report a constant value, it might be malfunctioning.

Extreme weather conditions, water penetration, thermal shock, freeze-thaw cycling, physical trauma (snowplows, for example), and communication link failure all contribute to the failure of the RWIS weather sensors. This results in an incorrect value being reported from these sensors. For example, the air

temperature and relative humidity sensor with a broken shield will report an incorrect value of air temperature and relative humidity.

The visibility sensors for RWIS which use infrared light beam might report erroneous data if the infrared light beam is attenuated by dirt or spider webs. In such a case, it may report a low visibility under conditions of a high visibility as its optical path is blocked.

Another example could be of a wind sensor with ice accumulated on its blades resulting in an erroneous data being received from it. Figure 2.14 shows such a wind sensor. This accumulation of ice affects the smooth movement of wind sensor's blades causing it to report the irregular values.

A sensor could simply report the last accurate value for a variety of reasons, and this might not be obviously an error without significant analysis. As the accuracy of RWIS system's weather forecast completely relies on the values being reported by the weather sensors, malfunctioning of these sensors needs to be identified as soon as possible. As it might not be practically possible to visit every site and verify accuracy of every sensor at the site, automatic detection of sensor malfunctioning via analysis of reported sensor values is needed.

Figure 2.14: Ice Accumulated on the blades of Wind Sensor

Reported Fields
Air Temperature in celsius
Dew Temperature in celsius
Relative Humidity in percentage
Average Wind Speed in m/sec
Maximum Wind Speed in m/sec
Average Wind Direction in degrees
Precipitation Intensity as an integer which is interpreted as per table 2.12
Precipitation Type as an integer which is interpreted as per Table 2.13
Visibility in meters
Air Pressure in millibars
Rate of Precipitation in cm/hr
Accumulation of Precipitation in cm/day
Direct Solar Radiation over 10 minutes and 24 hours in joules/sq. meter
Maximum Temperature in celsius
Minimum Temperature in celsius
Wet Bulb Temperature in Celsius
Precipitation Start in yyyymmddHHMMSS
Precipitation End in yyyymmddHHMMSS
Precipitation Accumulation for last 1 hour, 3 hours, 6 hours, 12 hours, 24 hours in cm.

Table 2.11: Site Weather Record

Record Value Reported	Description
0	None
1	Light
2	Slight
3	Moderate
4	Heavy
5	Other
6	Unknown
7	Special

Table 2.12: Precipitation Intensity: Record Values

Record Value Reported	Description
0	None
1	Yes
2	Rain
3	Snow
4	Mixed
5	Light
6	Light Freezing
7	Freezing Rain
8	Sleet
9	Hail
10	Frozen
11	Unidentified
12	Unknown
13	Other
14	Special

Table 2.13: Precipitation Type: Record Values

Chapter 3

Solution

3.1 Overview

RWIS sensors located along the roadside are subject to failure and could report wrong weather data. Detecting such conditions is important for the accuracy of the RWIS system. Since roadway management decisions, notifications of severe weather and weather forecasts used by MnDOT are based on the data collected from the RWIS sensors, it is essential that they function properly.

RWIS sensors can fail for a variety of reasons. In some cases the errors are fairly straightforward to detect such as the sensor is simply not reporting (or reporting an error). But in some cases, a sensor may continue to report, but for a variety of reasons may not report a correct value. For example, a spider might build a web between the two parts of a precipitation sensor causing it to always report precipitation.

Detecting such malfunctions in general requires some level of reasoning by a human being, but some detectable situations that suggest something is going on would include (1) that the sensor is reporting the same value for a long period of time (this is especially useful for sensors whose values are expected to vary such as temperature sensors) and (2) that a sensor is reporting a value that is significantly different from its neighbors. For example, a temperature sensor reporting 20 degree celsius for 24 hours or an air temperature value that is 10 degrees less or more than the value reported by the sensors nearby it, suggests that the sensor might be malfunctioning. Detecting such situations at an RWIS site suggests a probable maintenance requirement for that site. These occurrences can be detected by analyzing the weather and surface sensors' data which is downloaded from the rwis.dot.state.mn.us FTP server.

As a sensor reporting the same value for only a shorter period of time does not suggest that it is malfunctioning, it is very important to consider an appropriate time period for analyzing such an occurrence. For example, an air temperature sensor reporting 30 degree celsius for 2 hours is likely not malfunctioning, but if it reports 30 degree celsius for 24 hours, it might be. Similarly, what constitutes a significant difference of a sensor value from its nearby sensors needs to be carefully considered. For example, if an air temperature sensor value deviates from its nearby sensors by 1 degree celsius, it is

unlikely that it is not malfunctioning. But if its value deviates by a considerable amount (for example, 10 to 12 degree celsius), it might be malfunctioning. The analysis to detect malfunctioning of a sensor is also influenced by its nearby sensors. Hence, considering the sensors in an appropriate radius around the sensor is also important for the accurate analysis of the situation.

These parameters (for example time period and radius) might be supplied manually or generated programmatically. Manual entries of the parameters might not result in an accurate depiction of the sensor failures. Automatic generation of parameters via analysis of historical data could help improve the accuracy of failure detection. Historical data analysis can also help to select specific parameters for the conditions which could result in better sensor failure detection.

To detect a malfunctioning of sensor using machine learning methods, we implemented a weather sensor analyzer system that incorporates the above sensor failure situations. These sensor failure situations are termed as if -then rules in the analyzer system. The system allows the user to setup rules for the system to detect possible malfunctioning of sensors. These rules can be used to check specific sensor sites by creating profiles with the sites of interest. Rules can be made to trigger on a single or multiple sensors. Multiple sensors can be considered with 'And' condition or 'Or' condition. When connected with 'And', all the sensors are tested for the rule conditions and when all of the sensors meet the condition, rule is triggered. When connected with 'Or', if any of the sensors meet the condition, rule is triggered.
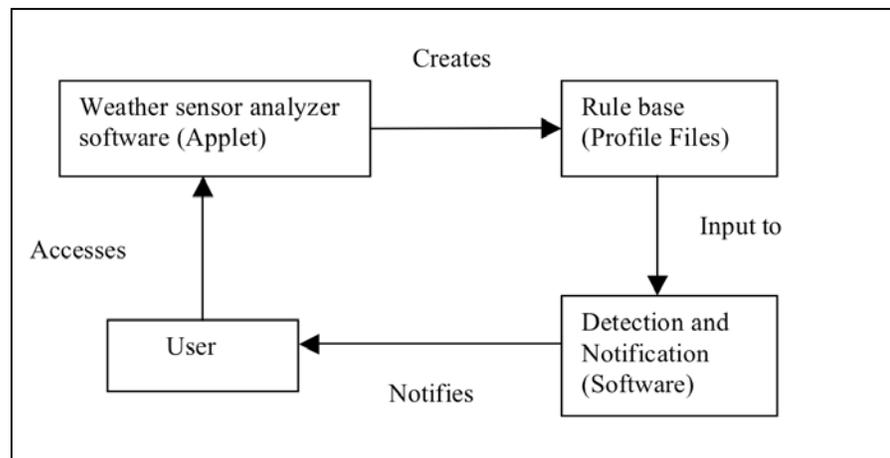
Figure 3.1: System Interaction

Figure 3.1 shows the block diagram of interaction of the system. Weather sensor analyzer software allows the user to create a rule base to detect a malfunctioning sensor. This rule base is used by the detection and notification module to notify the user about a malfunctioning sensor.

Software implemented provides a map view which displays the sensor sites and colors along with these to depict the possible sensor failures as per the rules.

3.1.1 Access to the Weather Sensor Analyzer System Software

Our weather sensor analyzer software is publicly accessible via the internet. In order to access the software, the user navigates to the web page at the address http://www.d.umn.edu/~bhale001/deploy/appletapr22.html.The applet at this web address is self-signed, so the user is presented with a dialog asking to authorize our security certificate, and must click "Run", "Trust", or "Allow" - depending on the browser - the owner/signer of the certificate should be listed as "prafulla" or "umd". Depending on the security settings, the web browser may ask the user to authorize the "Active Content" before presenting the aforementioned dialog. Once the applet is allowed to load, it is downloaded on the computer and is available to use.

Figure 3.2 shows the screen that is displayed to the user whenever the application starts.

3.2 Features

This section will cover the various features of the Weather Sensor Analyzer software. The first sub section will cover the description of the initial display screen which shows the sensor sites and the color codes indicating the malfunctioning of a sensor at the site. Next we will cover the creation of a profile, which is a set of sensors and a set of rules. Following that are sections on rule and sites editing in a profile, analysis of rules, triggering notification feature of the tool and the wizard which allows the user to quickly add the rule to their profile.
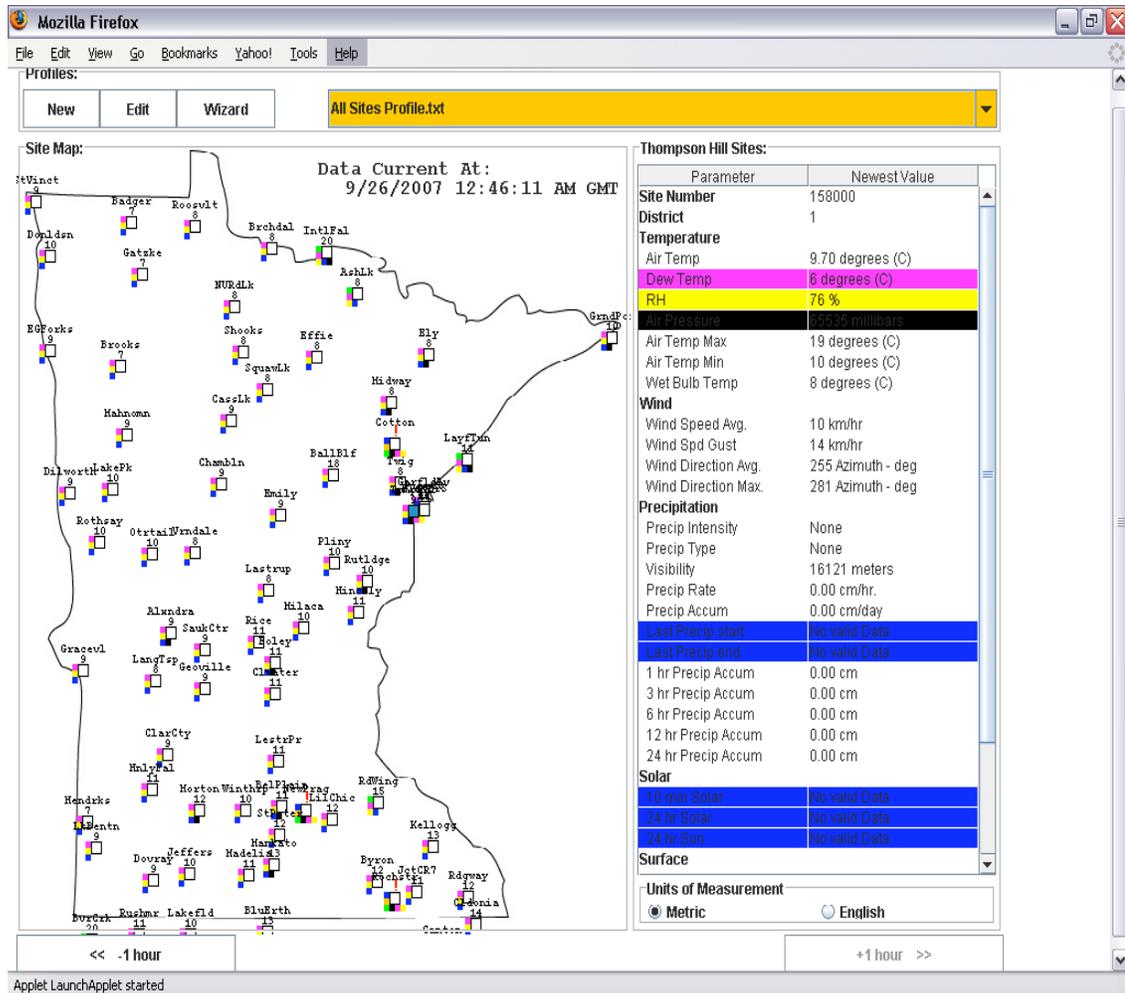
3.2.1 Map/Parameter Screen

Initially, the screen shown in the Figure 3.2 will be displayed with a dialog which shows the progress of the weather history data being downloaded. Once the whole history data is downloaded, the dialog will disappear and the Weather Sensor Data Analyzer will be available for use. Historical data is needed for the application to analyze various rules and allow the system to access the historical weather data over the map. Historical data also helps the system to suggest various rule parameters to the user.

Figure 3.3 shows the Map / Parameter screen which become available when history data reading is completed. The top-left portion of the screen has three buttons `'New'`, `'Edit'` and `'Wizard'`. The button `'New'` helps the user to create a profile to model the system as per their needs. A profile is a set of sensors and a set of rules applied to those sensors.
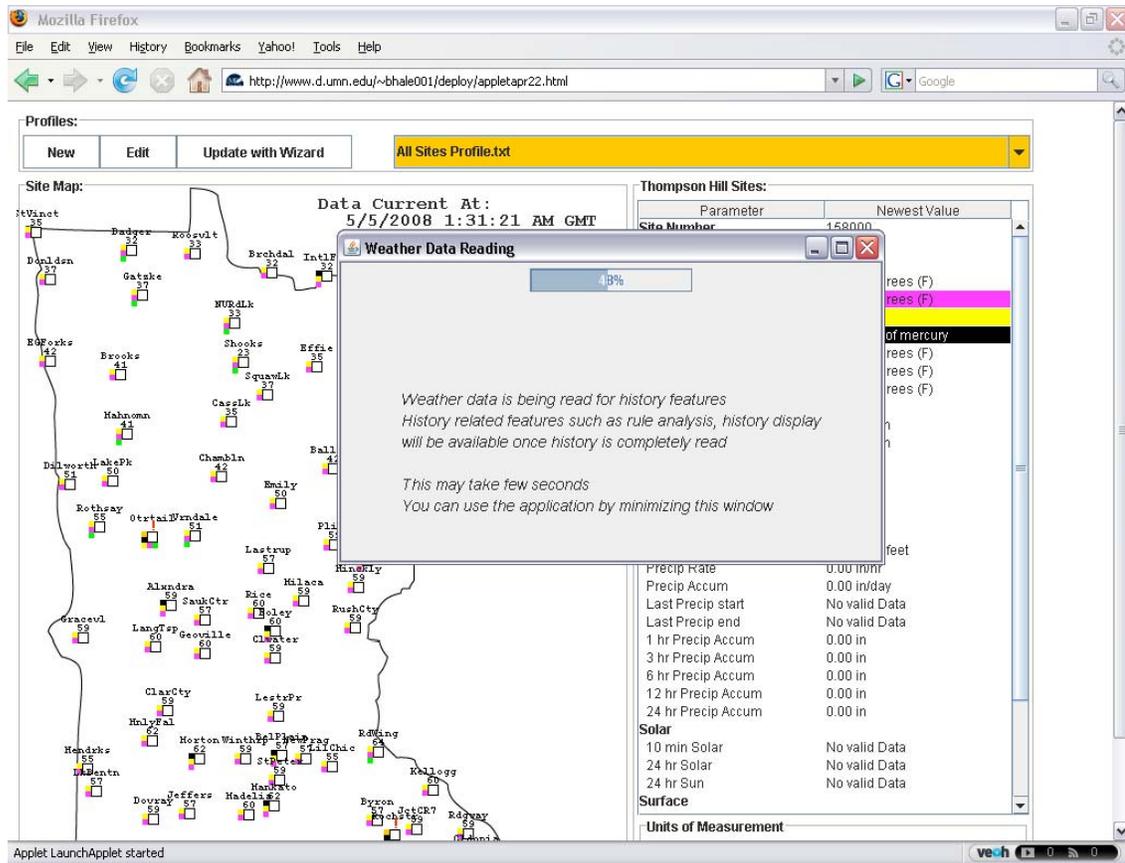
Figure 3.2: Initial Application Screen

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The button 'Edit' helps the user to edit an already created profile. This allows user to navigate to another screen which will allow them to add, delete or edit the sensors and rules in their profile. The button 'Wizard' links to a new screen which takes the user through a series of simple questions to add a rule to their profile.


Figure 3.3: Map and Parameter Screen

The top-right portion of the screen has a drop-down list which shows the profiles created on the computer from which the application is being accessed. It also provides two default profiles named 'All Sites Profile' and 'Demo Profile'. The 'All Sites Profile' has all the sites from the Minnesota State and has some default rules. The 'Demo Profile' has some specific sites and rules for

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the demonstration purpose. These two profiles help the user get started and will always load with their default values whenever the application starts.

The map panel in Figure 3.3 displays the RWIS sites in Minnesota State and the table accompanying shows the weather sensors and values reported by these sensors for the site selected. The user can click on any of the small white boxes on the state map representing various sensor sites around the state which will bring up all of that site's parameters with the triggered parameters highlighted with the color selected for the rule and their values in the table on the right side of the window. The user can also click on any of parameters in the table and the map will be updated, reflecting the current value of that parameter at each site which supports that sensor, sites which do not support that sensor, or are not reporting a value for it, will have a red exclamation mark shown instead.
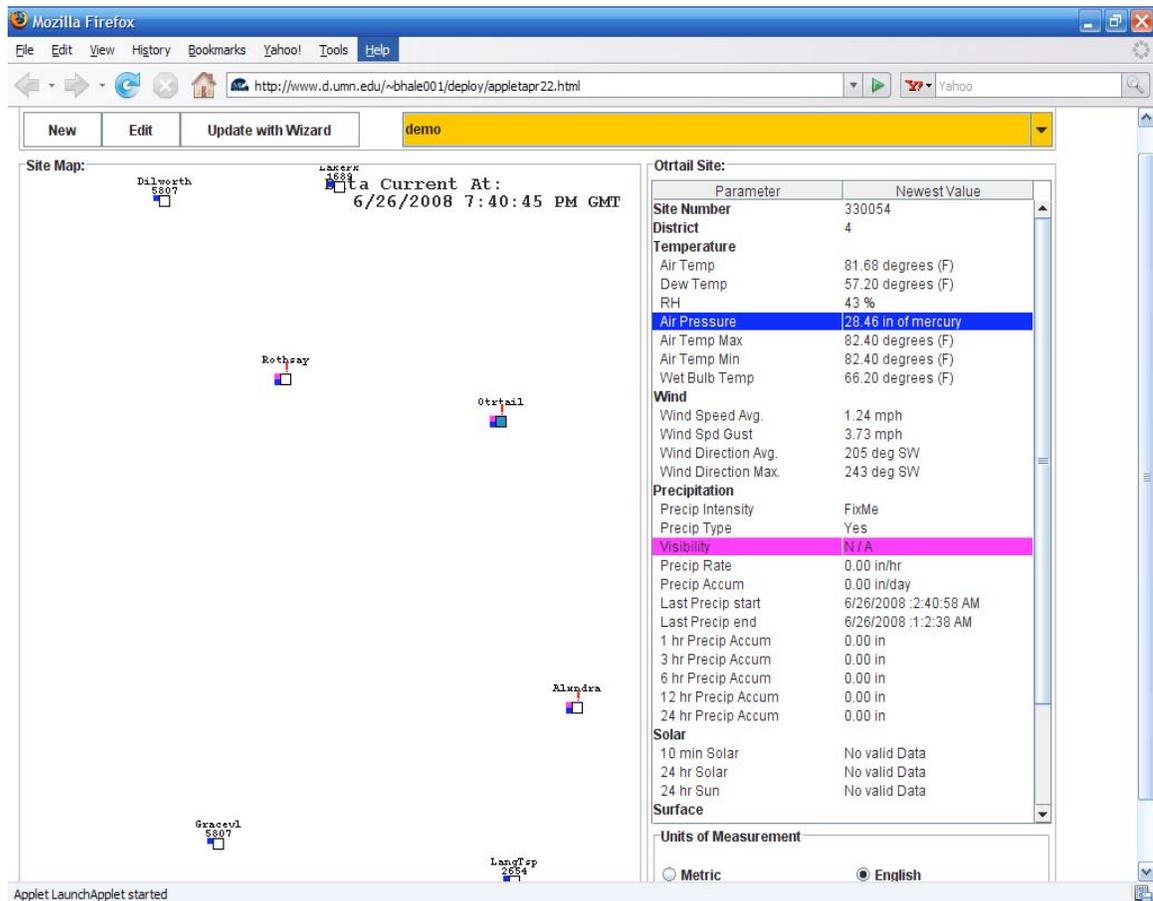
Figure 3.4: Parameter Highlighting for Sites

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Figure 3.4 shows the parameters highlighted for the 'Otrtail' site. 'Air Pressure' is highlighted with blue and 'Visibility' is highlighted with magenta color. As this site does not have a visibility sensor, a red exclamation mark is shown on the top of the site when the visibility parameter is selected.

To change profiles, simply click the drop-down box colored in orange near the top of the screen and select one of the options, or click the 'New' button to create a new profile. If the user creates a new profile, they should then add sites and rules to that profile using the profile editing screen(s). The small squares of color surrounding many of the sites reflect rules that have been triggered at that site. In order to edit these rules as well as add or remove sites from the current profile, click 'Edit' next to the profile selection box. Clicking 'New' will accomplish the same task, but also prompt for a name and open up the profile manager with a new blank profile.

The user can click '<< -1 hour' button at the bottom of the page to view the sensors' data reported 1 hour previously. The user can also click '+1 hour >>' button at the bottom of the page to scroll 1 hour ahead in sensors' data when they are viewing the history.

The user can click the wizard button at the top to get assistance with adding a rule to the existing profile or creating a new profile with a rule added. Rules are used to recognize when potentially problematic situations have occurred (indicating a sensor may have failed). The rule wizard is discussed in more detail in the Wizard section.

Zooming Facility:

As sites displayed on the map are quite close to each other and sometimes it might not be possible to distinguish between the sites, a zooming facility is provided to zoom the map. The map can be zoomed by right clicking the area that need to be zoomed and could be resetted by right clicking again. Figure 3.5 shows the map panel when it is zoomed.
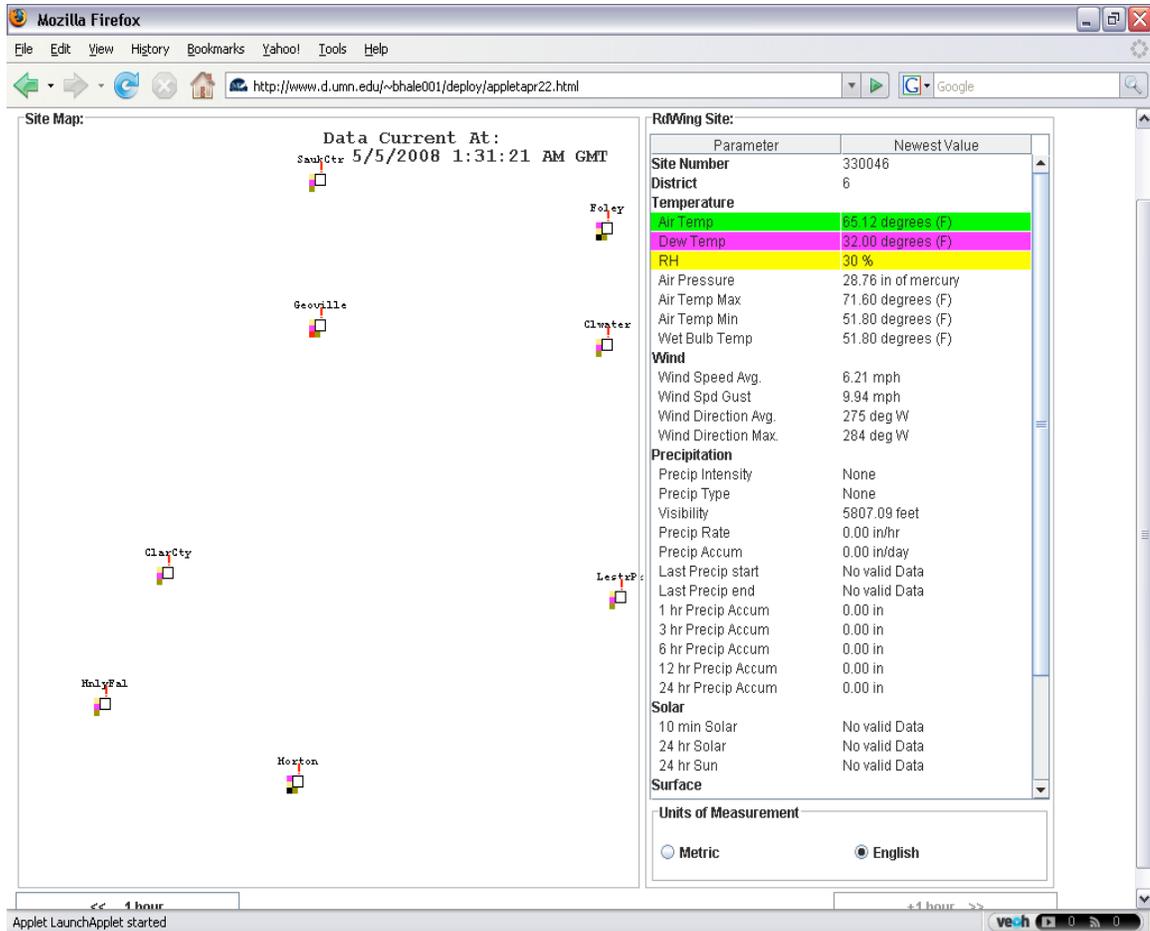
Figure 3.5: Map Zooming

3.2.2 Creating a Profile

Our tool allows the user to tune the profile to their needs. The profile is a set of sensor sites and a set of rules which are applied to the sensors at these sites. This helps the user to focus on specific sites and apply desired rules to test the sensors at these sites. To create a new profile, the user clicks on the `'New'` button located on left hand side of the Map/ Parameter screen. This will pop up a small dialog for the user to input a new name for the profile being created as shown in Figure 3.6.
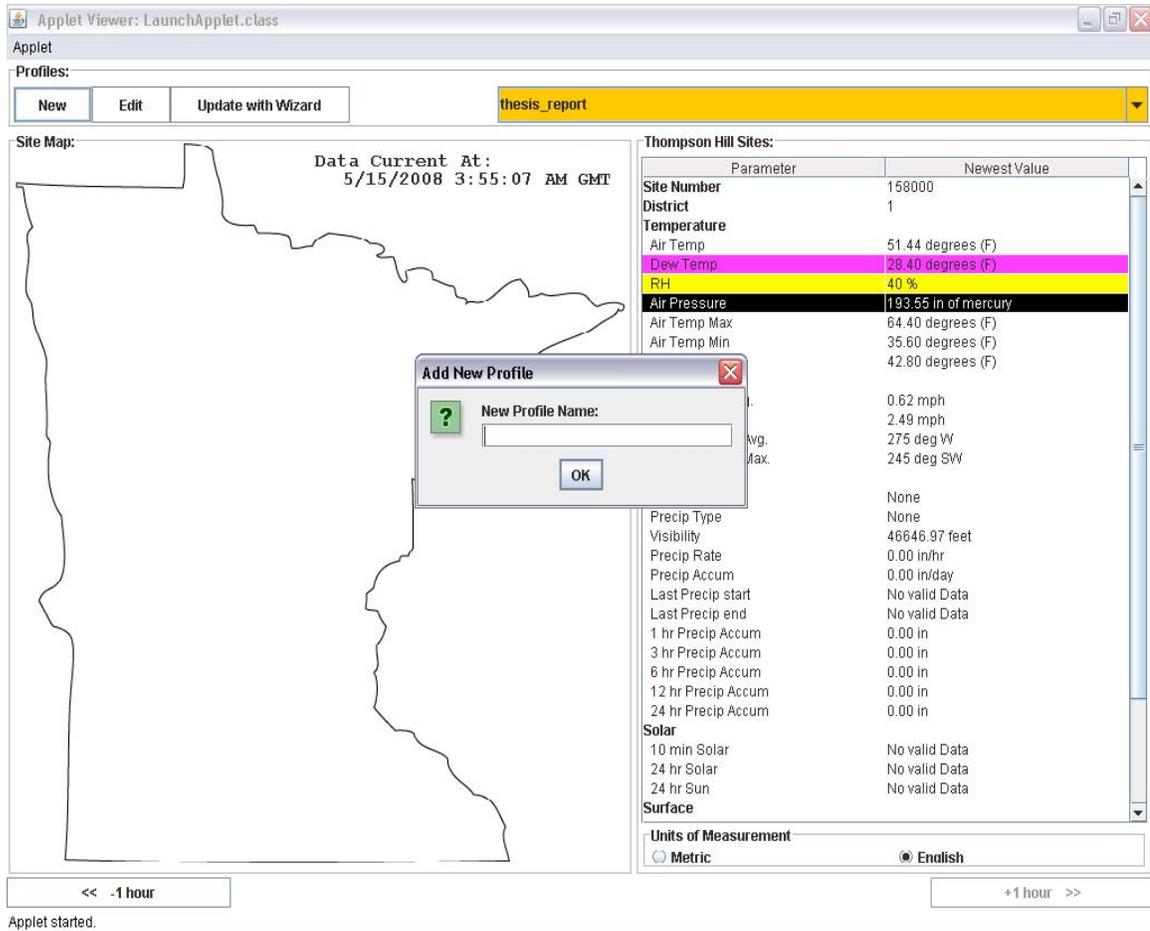
Figure 3.6: New Profile Creation

Once the user enters the profile name and clicks ok, the application will navigate to the Profile Manager screen which allows user to add rules and sites to the profile. The following section describes the process to add rules and sites to the profile.

3.2.2.1 Adding or Editing a Rule

To enable the user to configure the system specifically for their needs, the application provides a `'Profile Manager'` screen which helps the user to create or modify the profile to indicate which sensors to use and to define the rules of interest to the user.
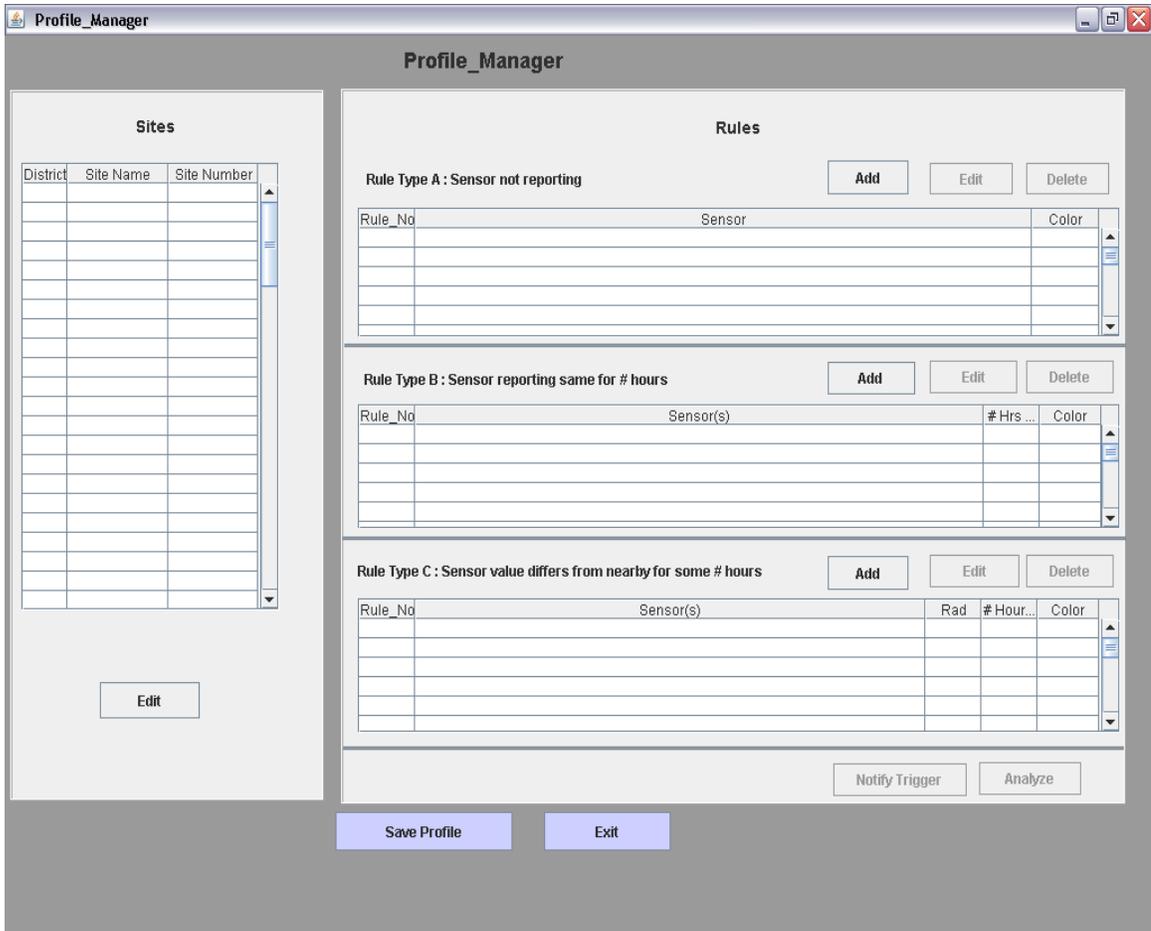
Figure 3.7: Profile Manager Screen

The left side of the 'Profile Manager screen' shows the list of the sensors already in the profile and has 'Edit' button below the list to allow the user to add or delete the sites from the profile. On the right side of the screen are the three tables listing three types of rules in the profile along with the 'Add', 'Edit', 'Delete' buttons to allow these operations.

There are three types of rules in our system A, B, and C. Rules of Type A are triggered if the selected sensor(s) are not reporting any values for the current day Rules of type B are triggered if the selected sensor(s) have reported identical values for a user-defined number of hours. Rules of type C are triggered if the selected sensor(s) deviate by a user-defined amount from other sensors at Sites within a radius of and for a number of hours defined by the user.

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The 'Notify Trigger' button at the bottom of these tables allows the user to setup a trigger notification via email or popup window which will be discussed in the section 3.2.5. The 'Analyze' button lets the user analyze how good a rule is. This will be discussed in the section 3.2.4.

The 'Save Profile' button at the bottom of the screen allows the user to save all the changes done to the profile. This saves the profile file to the user's computer so that it can be accessed later with the updated information. The 'Exit' button at the bottom of the screen exits the Profile Manager without saving any changes done to the profile. More detailed description and the process to add or delete rules follows here.

Rules are used to recognize when potentially problematic situations have occurred (indicating a sensor may have failed). Rules are defined and edited as discussed below. After clicking Edit or New from the map window, a different window called the Profile Manager will appear.

In the Profile Manager window, the current sites to be shown on the map screen as well as the rules that are defined are shown. The user clicks the 'Edit' button below the 'Sites' table to add or remove sites from the profile. See Section 3.2.2.2 below for more details.

The three tables on the right side of the Profile Manager window represent the three types of rules currently implemented. Rules are added by clicking the appropriate Add button (one for each type of rule A, B, or C) and edited by selecting the appropriate rule of interest in the Rule table and clicking 'Edit'. Once rules have been added, the color associated with the rule is shown on the map screen next to sites which have triggered that rule. In the map screen, if a user clicks on a site the current sensor values for that site appear on the right of the screen, and the values that explain why the rule is active are highlighted in the rule color.

The 'Analyze' button on the rule panel helps to analyze a particular rule by selecting the rule and clicking the button. The system then consults the database to sample the values corresponding to that rule and generates a graph showing how often the rule might fire given various threshold values for the rule.

More about this is discussed in the section 3.2.4.

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The 'Notify' button on the rule panel helps to specify the rule triggering notification to be sent via email or shown in the popup window. More about this is discussed in Rule Triggering Notification section (3.2.5)

3.2.2.1.1 Adding or Editing a Rule of Type A (Sensor is not responding rule)
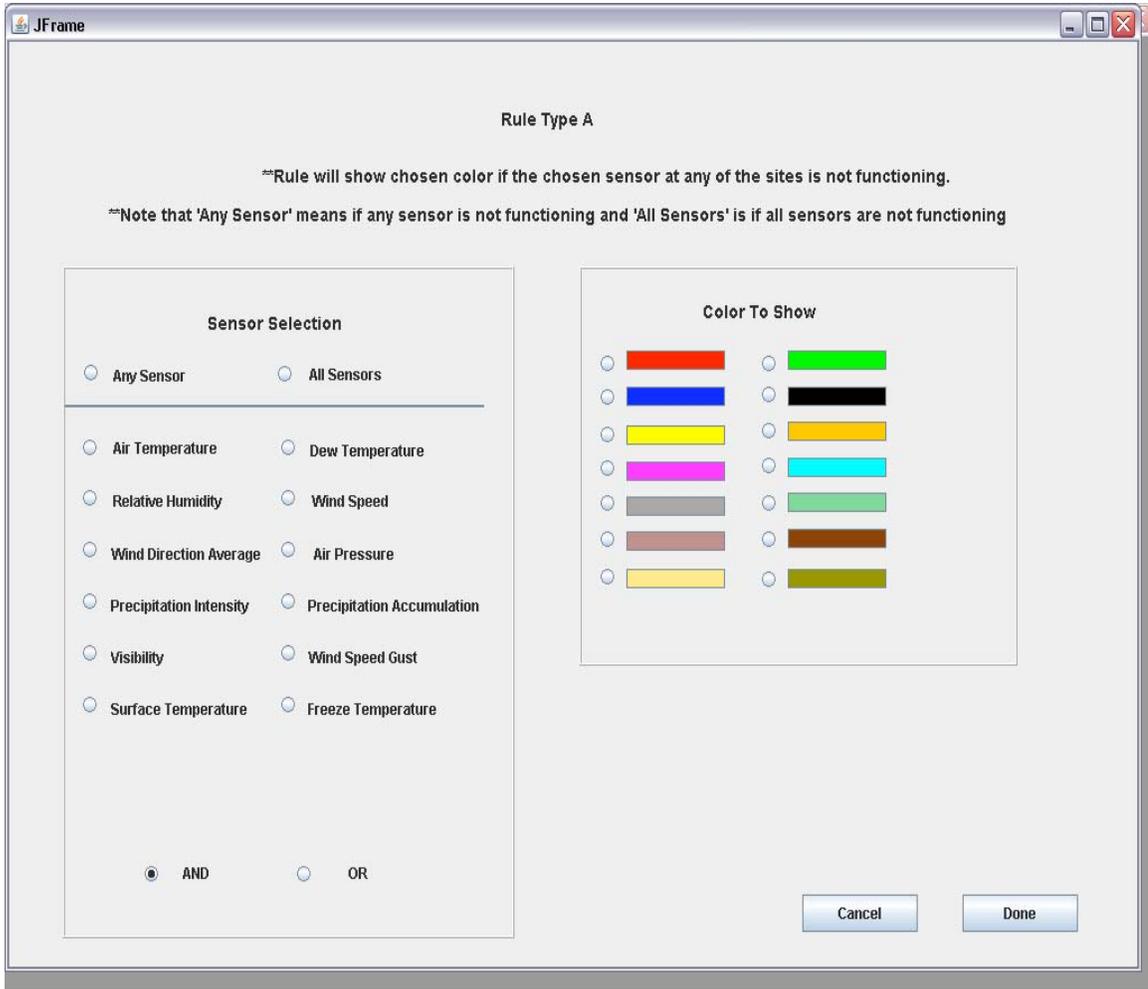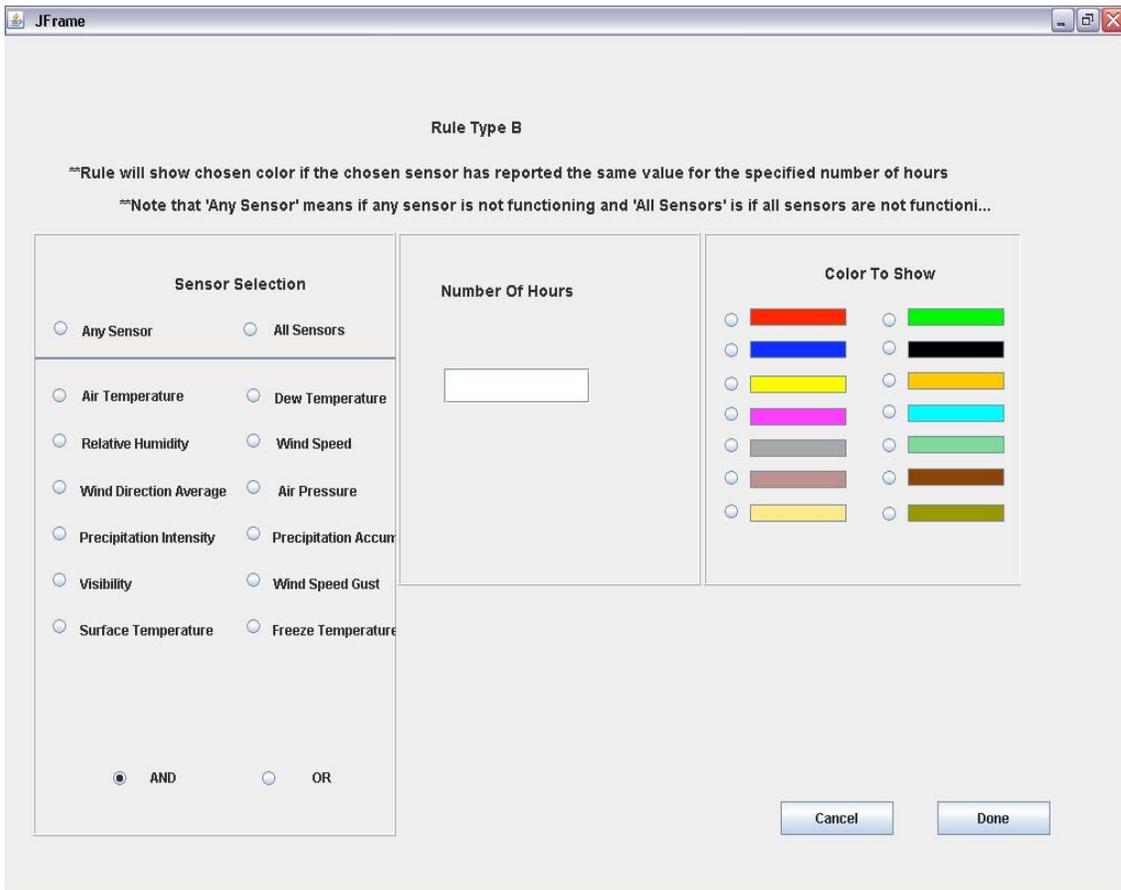

Figure 3.8: Rule Type A Add / Update Screen

Rules of Type A are triggered if the selected sensor(s) are not reporting any values for the current day. To add such a rule, the user selects a sensor to observe and color to be displayed on the map when this rule is triggered. The user clicks 'Done' to add the rule.

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For example, if the user selects the 'Air Temperature' sensor and the 'Yellow' color, a rule will be added to their profile which will be triggered when the 'Air Temperature' sensor will not be reporting any values for the day. The 'Yellow' color will be shown on the map screen next to the sites which will have triggered this rule.

3.2.2.1.2 Adding or Editing a Rule of Type B (Sensor has been reporting the same value for some number of hours)

Rule Type B

Rule will show chosen color if the chosen sensor has reported the same value for the specified number of hours

Note that 'Any Sensor' means if any sensor is not functioning and 'All Sensors' is if all sensors are not functioni...
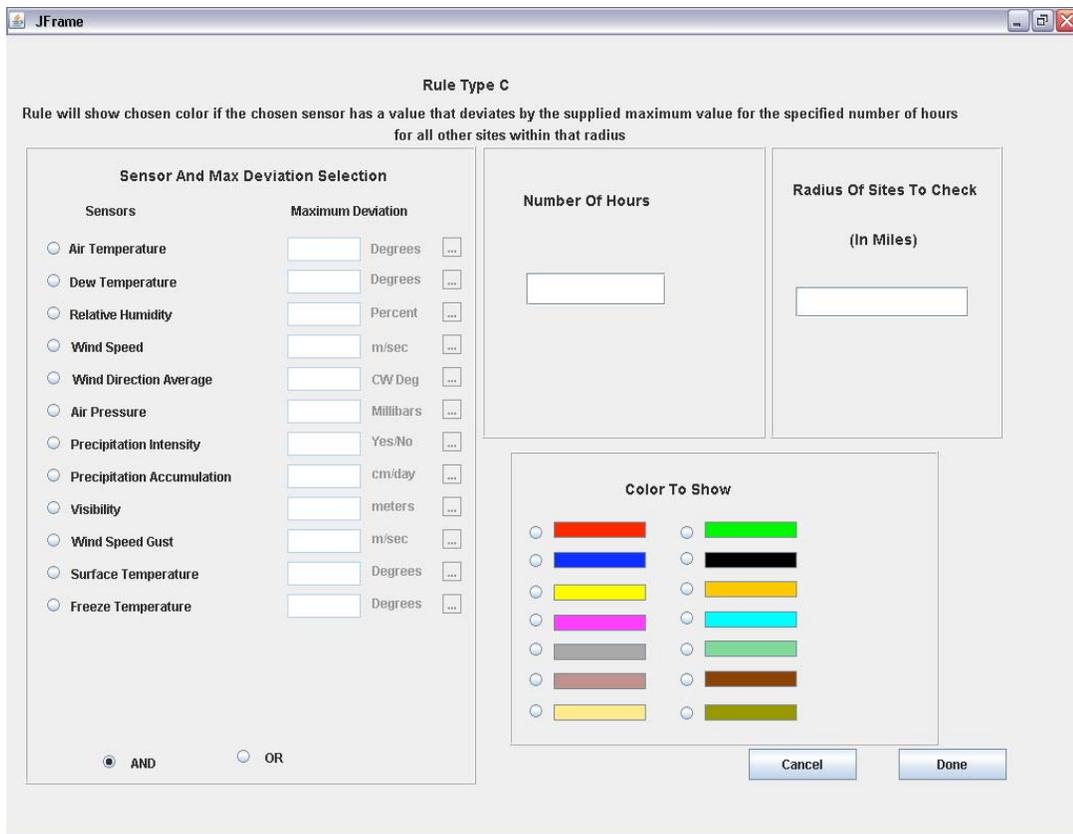
Figure 3.9: Rule Type B Add / Update Screen

Rules of type B are triggered if the selected sensor(s) have reported identical values for a user-defined number of hours. To add the rule, the user selects a sensor, the number of hours and a color to be displayed on the map when this rule is triggered. The user clicks 'Done' to add or update the rule.

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For example, if the user selects the 'Dew Temperature' sensor, inputs '5' as the number of hours and selects the 'Magenta' color, a rule will be added to their profile which will be triggered when the 'Dew Temperature' sensor will report identical values for 5 hours. The 'Magenta' color will be shown on the map screen next to the sites which will have triggered this rule.

3.2.2.1.3 Adding or Editing a Rule of Type C (Sensor has been significantly different from its neighbors for some number of hours)


Figure 3.10: Rule Type C Add / Update Screen

Rules of type C are triggered if the selected sensor(s) deviate by user-defined amount from other sensors at sites within a user-defined radius for a number of hours (also set by the user). To add the rule, the user selects a sensor. Then the user enters the amount the sensor value will differ from other sensors. The user can also click the small button near the deviation entry text box to look at the history of deviation

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values. This can be used to select an appropriate deviation value. The user enters the number of hours and radius for sites to be considered for sensor's value deviation check and the color to be displayed on the map when this rule is triggered. The user clicks 'Done' to add or update the rule.

If the user clicks the button near the deviation entry text box, a screen like that in Figure 3.11 pops up to show the history of the sensor of interest.
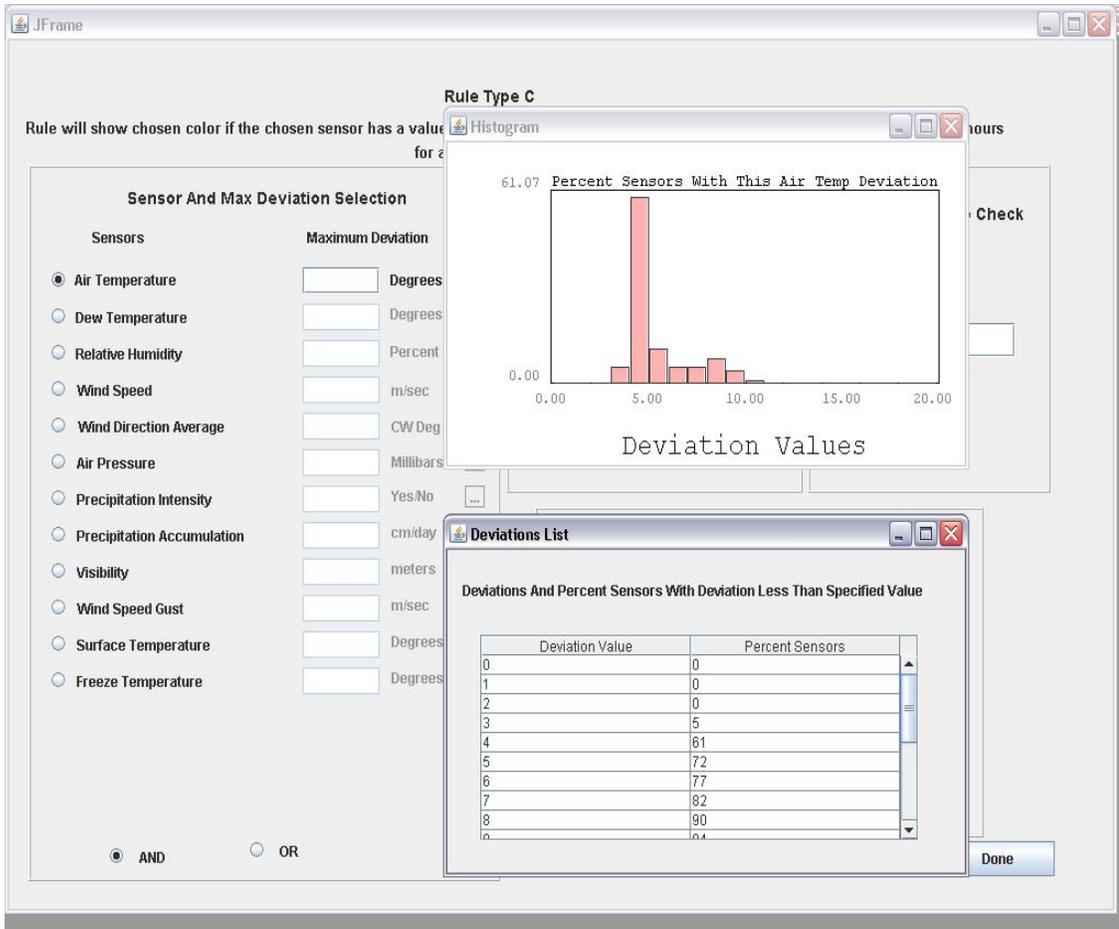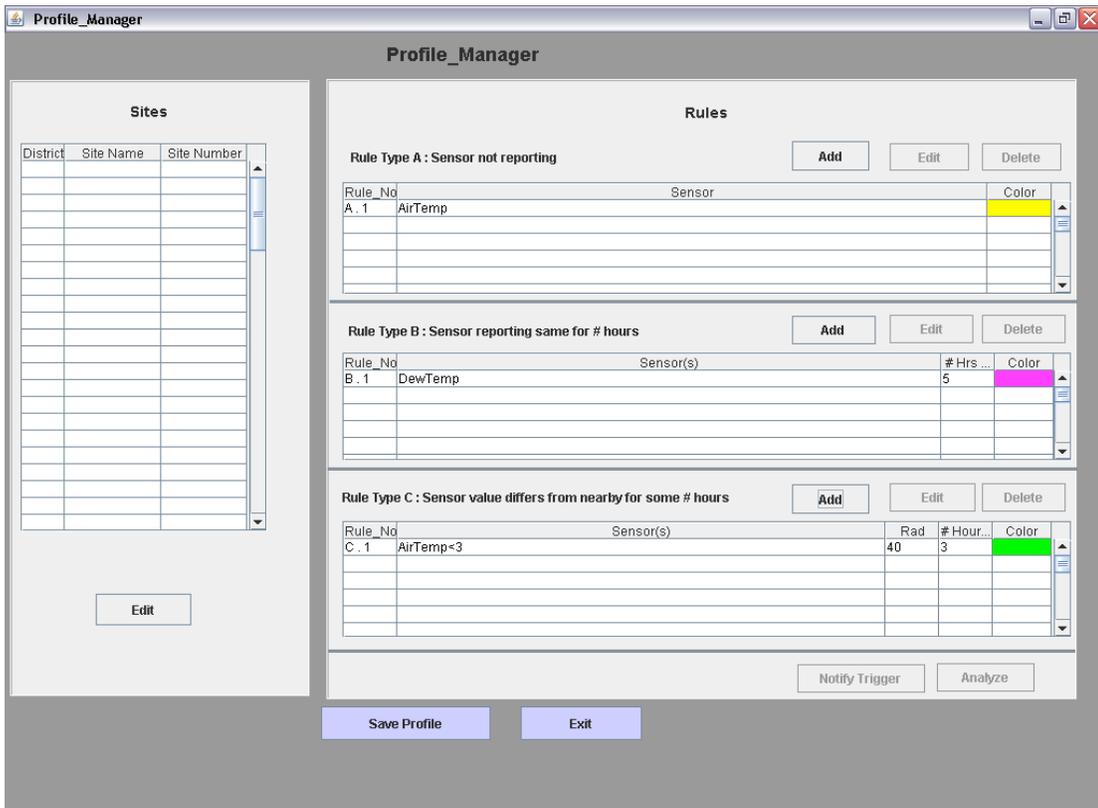

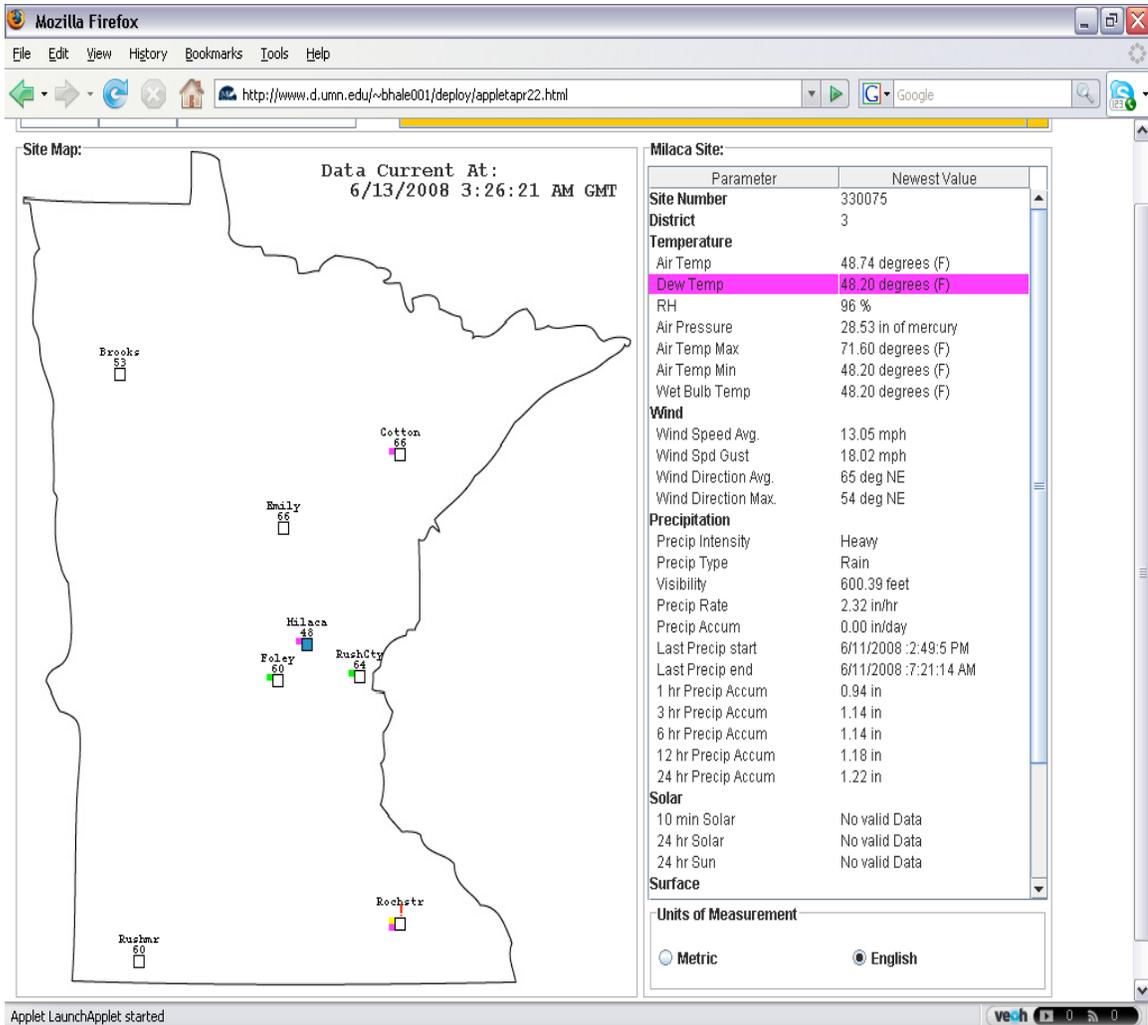**Figure 3.11: Rule Type C Deviation Histogram**

The histogram in Figure 3.11 shows the percentage of sensors with corresponding deviation. The table below the histogram summarizes the same by showing the percentage sensors with the deviation equal to or less than the value. This histogram and table helps to select a proper deviation value to set for the Rule type C.

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For example, if the user selects the 'Air Temperature' sensor, inputs '3' as the maximum deviation, '40' as the radius, '3' as the number of hours and selects the 'Green' color, a rule will be added to their profile which will be triggered when the 'Air Temperature' sensor deviates by '3' degree celsius from other sensors at sites within a radius of 40 for 3 hours. The 'Green' color will be shown on the map screen next to the sites which will have triggered this rule.

Figure 3.12 shows the Profile Manager when the rules described in examples above, are added to the profile. We have added one for each type of rules to the profile.

Figure 3.12: Profile Manager Screen: Rules Added

Data Current At:
6/13/2008 3:26:21 AM GMT

Site Map:

Brooks 53

Cotton 66

Emily 66

Milaca 48

Foley 60 RushCty 64

Rochstr

Rushmr 60

Milaca Site:

Parameter	Newest Value
Site Number	330075
District	3
Temperature	
Air Temp	48.74 degrees (F)
Dew Temp	48.20 degrees (F)
RH	96 %
Air Pressure	28.53 in of mercury
Air Temp Max	71.60 degrees (F)
Air Temp Min	48.20 degrees (F)
Wet Bulb Temp	48.20 degrees (F)
Wind	
Wind Speed Avg.	13.05 mph
Wind Spd Gust	18.02 mph
Wind Direction Avg.	65 deg NE
Wind Direction Max.	54 deg NE
Precipitation	
Precip Intensity	Heavy
Precip Type	Rain
Visibility	600.39 feet
Precip Rate	2.32 in/hr
Precip Accum	0.00 in/day
Last Precip start	6/11/2008 :2:49:5 PM
Last Precip end	6/11/2008 :7:21:14 AM
1 hr Precip Accum	0.94 in
3 hr Precip Accum	1.14 in
6 hr Precip Accum	1.14 in
12 hr Precip Accum	1.18 in
24 hr Precip Accum	1.22 in
Solar	
10 min Solar	No valid Data
24 hr Solar	No valid Data
24 hr Sun	No valid Data
Surface	

Units of Measurement

○ Metric   ● English

Applet LaunchApplet started

Figure 3.13: Map Screen with triggered rules

Figure 3.13 shows the map screen displaying the sites with the color codes around them indicating the rules from Figure 3.12 triggered for these sites. Site 'Rochstr' has a yellow colored flag indicating that it has a rule type A triggered for it. Sites 'Cotton', 'Milaca' and 'Rochstr' have a magenta colored flag indicating that they have a rule type B triggered for them. Sites 'Foley' and 'Rushcty' have a green colored flag indicating that they have a rule type C triggered for them.

3.2.2.1.4 <u>Deleting a Rule</u>

The Profile Manager Screen (Figure 3.12) also allows the user to delete a rule from the profile. For each rule of type A, B or C, a rule table in Figure 3.12 gives a quick description of each of the existing rules as well as a delete button. In order to delete a rule, the user selects a rule and clicks 'Delete'. This pops up a window to confirm the deletion. Once the user confirms the deletion, the rule will be deleted from the profile.

In order to save all the changes done to the profile, the user needs to click 'Save Profile' button at the bottom of the Profile Manager as this updates the profile file stored on the system.

3.2.2.2 <u>The Site Editor Window</u>

The Profile Manager Screen is an interface for the user to create a profile with sites of interest so that they can focus on only these to analyze the possible sensor failures at these locations. Clicking 'Edit' below the sites list on the Profile Manager pops up the 'Site Editor' which helps the user to add, delete sites in their profile.

The top-left portion of the screen lists the districts in Minnesota State which have the RWIS sites. Below this list, there is a list of sites at these districts. This list shows the district number, site name, site number and a flag which indicates whether this sensor is part of the profile or not.

The table on the right hand side of the Site Editor window lists the sites already in the profile. The Current Sites in the profile, if any, are shown in the table labeled 'Current Sites'. To add more sites, the user first selects a district from the Districts table. This will result in the window showing the sites for that district. Sites that are already part of the current profile will be highlighted in black.
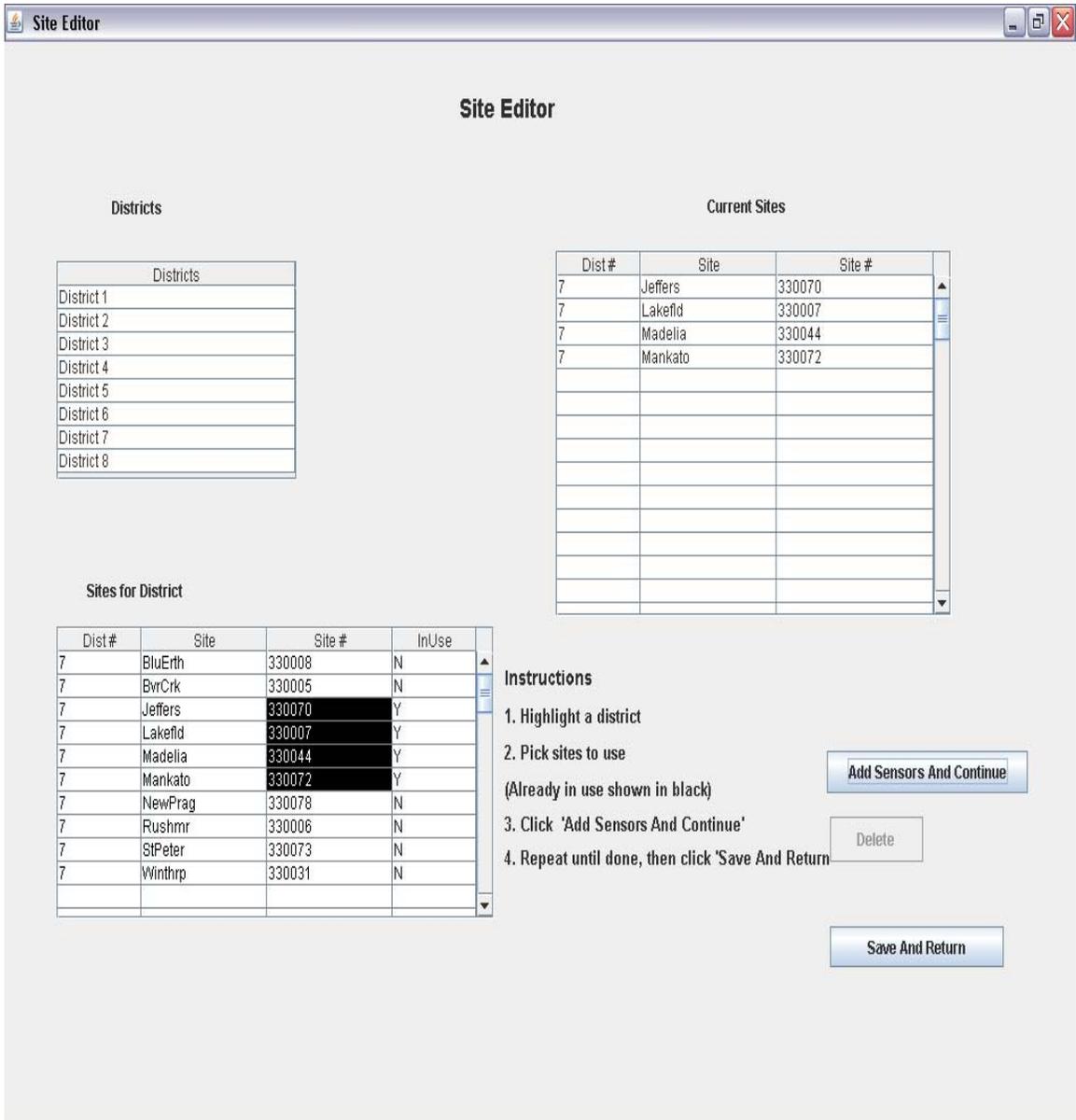
To add one or more sites to the current profile, the user selects them in the Sites for District table (the use r can select multiple sites by holding ctrl, or by clicking and dragging over multiple rows) and then clicking 'Add Sensors And Continue'.

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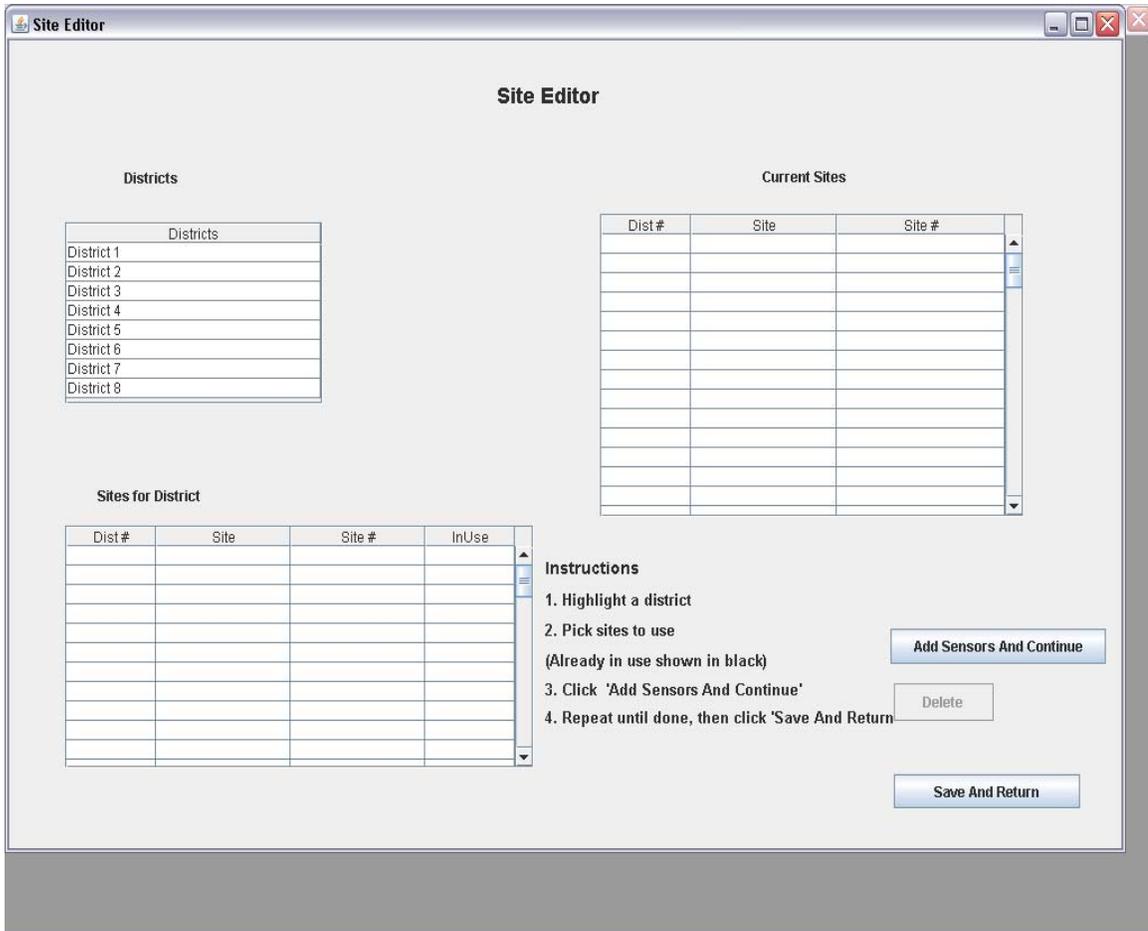
Figure 3.14: The Site Editor Window for adding and deleting sites from the profile

Sites may be deleted from the profile by highlighting one or more in the Current Sites table and clicking the 'Delete' button. To return to the Profile Manager screen, saving your changes, click on 'Save and Return'. Figure 3.15 shows the Site Editor when 'district 7' and 4 sites from that district have been selected.

Figure 3.15: Site Editor: Sites Selected

Once the user clicks **'Add Sensors and Continue'**, sites the user selected are added to the **'Current Sites'** list. Figure 3.16 shows the **'Site Editor'** with selected sites added to the **'Current Sites'** list.

Figure 3.16: Site Editor: Sites Added

Figure 3.17 shows the profile after it has been updated with the selected sites above. The

'Profile Manager' shows the sites' list and also lists the rules from the profile.
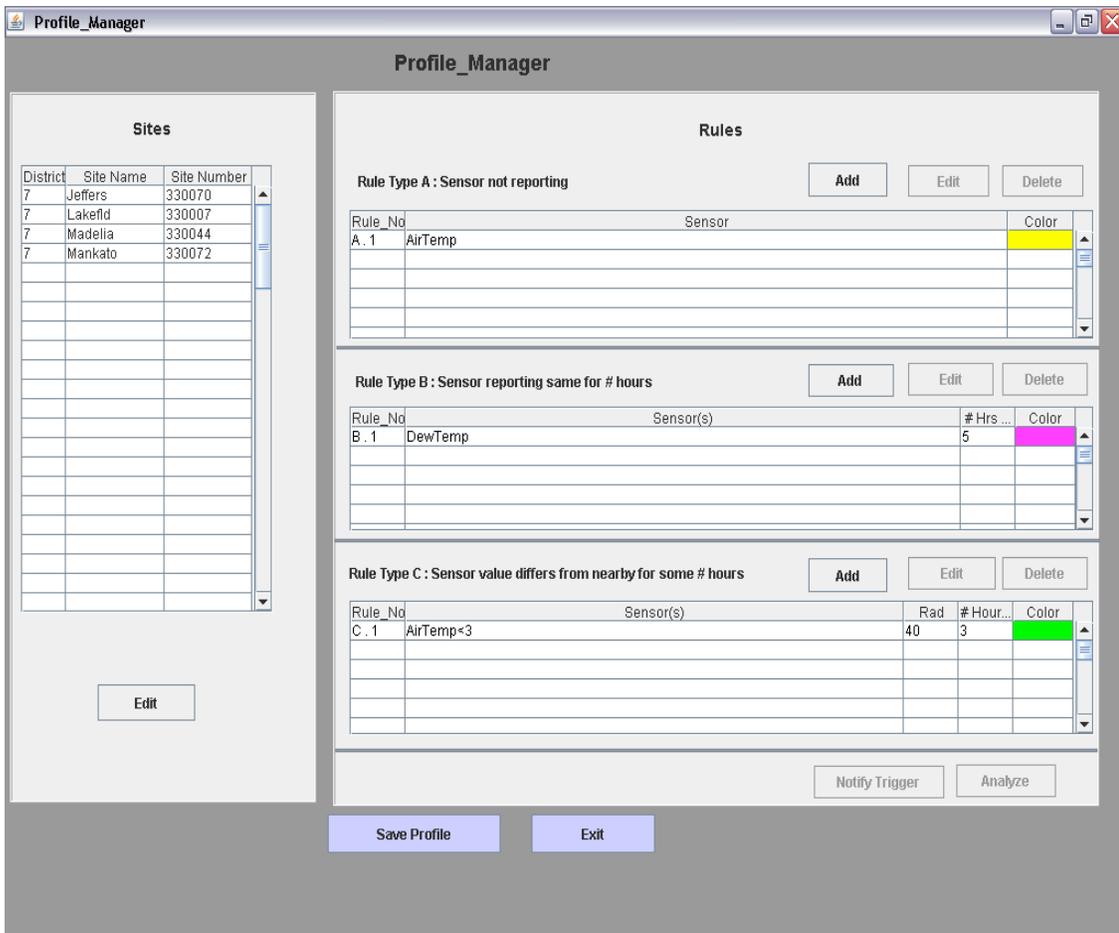
Figure 3.17: Profile Manager: Profile with Sites and Rules Added

In order to save this profile the user clicks 'Save Profile' at the bottom of the screen. This will cause the system to open the Map screen and will show the current sites from the profile on the map. This also applies the rules selected to the sites and if any of the rules are triggered, the color indicators around the site could be seen on the map and in the parameter list besides the map.

Figure 3.18 shows the sites added on the map and as it can be seen. At the 'Madelia' site a rule has been triggered to display a color on the map and parameter list besides the map. Rule C.1 is shown as triggered for this site.

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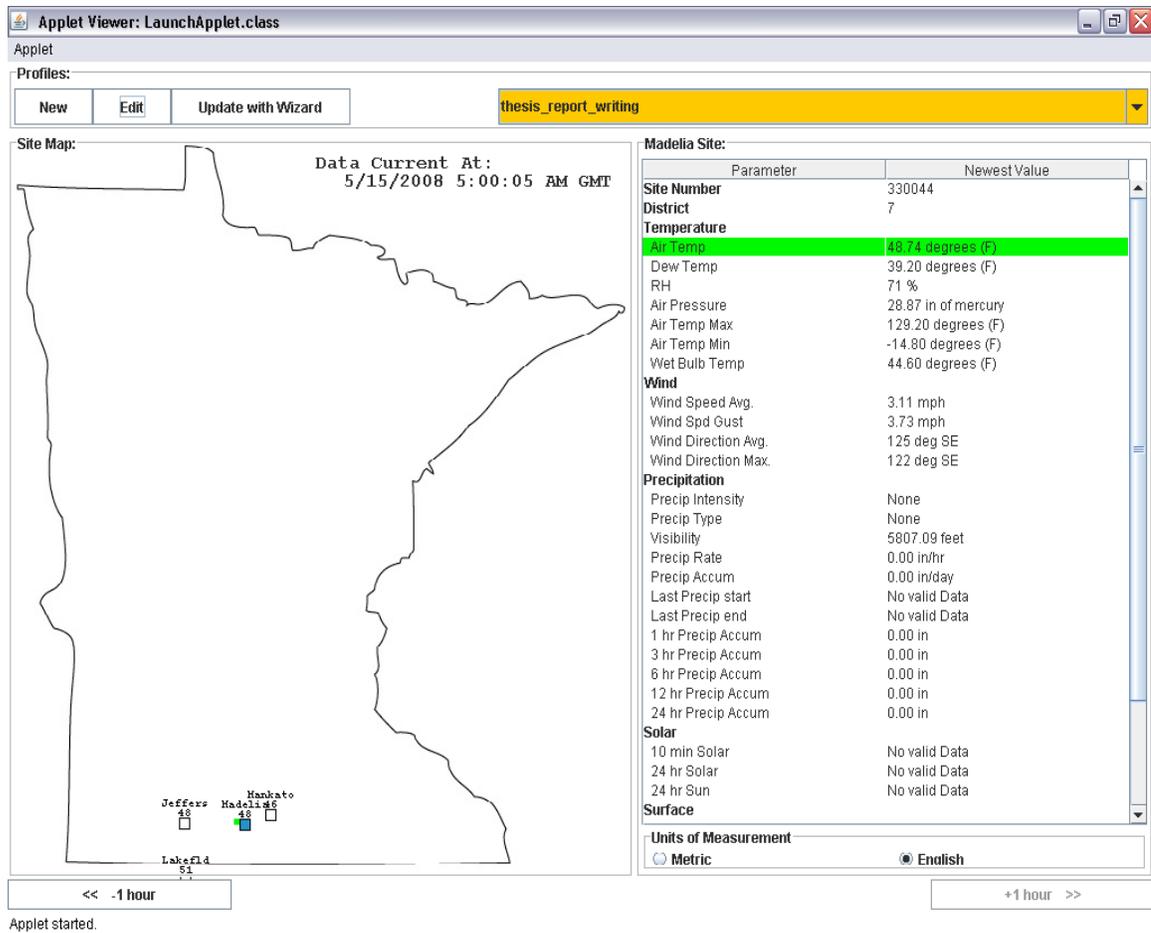
**Figure 3.18: Profile on the Map Screen**

3.2.3   Rule Analysis

One of the critical difficulties in making use of rules is that the user will likely want the rules to catch as many of the malfunctions as possible, but also wants to avoid getting a lot of `"false alarms"` from the rules, that is, cases where an alarm is raised but no malfunction is occurring. One tool that may help in dealing with this issue is the Rule Analysis button. When a user is adding or editing a rule they can use this button to get a reading on how often a particular rule might fire based on the historical data.

Clicking the Analyze button on Rule panel of Profile Manager can be used to analyze the selected rule by varying its parameters such as number of hours, radius or deviation.
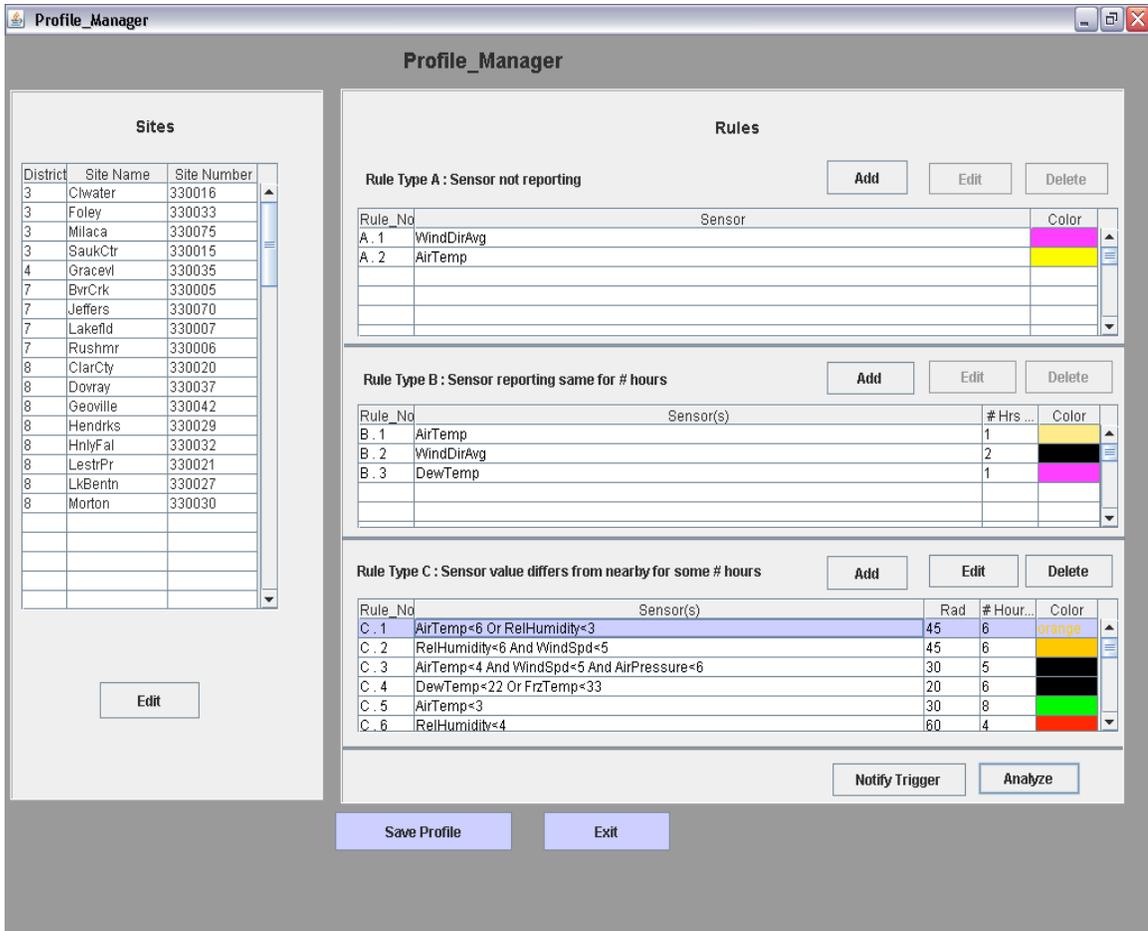
Figure 3.19: Profile Manager: Rule Selected to Analyze

Historical data is gathered to display the graphs depicting the rule triggering ability for various parameter values. Figure 3.20 graph shows the rule trigger percentage as the parameter 'Number of Hours' is varied for a certain rule. This graph gives a clear idea to the user to select the parameter 'Number of Hours' based on the triggering percentage desired. . As the sensors reporting correct data will not report the value deviating from nearby sensors for a long time, the percentage of sensors triggered decreases as the number of hours increase.
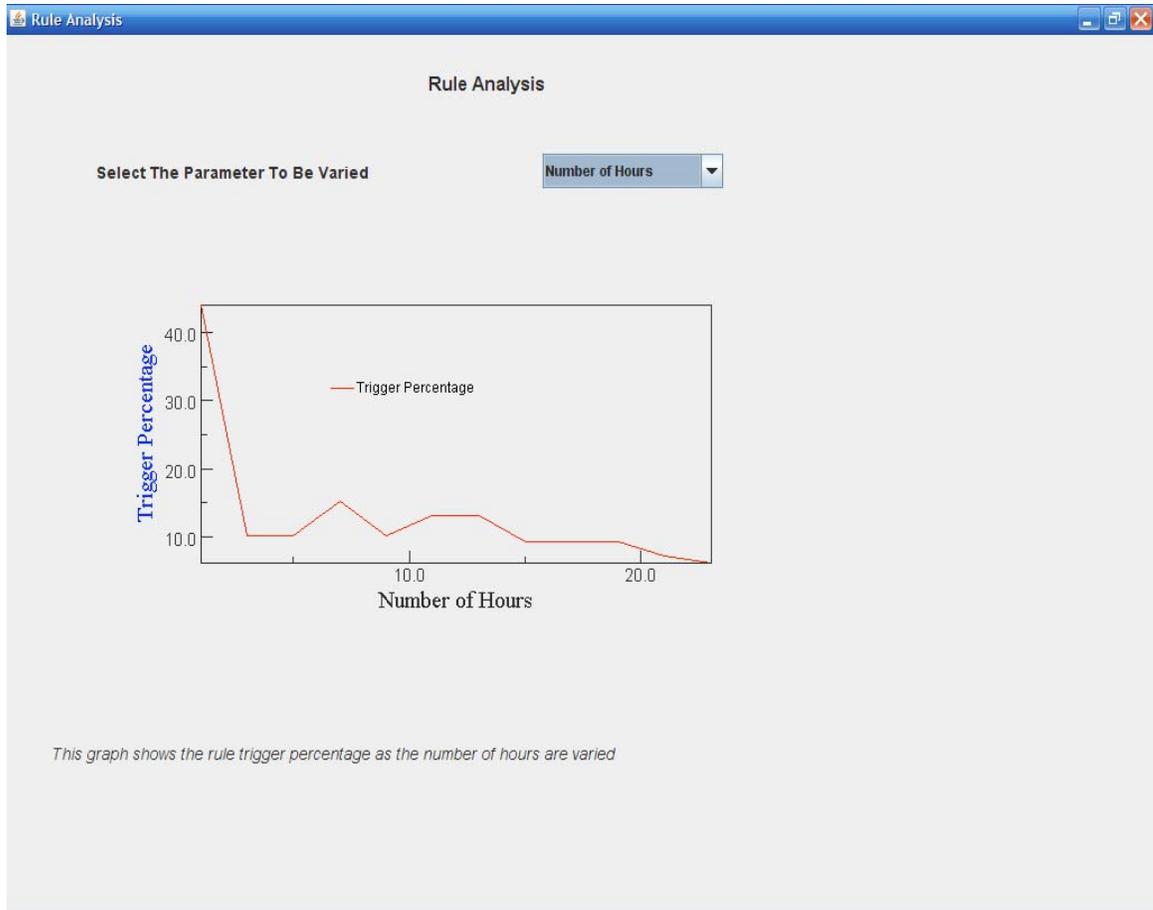
Figure 3.20: Rule Analysis Graph: Number of Hours Varied

Figure 3.21 shows the rule trigger percentage as the parameter 'Deviation' is varied for a certain Rule.This graph gives an idea to the user to select the parameter 'Deviation' based on the triggering percentage desired. As the sensors reporting correct data will not report the value deviating by a large amount from nearby sensors, the percentage of sensors triggered decreases as the deviation value increases.
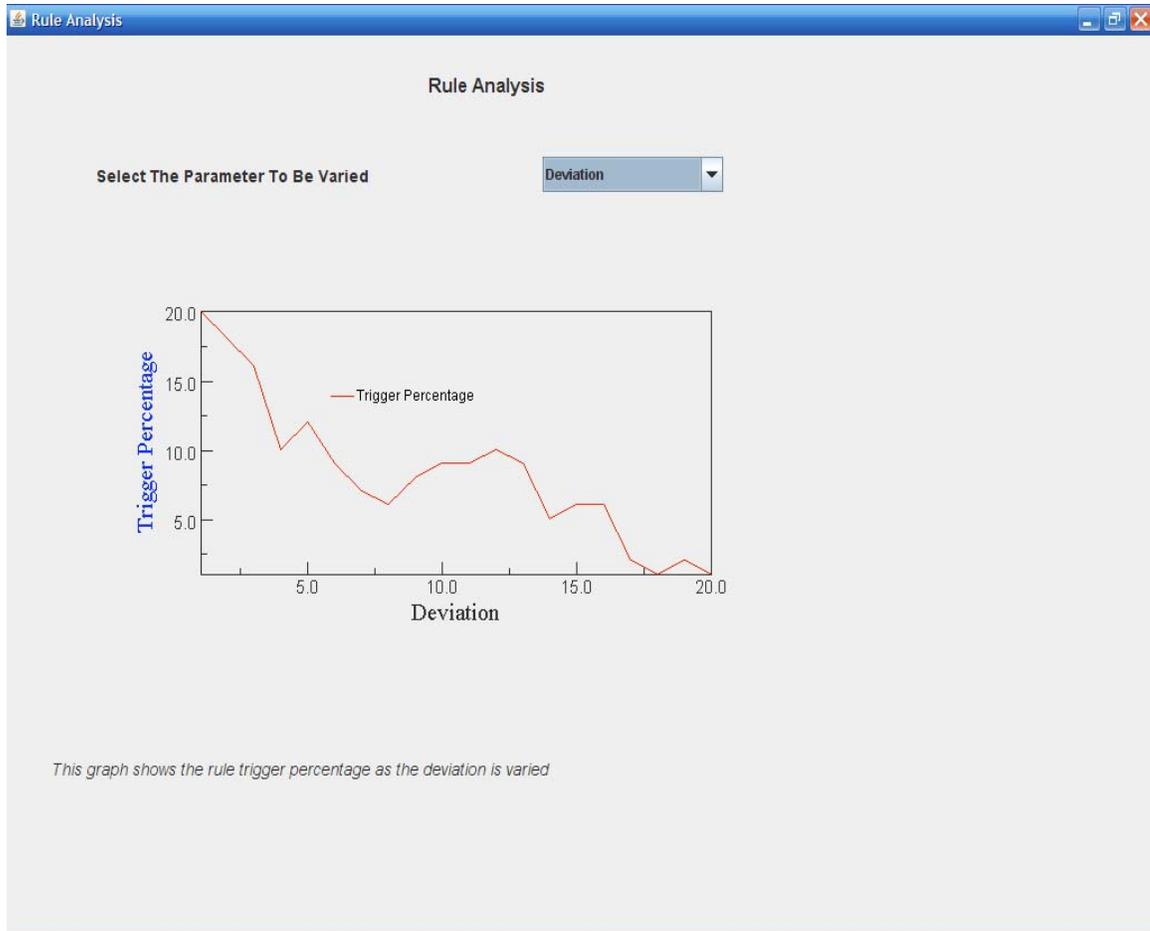
Figure 3.21: Rule Analysis Graph: Deviation Varied

Figure 3.22 shows the rule trigger percentage as the parameter 'Radius' is varied for a certain Rule. This graph gives an idea to the user to select the parameter 'Radius' based on the triggering percentage desired. As the radius increases, the number of neighboring sensors considered for the analysis increases. This causes an increase in the number of sensors being triggered. But as radius increases beyond a certain limit, some sensors find a match for a sensor value with the farthest sensor and will not be triggered. This result in a decrease in the number of sensors triggered.
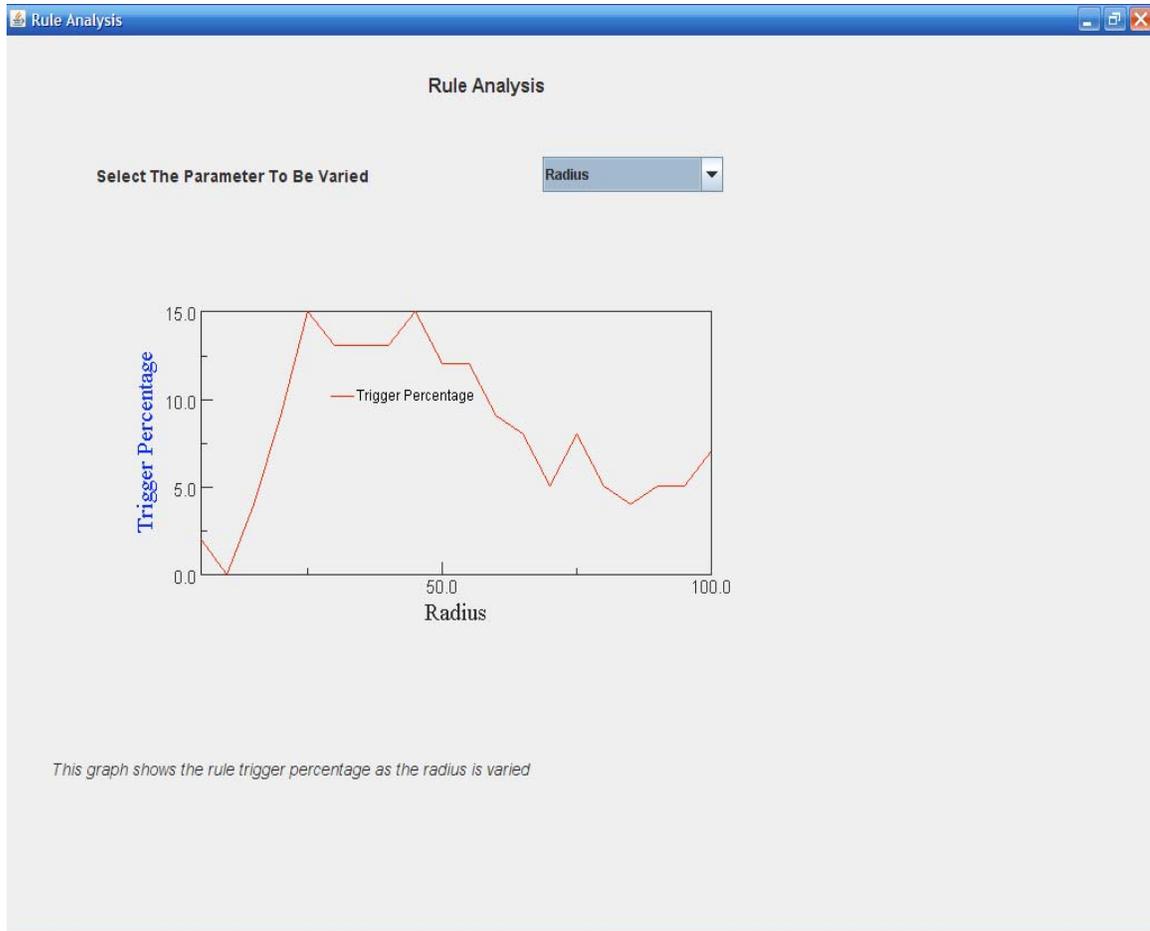
Figure 3.22: Rule Analysis Graph: Radius Varied

3.2.4 Rule Triggering Notification

For a user of this application, it might not be convenient to keep a check on the rule triggered by examining the map display. Hence the system provides a way to notify the user about the rule triggering. The user can set the system for Email or popup window notification showing the sites which are detected to meet the condition set by the rule. For each rule, a specific notification time could be setup.

To set a notification the user clicks the 'Notify Trigger' button on Rule panel of Profile Manager helps to set the triggering notification to be sent for the rule.
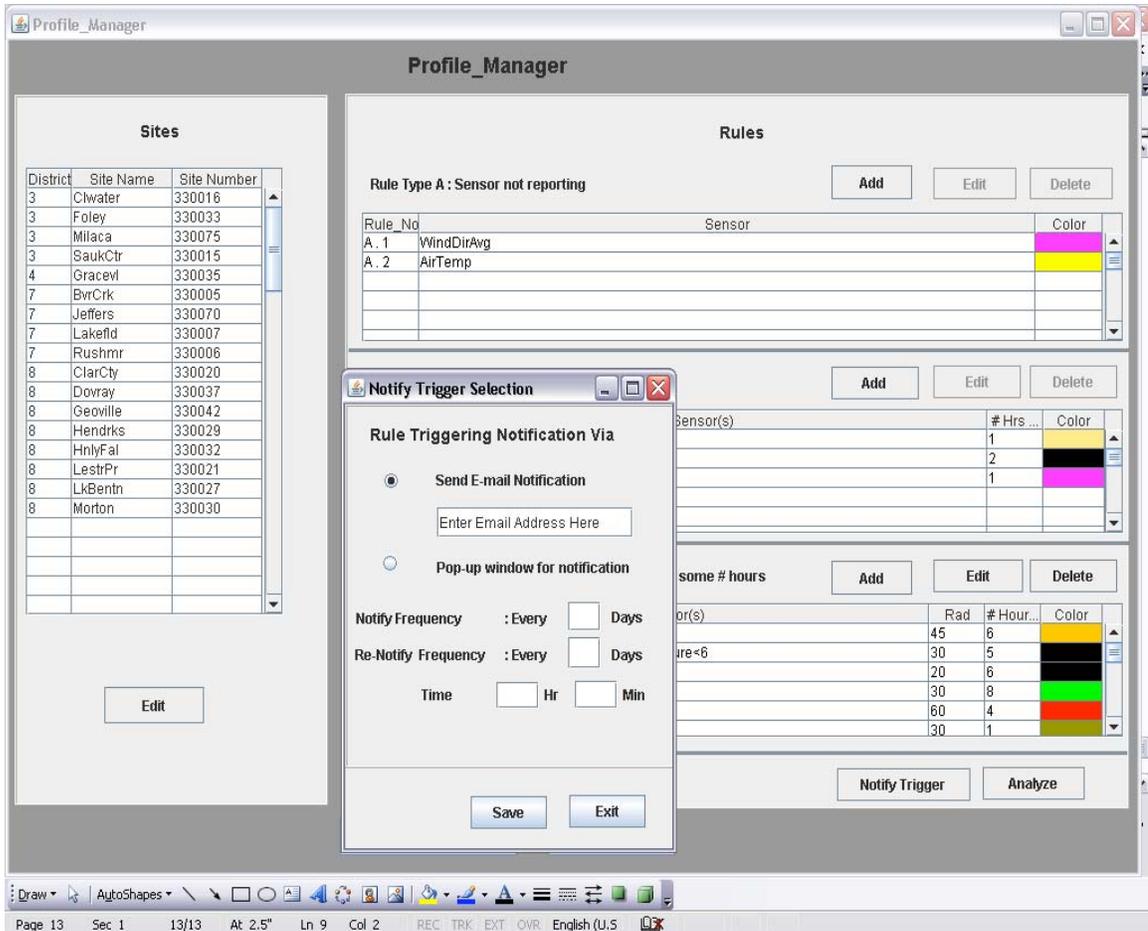
Figure 3.23: Rule Trigger Notification Window

The user can select either E-mail notification or pop-up window notification. If E-mail notification is selected, the user supplies the E-mail address for the rule triggering notification. Notify frequency helps to specify how frequently should the notification be sent via email or displayed on a popup window. The Re-Notify frequency helps to specify how frequently the user should again be notified via email or popup window. This needs to be a multiple of Notify frequency. Time specifies the time on 24 hr clock at which the notification should be sent or displayed. Figure 3.24 shows the popup window notification for a 'demo' profile about the 'AirPressure' sensor when the 'AirPressure' sensor is reporting same value for 1 hour. Figure 3.25 shows the email notification for a 'demo' profile

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about the 'AirPressure' sensor when the 'AirPressure' sensor is reporting same value for 1

hour.
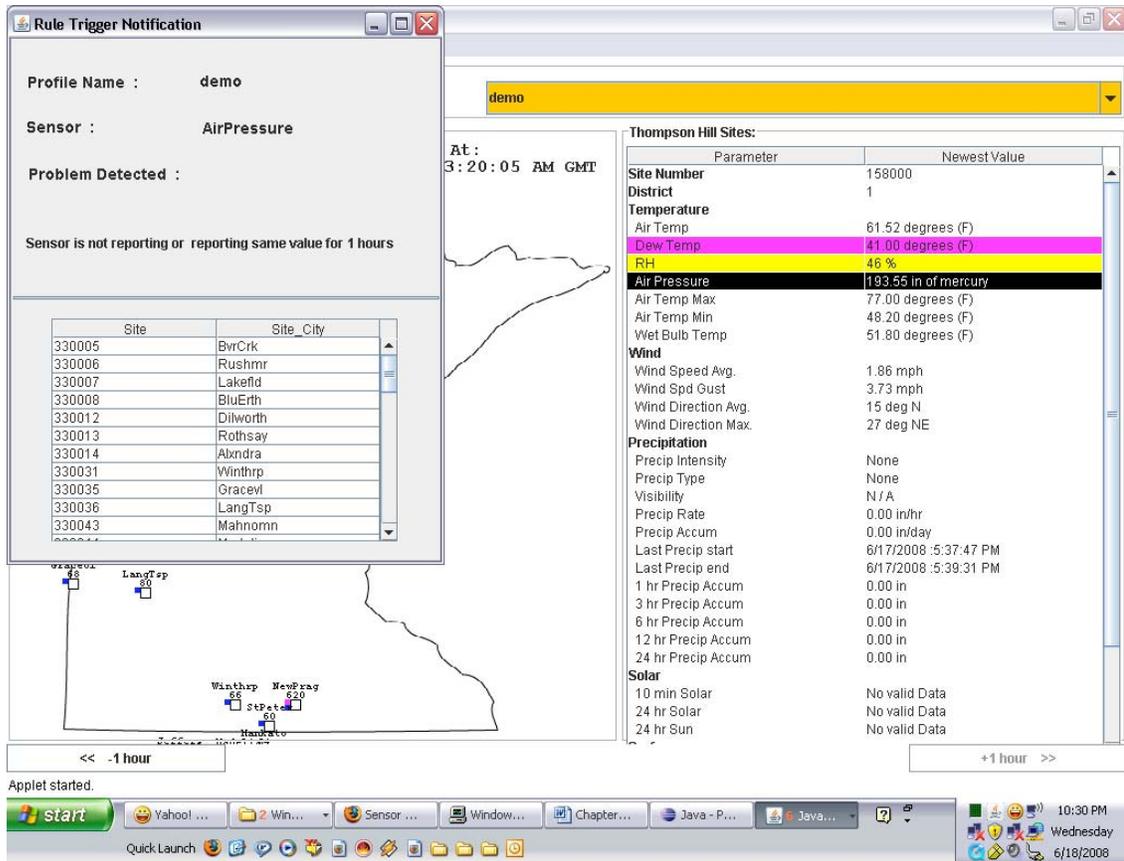
Figure 3.24: Pop-up Notification
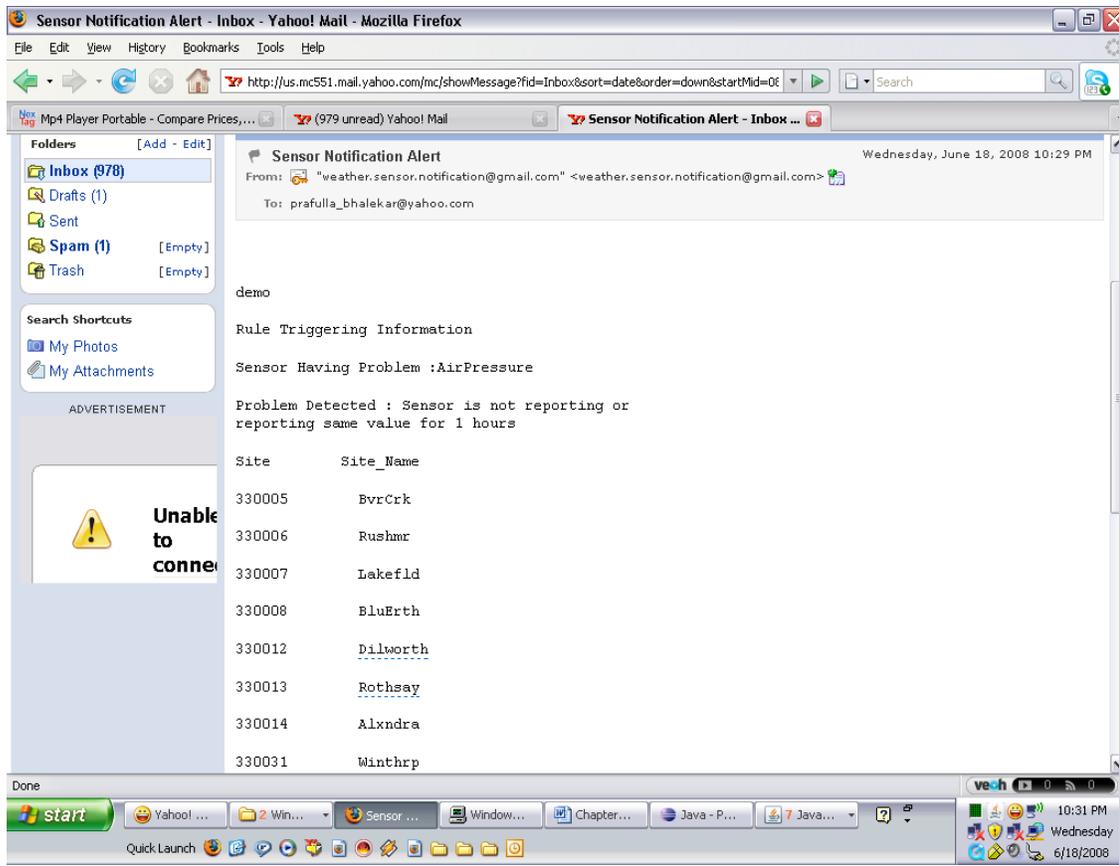
Figure 3.25: Email Notification

3.2.5 The Rule Wizard

To make the process of creating rules easier the system includes a wizard for creating rules that is done by answering a series of simple questions.

To use the wizard the user clicks the 'Update with Wizard' button on the Map/Parameter screen. The wizard window, which helps to add simple or complex rules to the profile under consideration, pops up. This helps the user to go through the process of adding a rule stepwise. User can select the complexity of rule to be added on the first screen. (See Figure 3.26)

As the user might prefer to add a single sensor or multiple sensors to their rule, the Wizard starts by asking the user to select the complexity of the rule which is one of the two types 1) a simple rule:

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This rule involves only a single sensor to be tested; and 2) a complex rule: This rule involves multiple

sensors to be tested together.
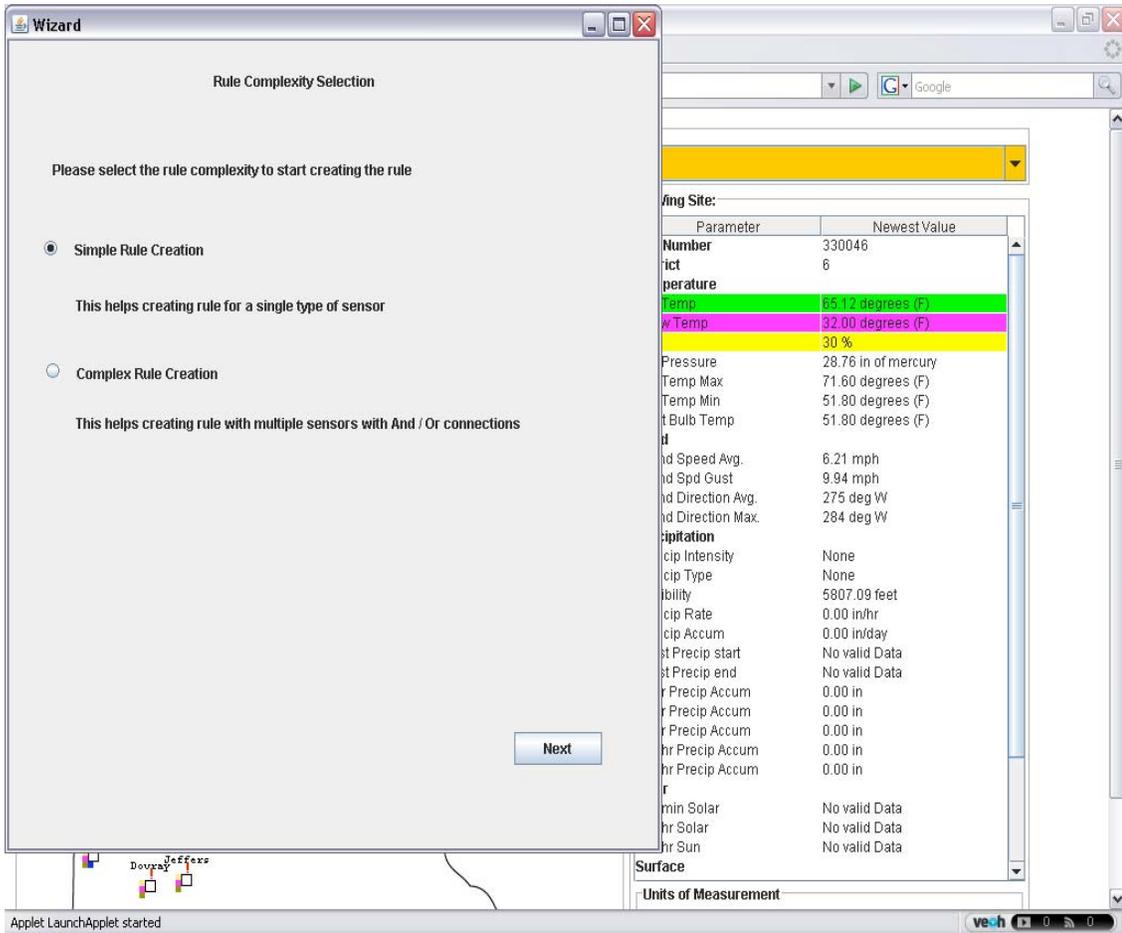
Figure 3.26: Wizard: Complexity Selection Screen

On the next screen (Figure 3.27), the user can select the type of rule to be added which could be one

of the Rules A, B or C. This allows user to add any of three types of rules for the system. For each rule, the

user will need to answer different types of questions to add the rule.
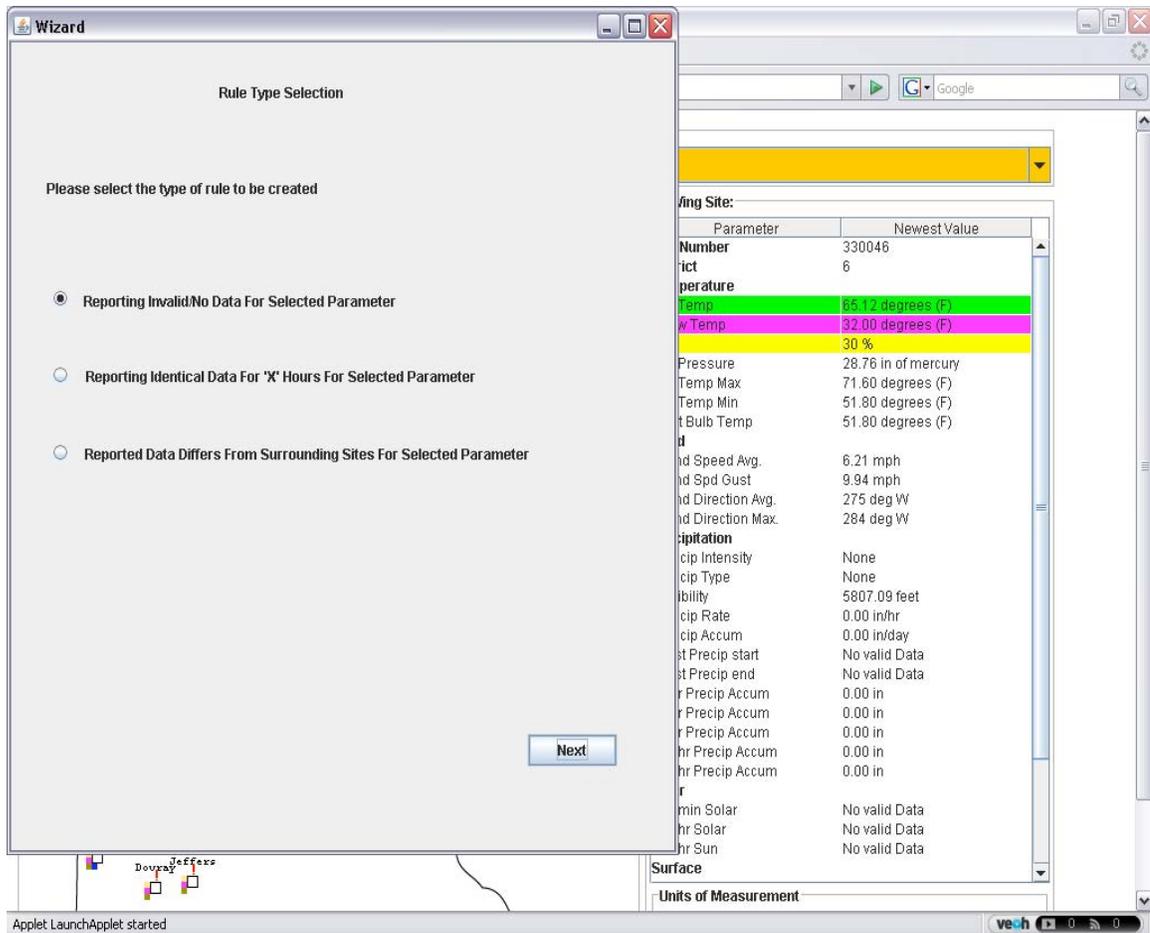
Figure 3.27: Wizard: Rule Type Selection Screen

The user might need to have a rule that is triggered if the multiple sensors meet the rule condition or one of the multiple sensors meets the condition. For this the Wizard allows the user to add a complex rule with multiple sensors connected with 'And' or 'Or' connection. When the sensors are connected via 'And' all the sensors are tested and for the rule to be triggered, all of the sensors need to meet the rule conditions. When sensors are connected via 'Or' if any one of the sensors meets the rule condition, the rule is triggered.

For example, consider a rule of Rule Type A which has **'Air Temperature and Air Pressure'** as its sensors. This rule will be triggered if the **'Air Temperature'** sensor is not be reporting any values for the day and the **'Air Pressure'** sensor is not be reporting any values for that day.

On the next screen (see Figure 3.28) the user selects the type of connection among the multiple sensors.

This could be **'And'** or **'Or'**.
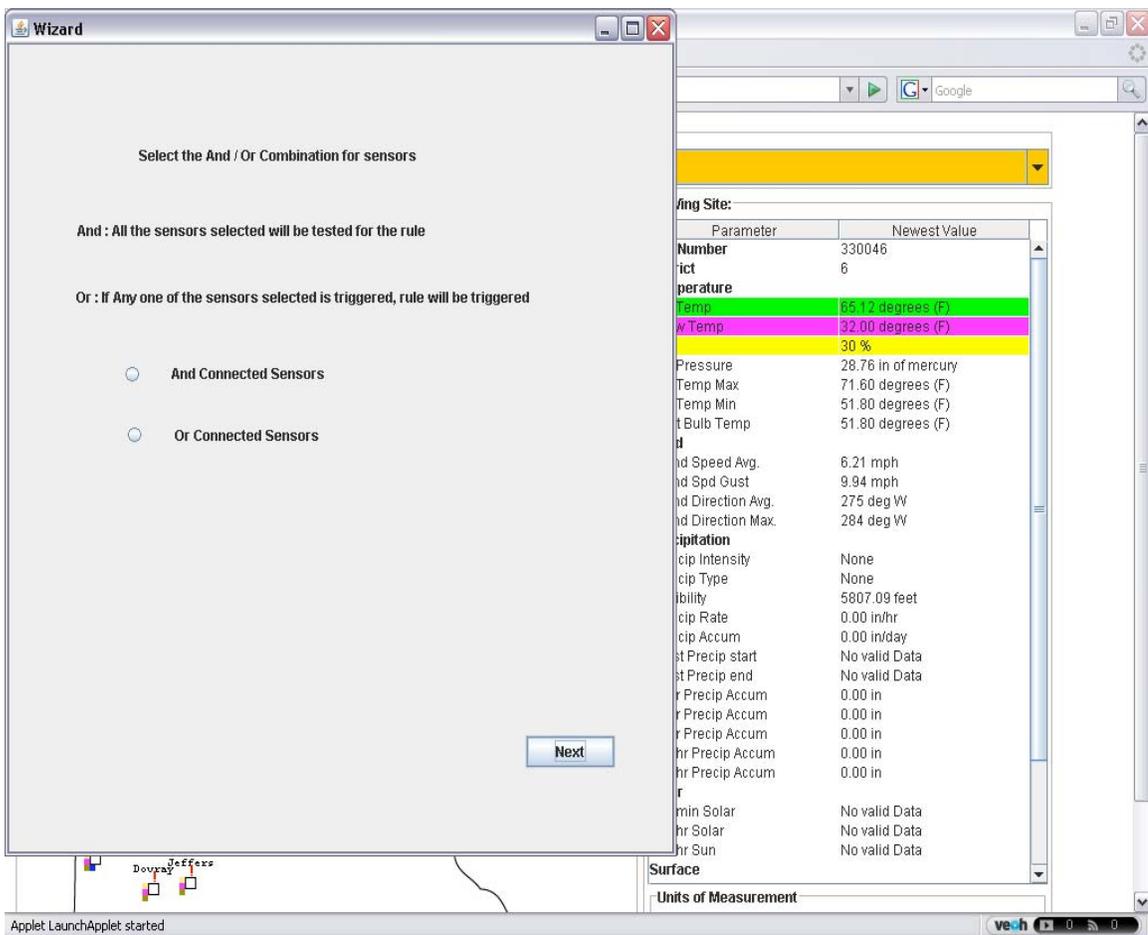
Figure 3.28: Wizard: Rule And / Or Flag Selection Screen

The next screen (see Figure 3.29) allows the user to select the sensors to be added in the rule. This screen allows the user to select sensors for which this rule needs to be applied. All the weather and surface sensors are available to be selected. For example, Figure 3.29 shows the selection of Air Temperature and Wind Speed sensors which are connected by 'Or' connection specifier. After selecting the sensors, the next screen (see Figure 3.30) helps user to select the number of hours for Rule type B and C.
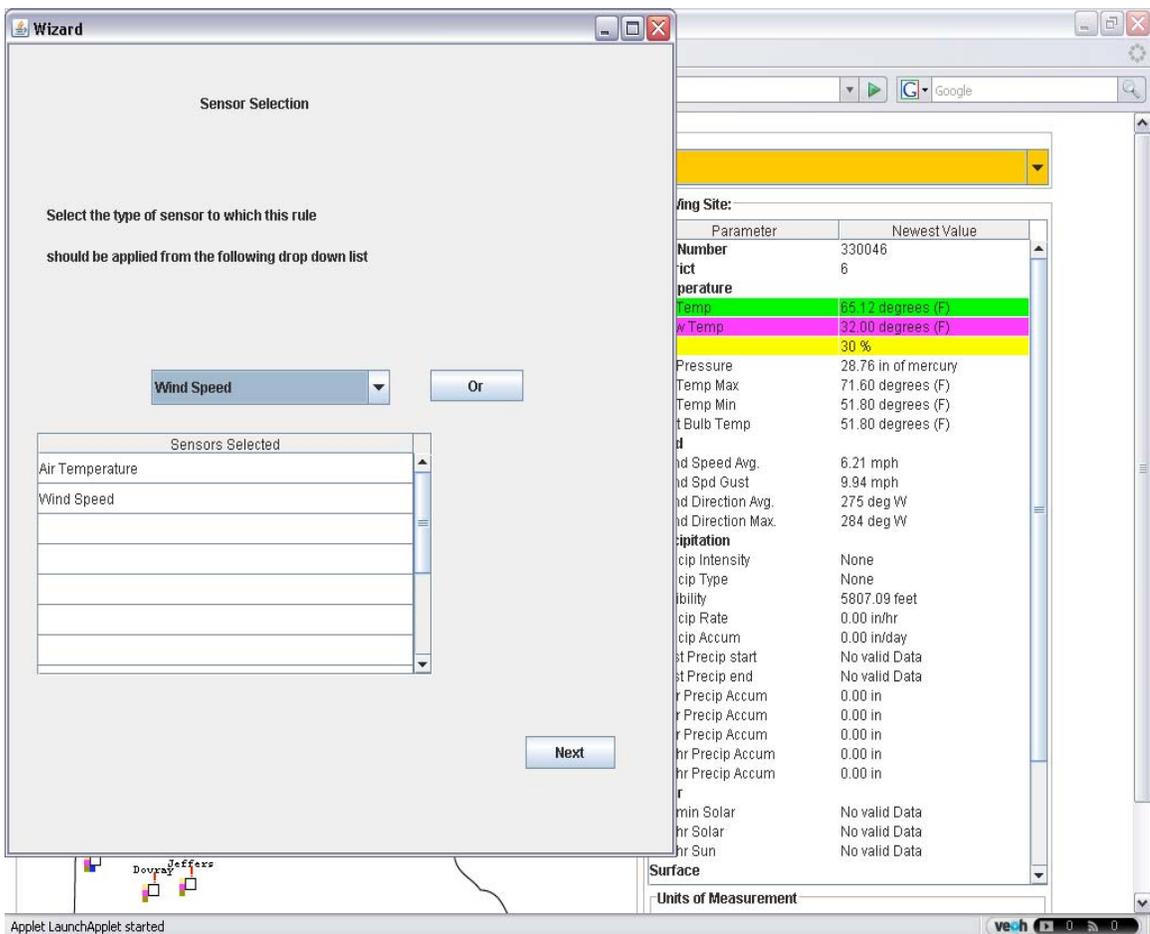
Figure 3.29: Wizard : Sensors Selection Screen

Consider a rule of Rule Type B which uses the sensor as `Air Temperature` and the number of hours 6. This rule will be triggered if the `Air Temperature` sensor reports identical values for 6 hours. As this rule requires number of hours to be inputted by the user, screen in Figure 3.30 allows the user to input the same.

Similarly, consider a rule of Rule Type C which has a sensor as `Dew Temperature`, the deviation as 5, the radius as 40 and the number of hours as 6. This rule is triggered if the `Dew Temperature` sensor deviates by 5 degrees from the other sensors at the sites within the radius of 40 miles for 6 hours. As this rule requires number of hours to be inputted by the user, screen in Figure 3.30 allows the user to input the same.
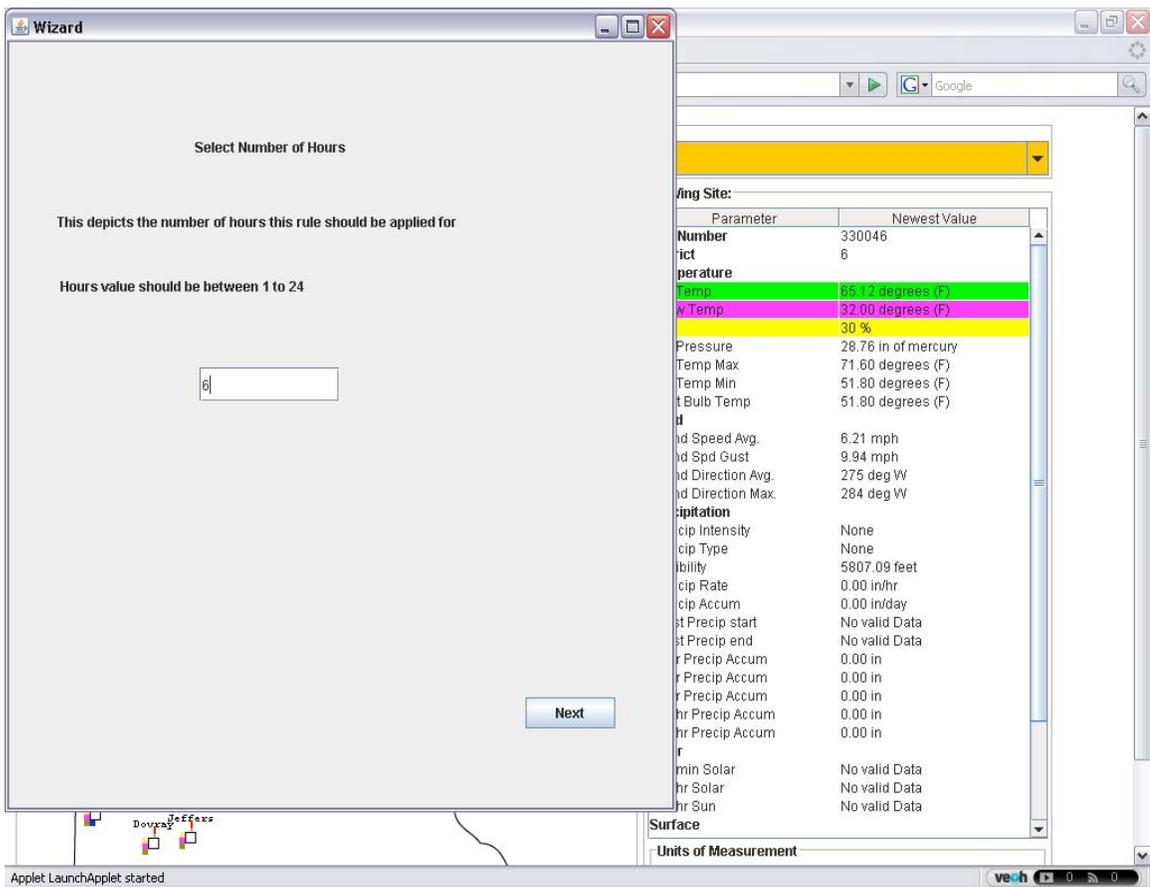
Figure 3.30: Wizard: Number of Hours Selection Screen

The user can input the radius required for the rule of Rule Type C using the screen in Figure 3.31.
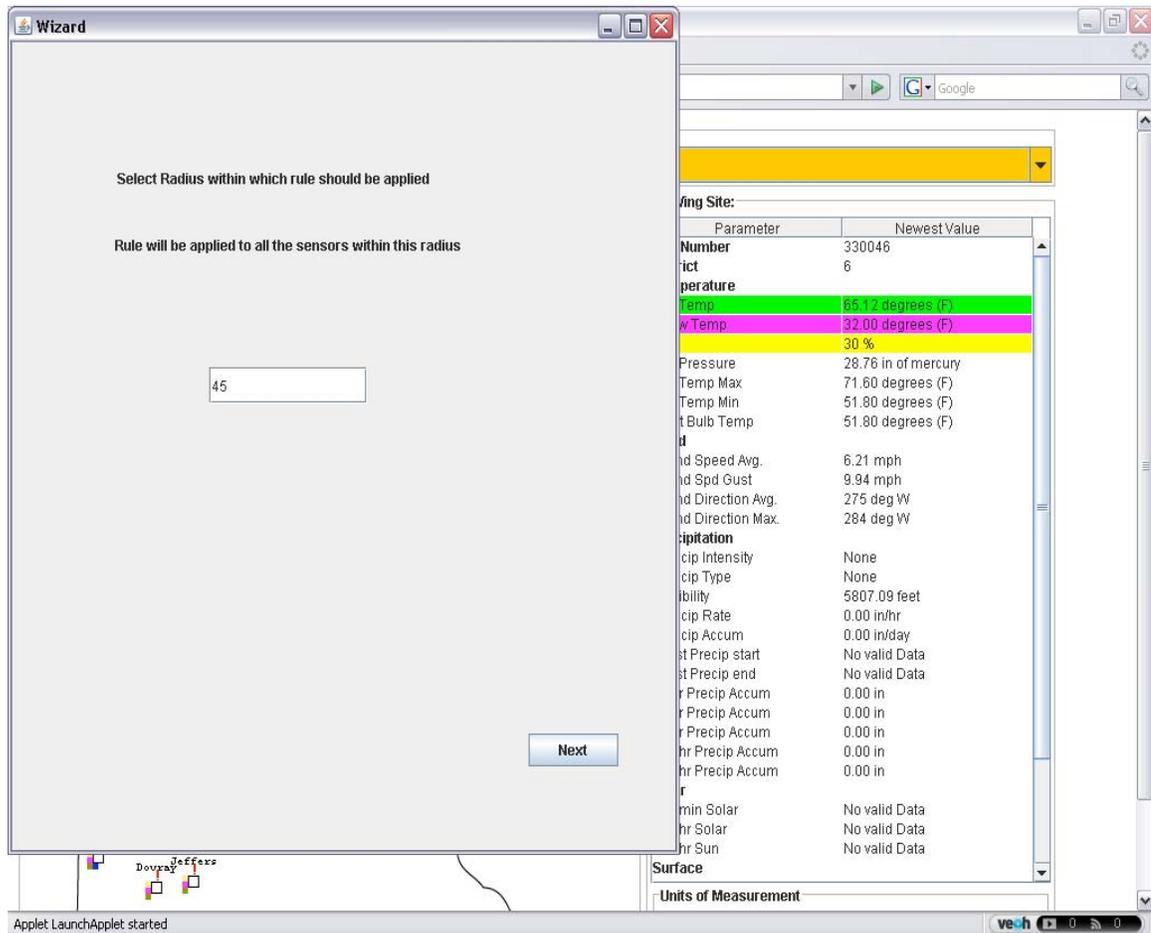
Figure 3.31: Wizard: Radius Selection Screen

As Rule Type C needs user to input the deviations for the sensors, the screen in Figure 3.32 helps the user

to select the deviations for all the sensors selected.

Rule Type C checks the sensor deviation from the nearby sensors within a specified radius. As it needs the user to input a deviation value, that is, the amount by which the sensor value deviates from nearby sensors, this screen allows the user to input the same.
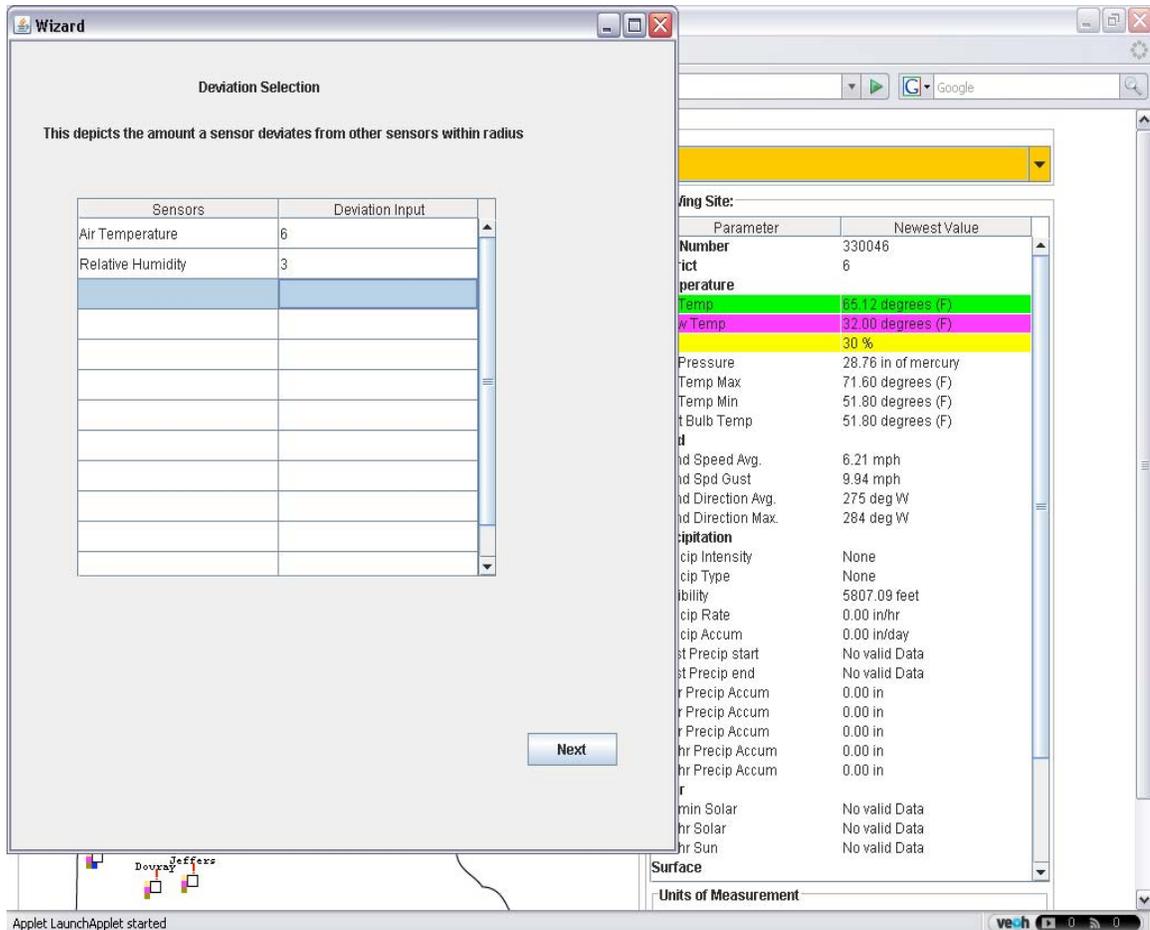
Figure 3.32: Wizard: Deviation Selection Screen

For each type of rule, the user needs to select a color that should be displayed on the map once the rule is triggered. Any rule triggered for a site is displayed on a map with a specific color which is specified by the user. Screen in Figure 3.33 allows the user to select the color for the rule being added.

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Figure 3.33: Wizard: Color Selection Screen

Chapter 4

Conclusions

In this thesis we attempted to assist in detecting RWIS sensor malfunctions using real time weather sensor data. Malfunctions are identified as the significant deviations in the values reported by the sensor from the actual conditions present at the site.

We implemented software that notifies maintenance personnel about a malfunctioning sensor by applying a pre-defined set of rules. Rules are the detectable situations that indicate a possible malfunctioning of a sensor. The detectable situations include a simple situation as the sensor itself is reporting an error as well as the situations such as a sensor is reporting the same value for a long period of time or is reporting a value that significantly deviates from the nearby sensors.

The software performs reasonably well in detecting potential malfunctions in sensor. Based on the rules set by the user, it analyzes the weather sensor data in the real time to notify any of the malfunctions with a reasonable accuracy. Inaccurate rule parameters set by the user might result in a false indication of a sensor malfunction. But if the user sets up the optimal rule parameters as per the suggestions from the software, accuracy of the software to detect a malfunctioning sensor increases.

We believe that the analysis of the weather sensor data as per the rules to detect the situations that indicate a possible malfunctioning of a sensor can be used effectively for detecting the weather sensor malfunctions and that the accuracy of this analysis can be improved by the optimal rule parameter selection.

Chapter 5

Future Work

In order to receive a feedback from the maintenance personnel working with the weather sensors' data, our `'Weather Sensor Analysis'` software was made available to the Minnesota Department of Transportation as an applet over the internet. The future work of the software based on the comments received follows.

Currently, the software does not display the surface sensors' data. This will be added in the future to display the surface data on the map screen. This will require a new process to parse a new file format with the surface data. This process will be linked into the current system to fill the sensor value tables.

In the RWIS system, most of the sites do not have all the weather sensors. The current software assumes that every site has all the weather sensors and hence flags the missing sensors at the sites as not reporting. As a part of future enhancement, the user will be given a tool to set the sensors present at the sites in their profile so that only the sensors present will be considered while applying rules at these sites.

The current color scheme provides the user with a limited set of colors. This will be enhanced with a color palette so as to have a wide range of color selection.

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Appendix A

Table A.1: RWIS Site Location

System	Site #	Latitude			Longitude		
		Degree	Minute	Second	Degree	Minute	Second
330	1	43	30	29.992	92	21	14.604
330	3	44	28	42.592	93	17	32.742
330	4	45	38	34.491	92	59	33.915
330	5	46	12	45.259	92	50	18.82
330	6	43	36	29.951	96	22	40.595
330	7	43	38	14.428	95	46	11.68
330	8	43	38	19.27	95	7	6.729
330	9	43	39	46.973	94	7	20.758
330	10	43	43	37.768	92	40	52.939
330	11	43	57	20.277	92	12	18.534
330	12	43	54	42.912	91	32	36.888
330	13	46	50	48.47	96	40	5.319
330	14	46	29	26.373	96	17	28.518
330	15	45	50	15.557	95	21	58.39
330	16	45	42	47.158	94	55	53.217
330	17	45	23	40.863	94	1	32.189
330	18	47	52	27.516	94	25	56.765
330	19	47	51	15.843	92	2	53.191
330	20	46	41	17.6	93	57	16.182
330	21	44	56	57.329	95	24	34.282
330	22	44	54	21.894	93	59	11.14
330	23	45	23	5.243	92	40	32.605
330	24	48	34	20.502	96	54	53.547
330	25	48	49	10.225	95	57	39.622
330	26	48	37	39.646	94	4	1.508
330	27	48	36	6.437	93	22	24.396
330	28	44	16	12.931	96	19	12.148
330	29	44	1	17.8822	92	42	29.35
330	30	44	27	32.004	96	26	6.848
330	31	44	32	40.952	94	59	43.533
330	32	44	32	35.479	94	24	50.828
330	33	44	41	29.831	95	36	50.44
330	34	45	36	59.145	94	1	17.356
330	35	46	8	39.324	94	6	14.789
330	36	45	33	29.578	96	29	38.116
330	37	45	29	18.293	95	33	43.74

330	38	44	3	25.838	95	35	50.256
330	40	43	43	9.575	91	26	12.31
330	41	47	36	12.868	94	7	36.272
330	42	44	24	33.285	92	51	30.475
330	43	45	25	56.478	94	55	56.533
330	44	47	16	27	95	56	1.8
330	45	44	4	32.03	94	22	5.672
330	47	44	36	3.663	92	41	52.052
330	48	47	58	35.104	89	41	5.892
330	49	46	54	42.218	94	43	22.487
330	50	46	20	23.13	93	15	43.374
330	51	46	58	42.11	93	16	25.258
330	52	47	50	25.334	93	29	6.679
330	53	48	12	25.739	94	33	14.408
330	54	46	2	35.251	96	29	39.068
330	55	46	24	13.167	95	36	7.662
330	56	48	26	1.241	95	43	52.304
330	57	48	58	15.061	97	12	6.122
330	58	47	17	45.4	96	43	53.94
330	59	44	56	10.219	96	26	30.45
330	60	47	52	50.92	96	55	0.63
330	61	47	22	16.46	94	28	46.69
330	62	46	52	38.827	96	6	41.193
330	63	46	24	48.019	95	3	15.787
330	64	45	45	59.566	94	13	58.241
330	65	43	30	53.832	91	53	5.966
330	66	47	12	40.548	92	29	15.67
330	67	48	17	39.254	92	58	13.674
330	68	47	46	13.27	96	0	3.67
330	69	44	17	5.339	91	59	22.83
330	70	43	54	8.408	92	28	56.281
330	71	44	5	1.297	95	7	11.821
330	72	48	8	4.67	93	52	42.54
330	73	44	9	15.599	94	2	2.272
330	74	44	21	55.928	93	57	47.342
330	75	44	34	20.191	93	50	33.703
330	76	45	52	33.042	93	39	50.671
330	77	45	59	6.151	92	56	53.459
330	78	48	47	21.7	95	3	3.71
330	79	44	32	37.093	93	37	29.321