# DSS-SLR Manual and Implementation Guide

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# Data Collection via CRS&SI Technology to Determine When to Impose SLR:

## Decision Support System - Seasonal Load Restrictions

**http://ne-slr.umassd.edu**

# Cooperative Agreement: RITARS-11-H-UMDA

### Between

### University of Massachusetts Dartmouth & USDOT RITA


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ABSTRACT: The project applies commercial remote sensing and spatial information (CRS&SI) technology to remotely monitor roadway subsurface road conditions real time, at three sites. From Mariaville, Maine, and Warren Flats, New Hampshire, data is transmitted via satellite to the Decision Support System for Seasonal Load Restrictions (DSS-SLR) website located at UMass Dartmouth. From Madison, Maine, data is transmitted using cellular technology. In addition, Atmospheric data is collected from these sites. The system modifies current data collection procedures from onsite manually downloading data to real time data transfer via CRS&SI technology.

The login protected website DSS-SLR, developed to wirelessly collect and store this roadside data, and developed to automate the analysis can be found at **http://ne-slr.umassd.edu**. The website also grabs data from Plymouth State University's collection of New Hampshire Regional Weather Information Service, RWIS, sites. In addition, it grabs weather data from wunderground.com. The DSS contains scripts to automatically determine the depth of frost and thaw penetration. This assists State DOTs to control road damage by properly applying seasonal load restrictions, SLR, which restrict heavy trucks from road usage for a period of time during spring thaw.

The DSS consists of a user-friendly geographic user interface (GUI) or map, a data evaluation tool or SLR Interpolator (SLRI), a frost-thaw predictive model and a centralized database that will house the new as well as historical data. Proper SLR timing by State DOTs minimizes unnecessary road damage, thus lowering maintenance costs. It also results in minimizing inconvenience to drivers and saves fuel costs to the commercial vehicle industry. The DSS is primarily being used as a monitoring tool for roadway subsurface road conditions during the critical spring thaw and recovery period, but the transportation agencies and the commercial vehicle industry are expected to expand the DSS with other applications.

The project implementation guide and flow chart are attached to this manual and additional information and quarterly reports are available at the following sites.

http://prezi.com/53zyouvf_uq5/?utm_campaign=share&utm_medium=copy

http://mzgis.prod.umassd.edu/dssslri/

http://mzgis.prod.umassd.edu/main_website/projects2.html

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## System Overview

The DSS-SLR is a decision support system that collects a wide array of data such as subsurface temperatures from various sites and displays plots and graphs to help the user make informed decisions. The website is accessed by entering the following web address into the browser: http://ne-slr.umassd.edu/

## Organization of the Manual

The user's manual consists of the following sections: Getting started, Using the system, Retrieving Raw Data, Advanced tool usage and Re-launching U30 Logger.

Getting started section explains how the initial page of the system looks and how to login to the system.

Using the System section provides a detailed description of the interface on the SLRI and how to navigate through the menus

Advanced tool usage section explains how the advanced tools in the system work. It shows how the system can provide the user with plots and graphs of the raw data and the different options and tools available.

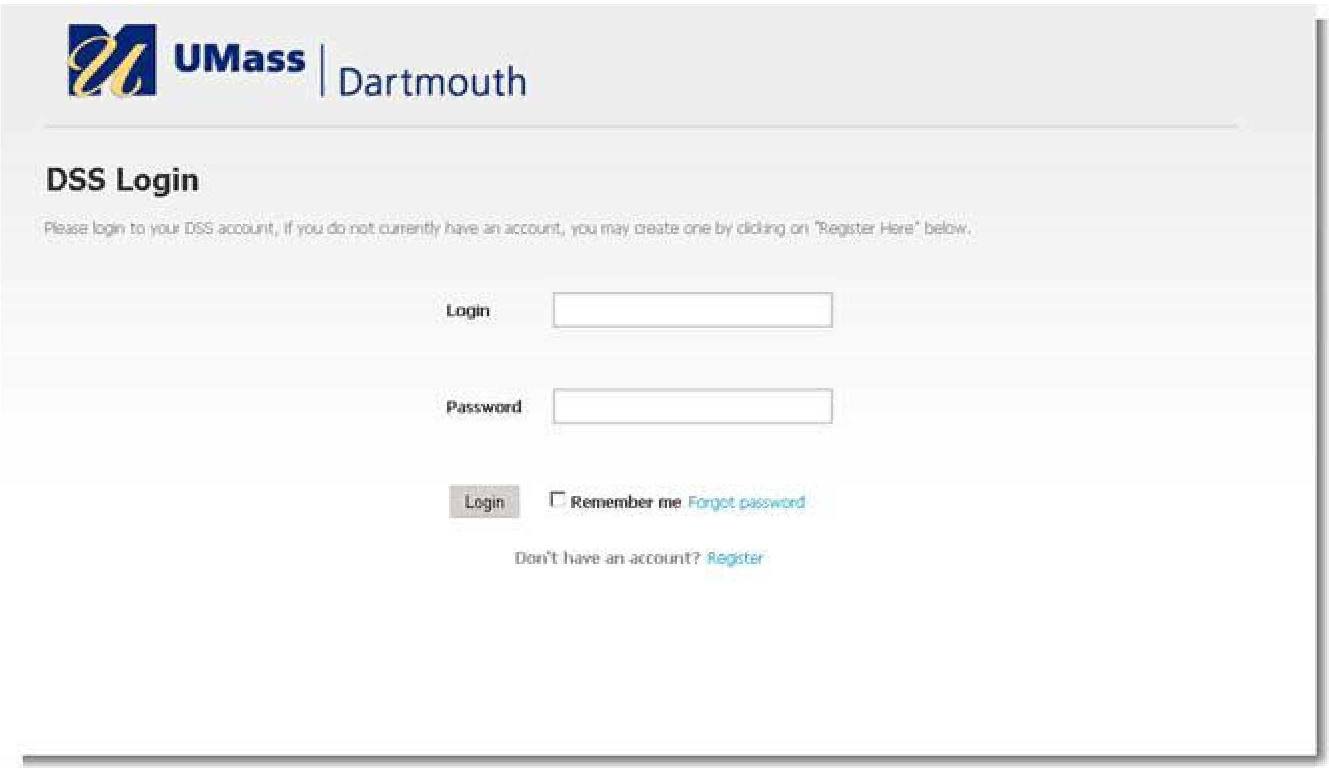
The Re-launching U30 Logger section describes how the Madison, Maine, cellular transmission site can be re-launched online.

# Section 1: Getting Started

The getting started section explains how to register for an account and how to login to the DSS-SLR.

## 1.1 Website and Login

Access the DSS-SLR by visiting the website http://ne-slr.umassd.edu/.



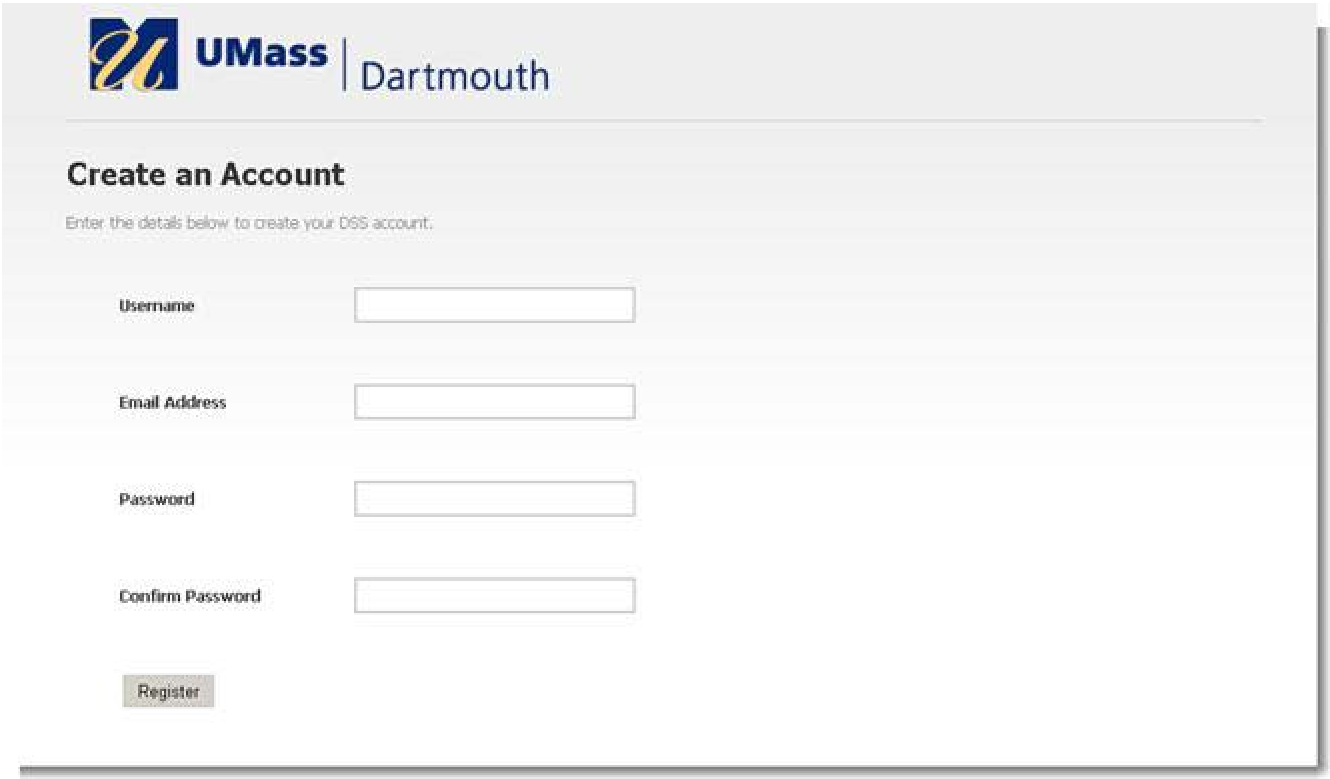

The user should enter their user name in the box next to 'Login' and the associated password in the 'Password' box. Then, click the Login button or press enter on the keyboard.

By checking the 'Remember me' box, you do not have to re-enter the username and password the next time you visit the site.

The 'Forgot password' link allows you to reset your password by sending an email to the email address associated with your username.

## 1.2 New User Account Registration

For new users, the 'Register' button creates a new account and brings up the following display.




On this page, enter a unique username and an email address along with a password. This process allows you to have access to the system.

## Section 2: Using the System

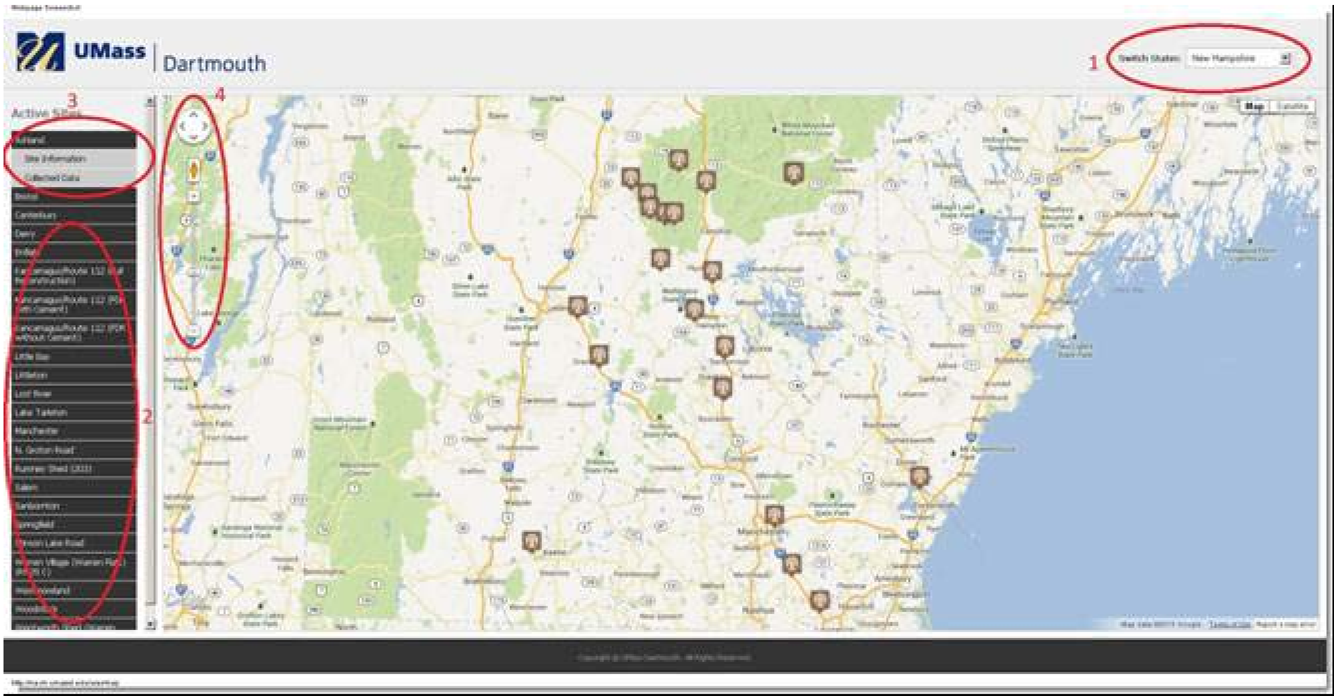
Successful login brings up the main navigation screen from which you can browse atmospheric data and subsurface temperature data from several locations. The following display has four circled sections, listed and described below:

1. The drop down menu on the top right corner of the screen selects the state where the different data collection sites are located. These sites all have various amounts of data accessible from the DSS database.

2. The menu bar on the left side of the screen displays all the various sites by name within the selected state.

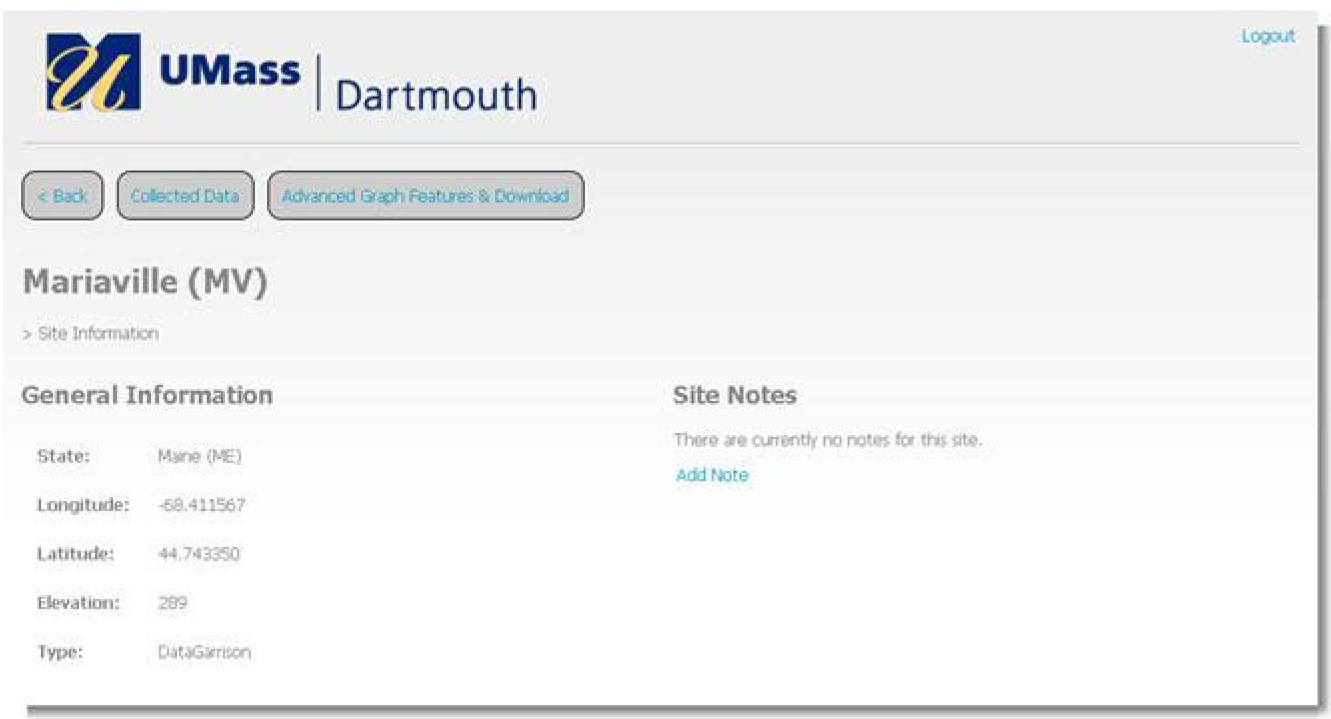
3. Clicking on a site name within the menu bar will open two options, Site Information and Collected Data. Clicking on one of these allows users to navigate to each of these options. The map will also allow users to navigate to a particular site. By clicking the site icon on the map, the same two options are available.

4. Zooming and navigation controls are located on the left side of the map.



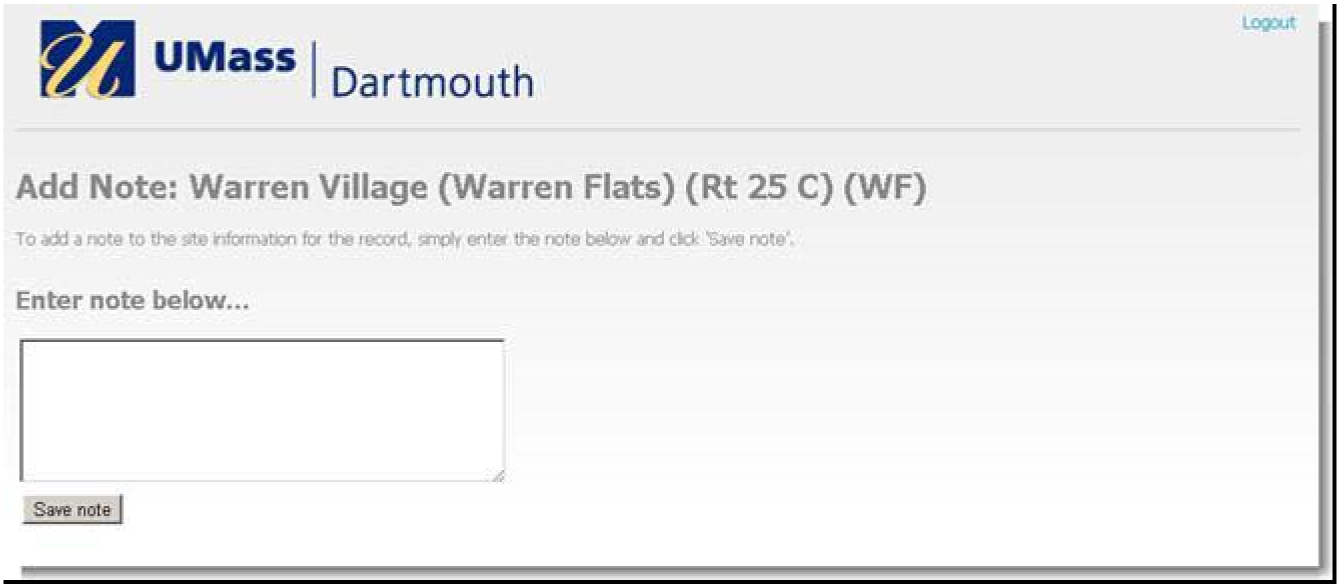

## 2.1 Site Information

Users display the following page by clicking on the Site Information.

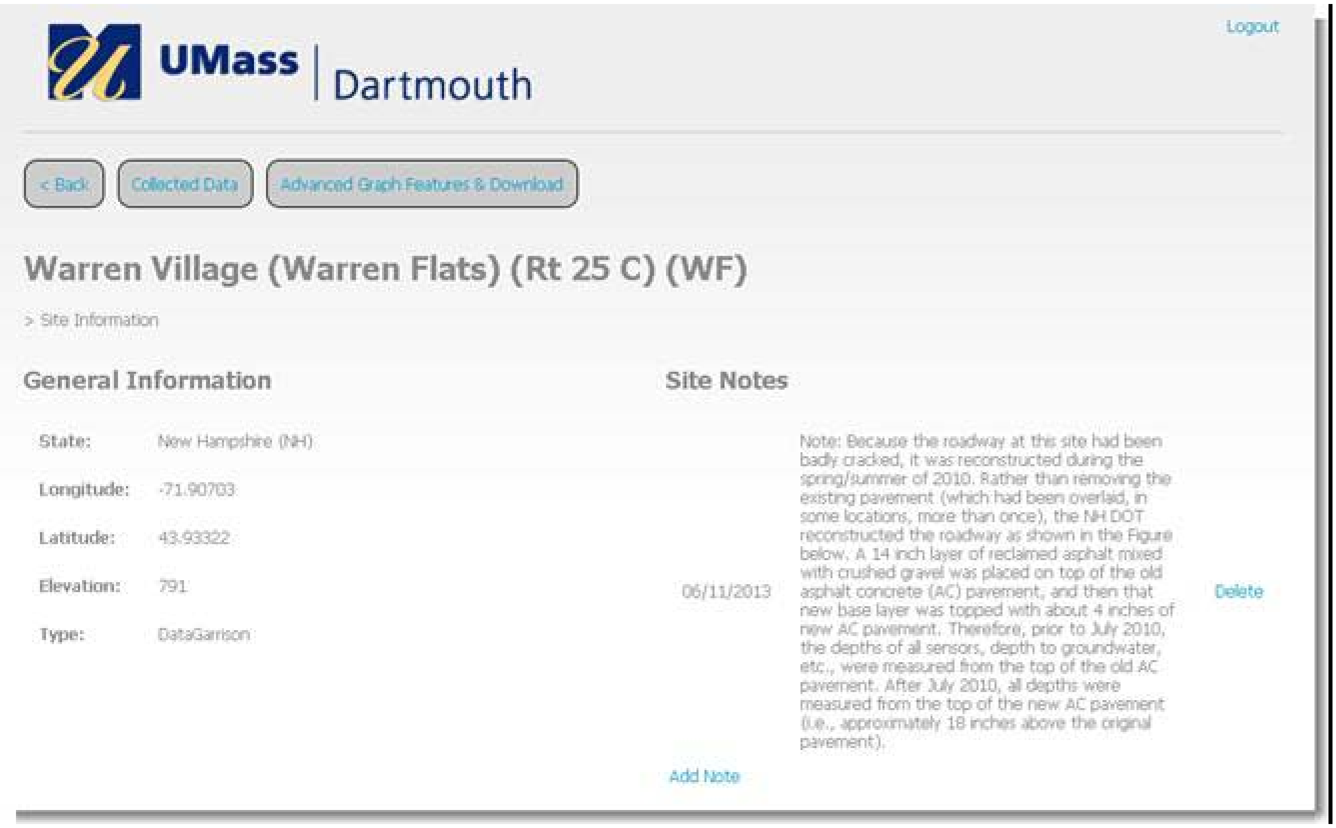



The page shows general information about the selected site such as the state it is located in, its co-ordinates and the source of the subsurface temperature data (which in this case is PSU, Plymouth State University). From this page, clicking the back button returns users to the main navigation screen.

Click the Add Note button, allows users to enter notes relevant to that particular site. The site information page displays notes along with the posted date. To add a note, simply type the note in the text box and click on the Save Note button.

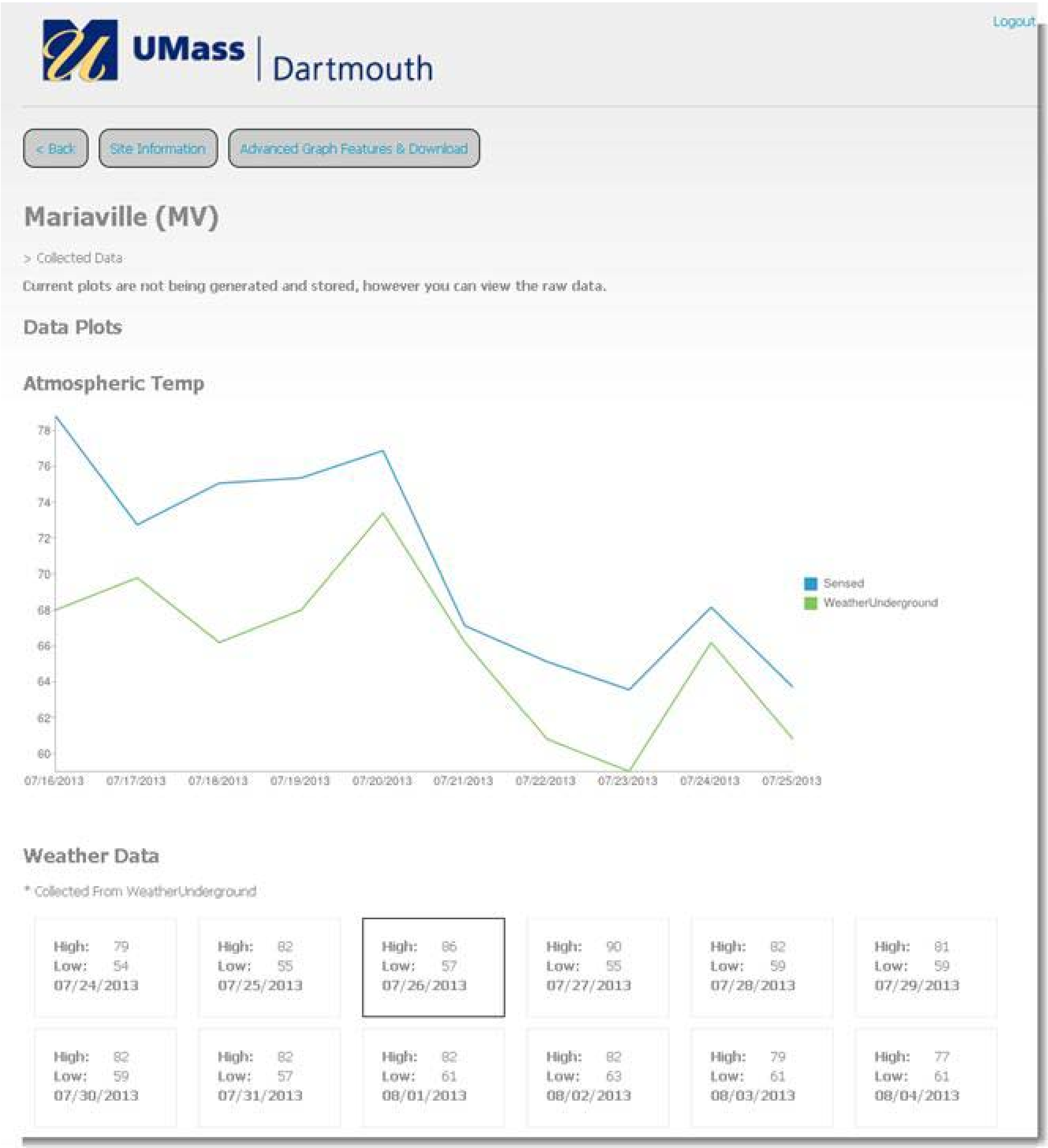



The following screen shot illustrates a note on the website. The delete button on the right side of the note allows the permanent removal of the corresponding note.



## 2.2 Collected Data

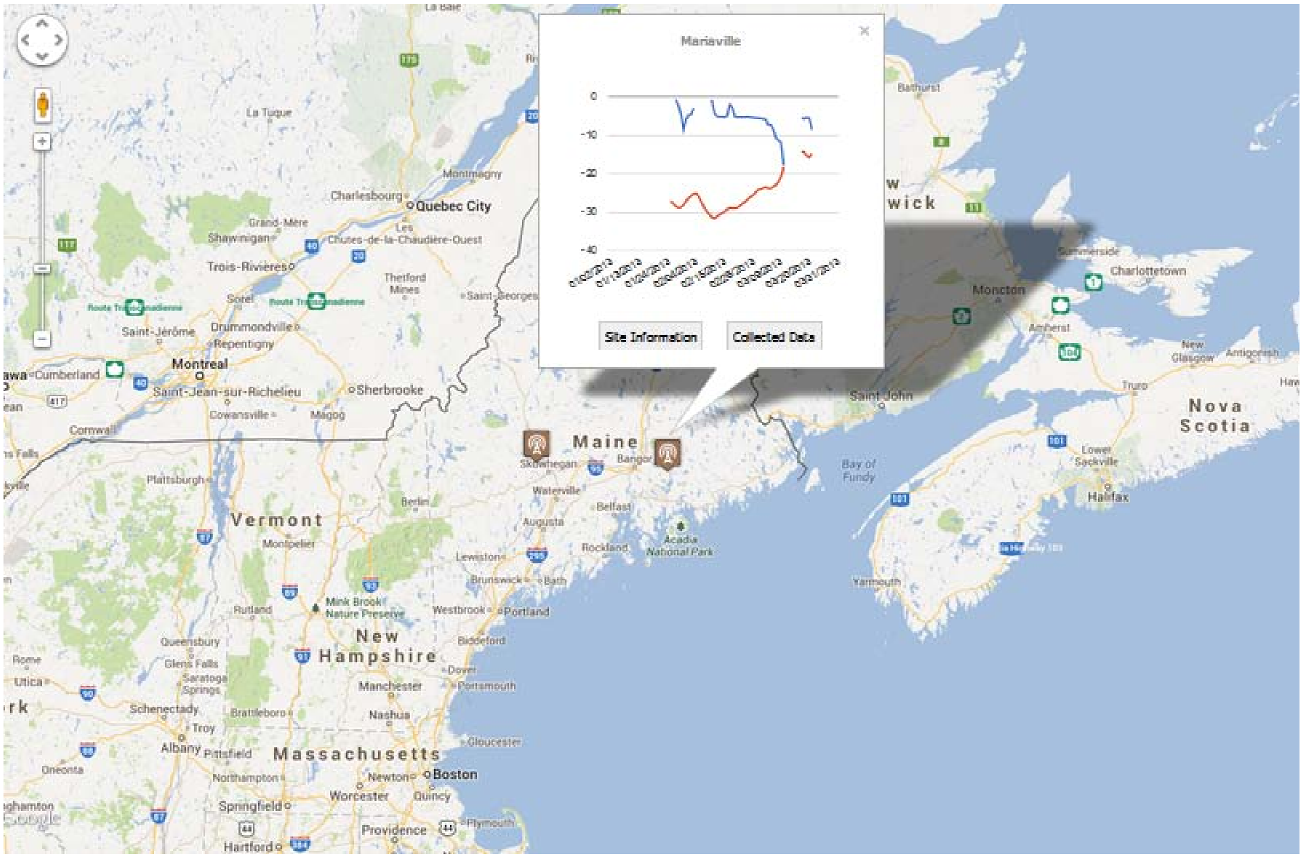
The main navigation page or the Site Information page provides access to the Collected Data screen, which displays the most recent 3 days of atmospheric temperature data and the predicted values for the next 7 days. Green indicates data from the website WeatherUnderground and Blue indicates data from the site's atmospheric temperature sensor. Listed directly beneath the graphs, are the high and low values.



## 2.3 Frost-thaw plots

Scrolling down further on the Collected Data screen brings users to the Frost-Thaw plots. Furthermore, this same Frost-Thaw plot is accessible on the Main Navigation page by hoovering your mouse over the site as displayed below.

Furthermore, this same Frost-Thaw plot is accessible on the Main Navigation page by hoovering your mouse over the site as displayed below.



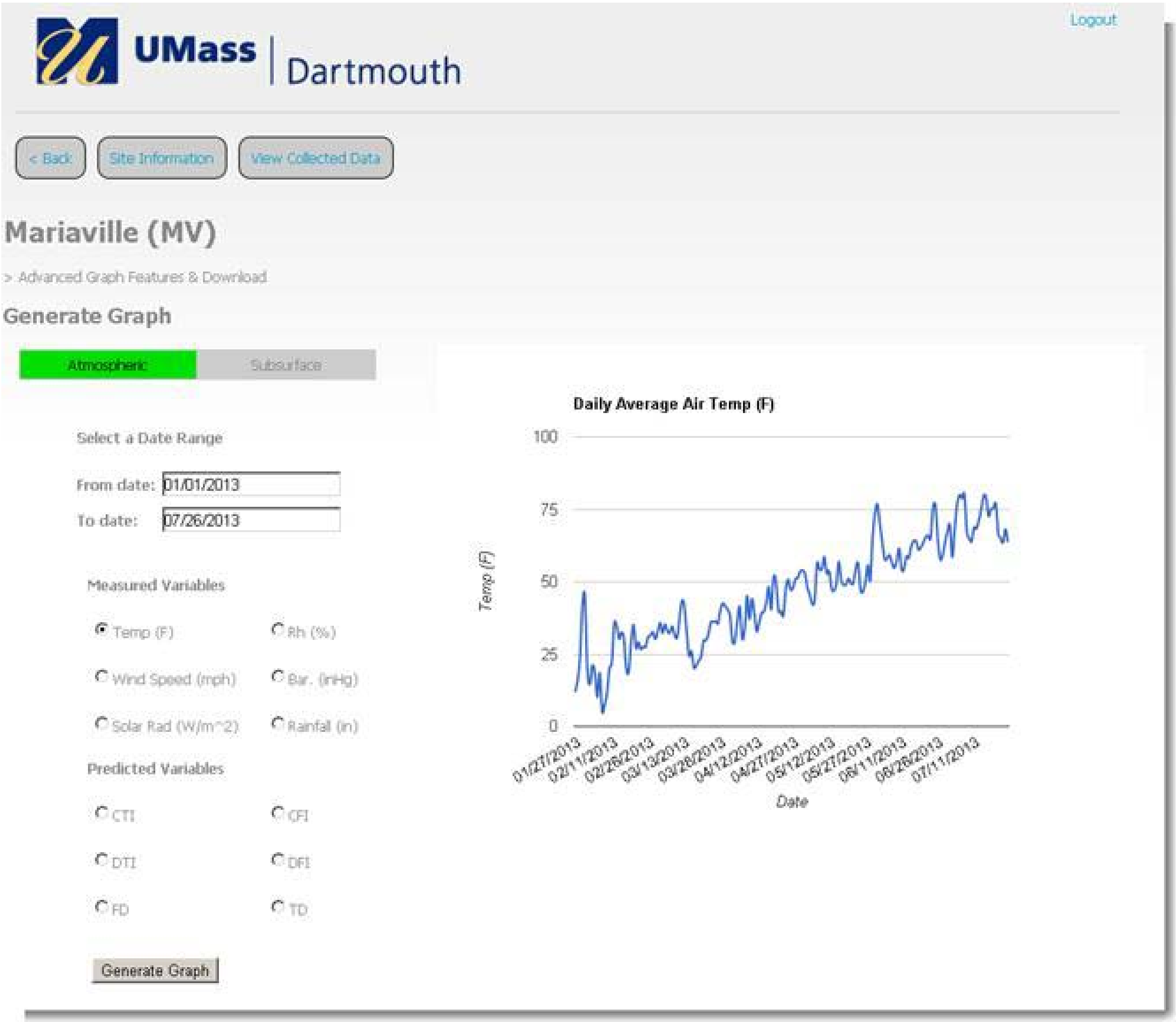

# Section 3: Advanced Tool Usage

The Advanced Graph Features & Download button at the top of the Site Information page or the Collected Data page displays a list of variables that users can choose to graph between chosen ranges of dates. By default, the page shows a list of the atmospheric temperature data. Clicking the gray colored Subsurface box next to the green colored Atmospheric box brings access to the list of subsurface depths at which the subsurface temperature is available. From this same page, in addition to generating graphical displays of the data, users can also download data into excel files.

## 3.1 Atmospheric Data Graphs

Users select one of the Measured Variables by clicking on the radio button in the list and then clicking on Generate Graph. The list of Measured Variables includes Air Temperature ($^{o}$F), Wind Speed (mph), Solar Radiation (W/m$^2$), Rh (%), Atmospheric Barometric Pressure (inches of Hg) and Rainfall (inches).

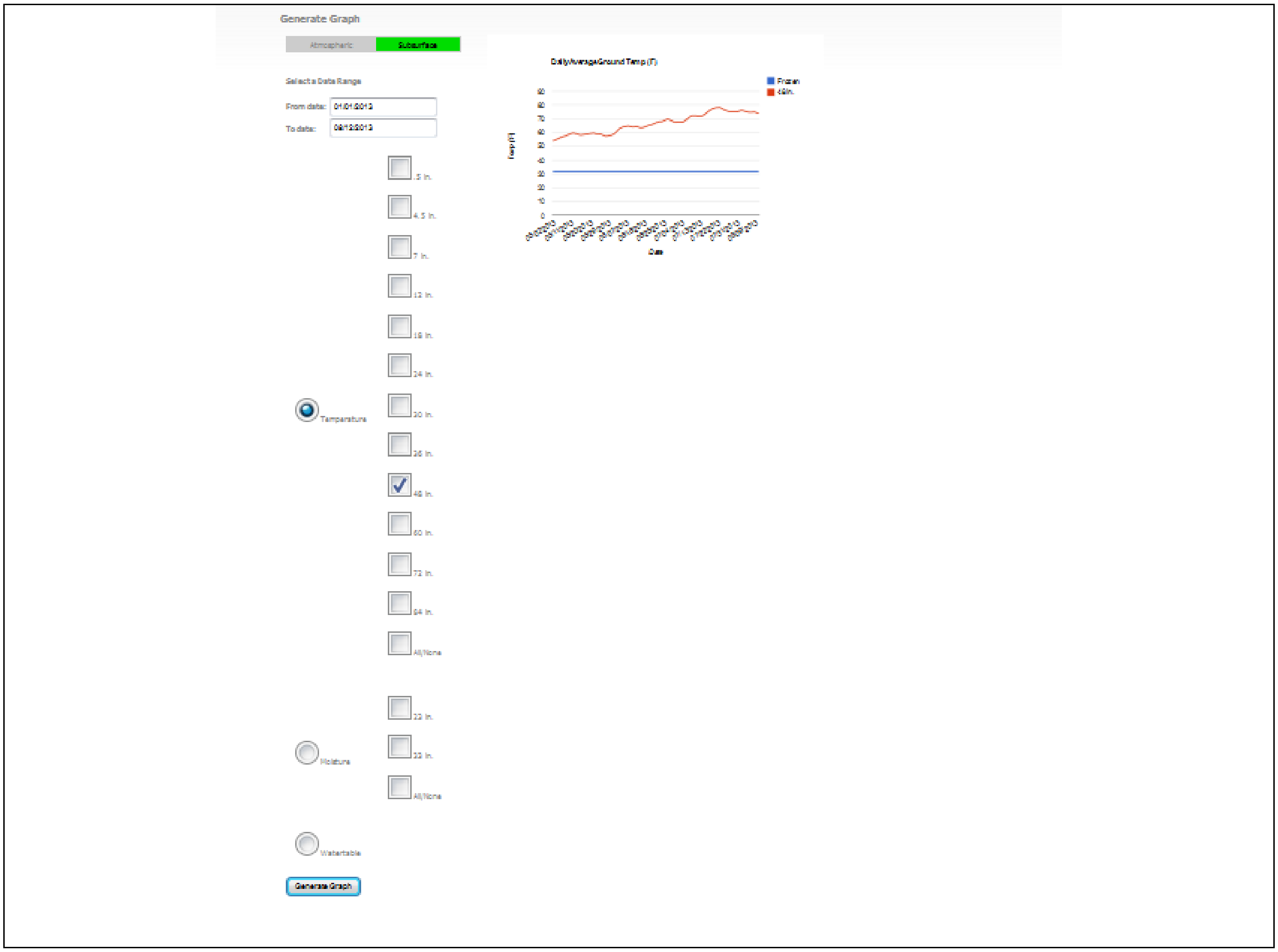
Clicking the radio button next to the listed Predicted Variables and then clicking on Generate Graph results in the predicted output of the Simple Prediction Model or the Modified Freeze-Thaw Index Model, or a display of the Frost and Thaw Depths predicted by the model. The list includes CTI, DTI, FD, CFI, DFI and TD.

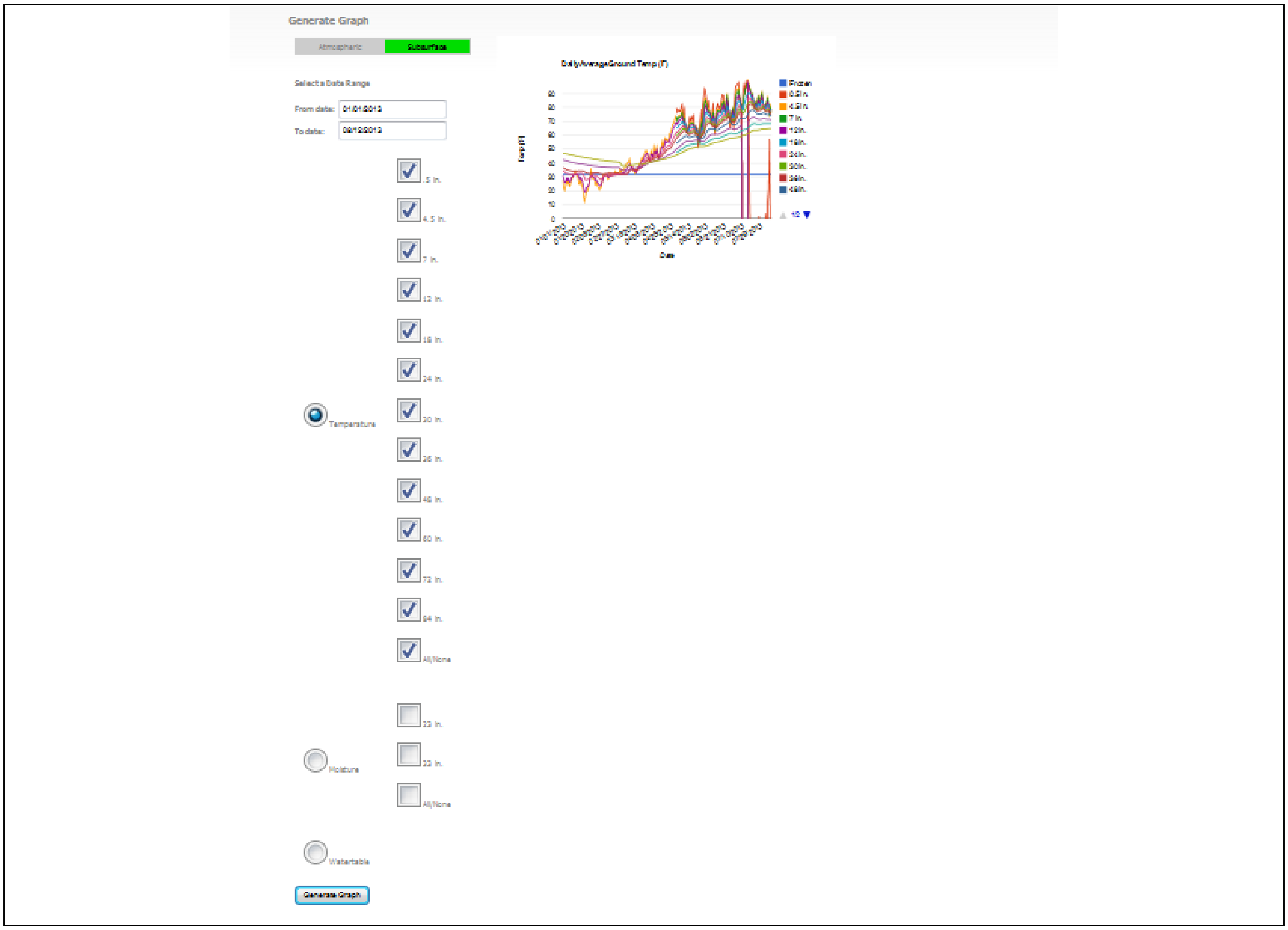


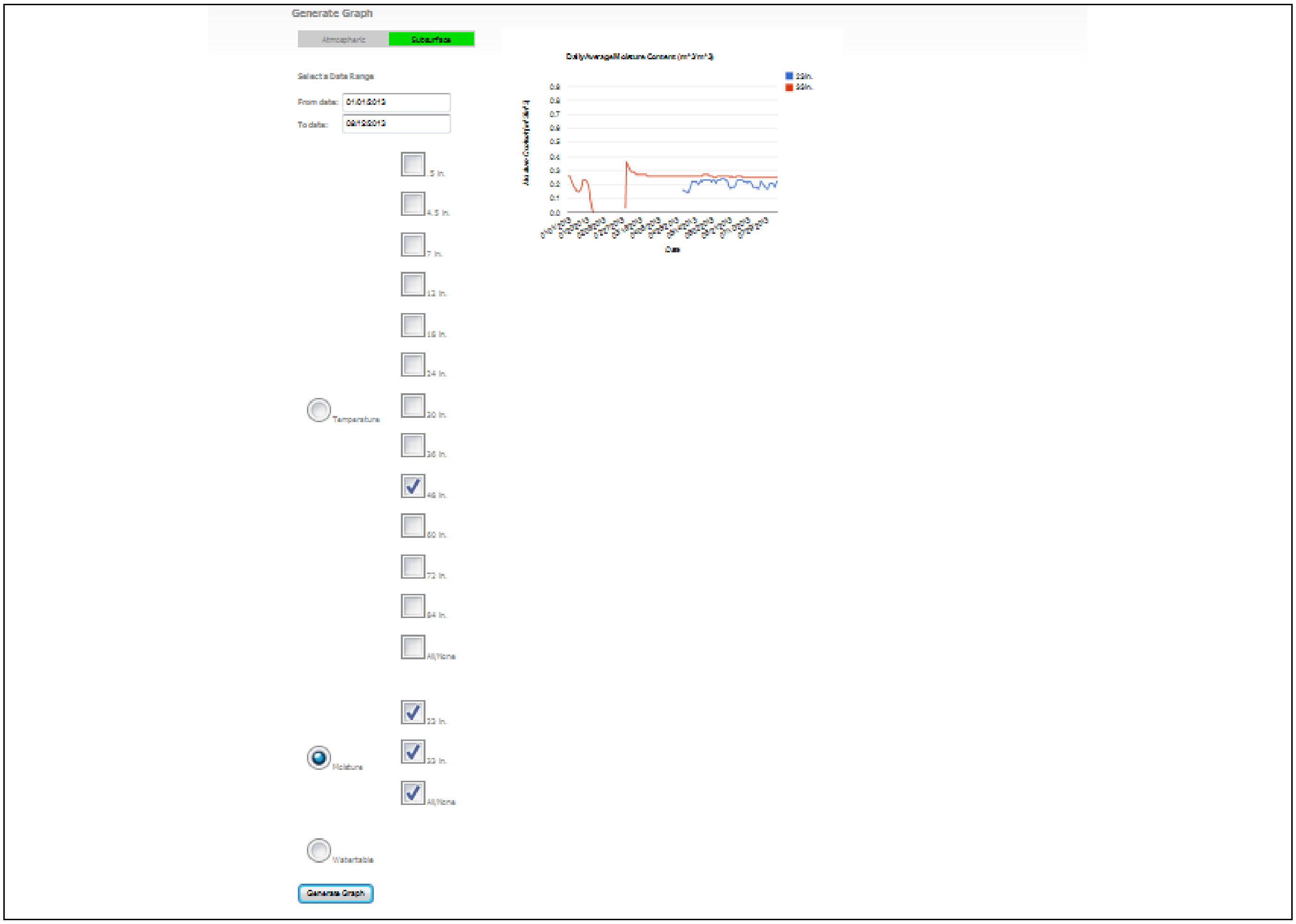

## 3.2 Subsurface Data Graphs

After clicking on Subsurface, users select one of the Subsurface Depths in the list and then click on Generate Graph to view plots of the subsurface temperatures at various depths. The list of depths varies from site to site. Similar to the Atmospheric variable graphs, users define the range of dates in the appropriate boxes. To plot temperatures at all available depths, users select the All/None radio button in the list.

The page can also graphically display the moisture data for the listed subsurface depths and the water table data. Similar to the Atmospheric Data, users click Generate Graph.

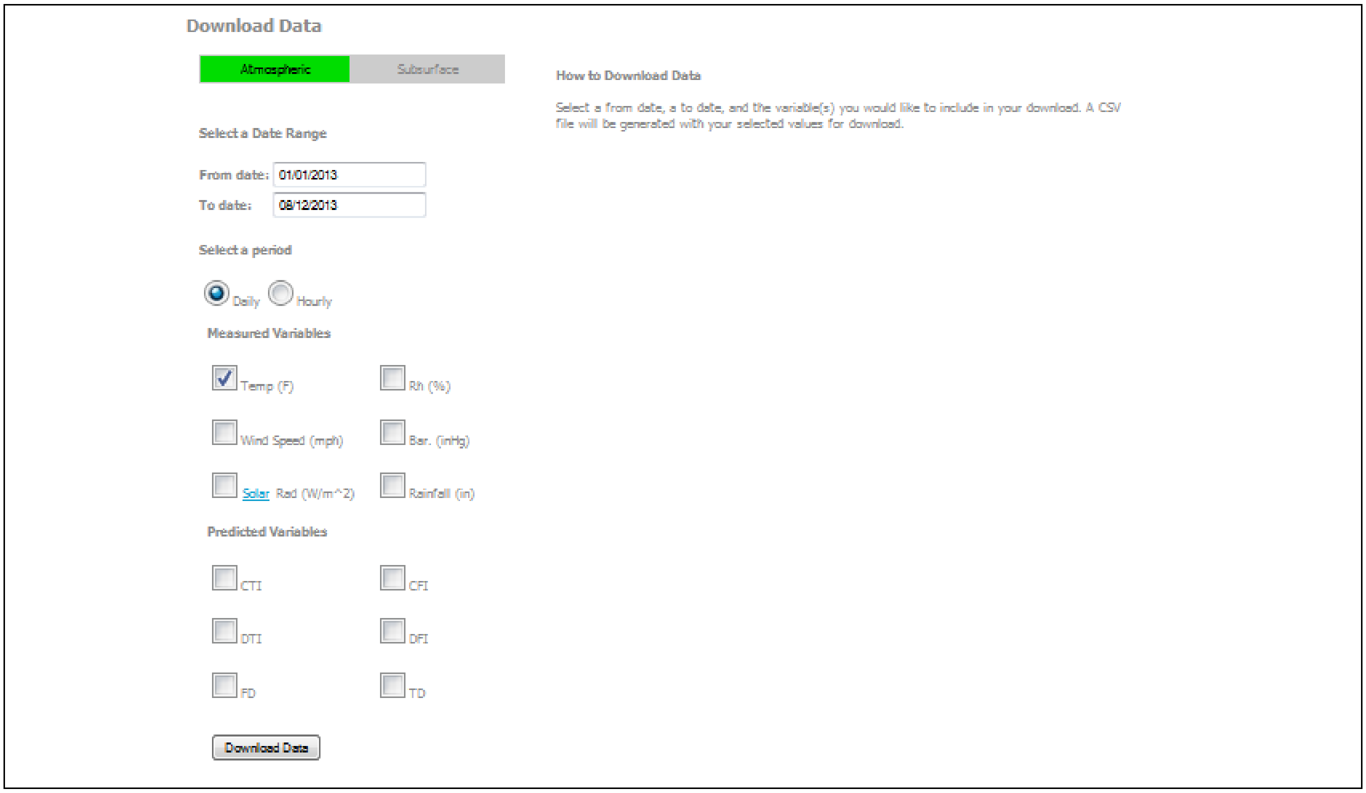

Generate Graph
Atmospheric
Subsurface
Select a Date Range
From date:
To date:
.5 in.
4.5 in.
7 in.
Frozen
Temperature
Moisture
Watertable
All/None
Generate Graph

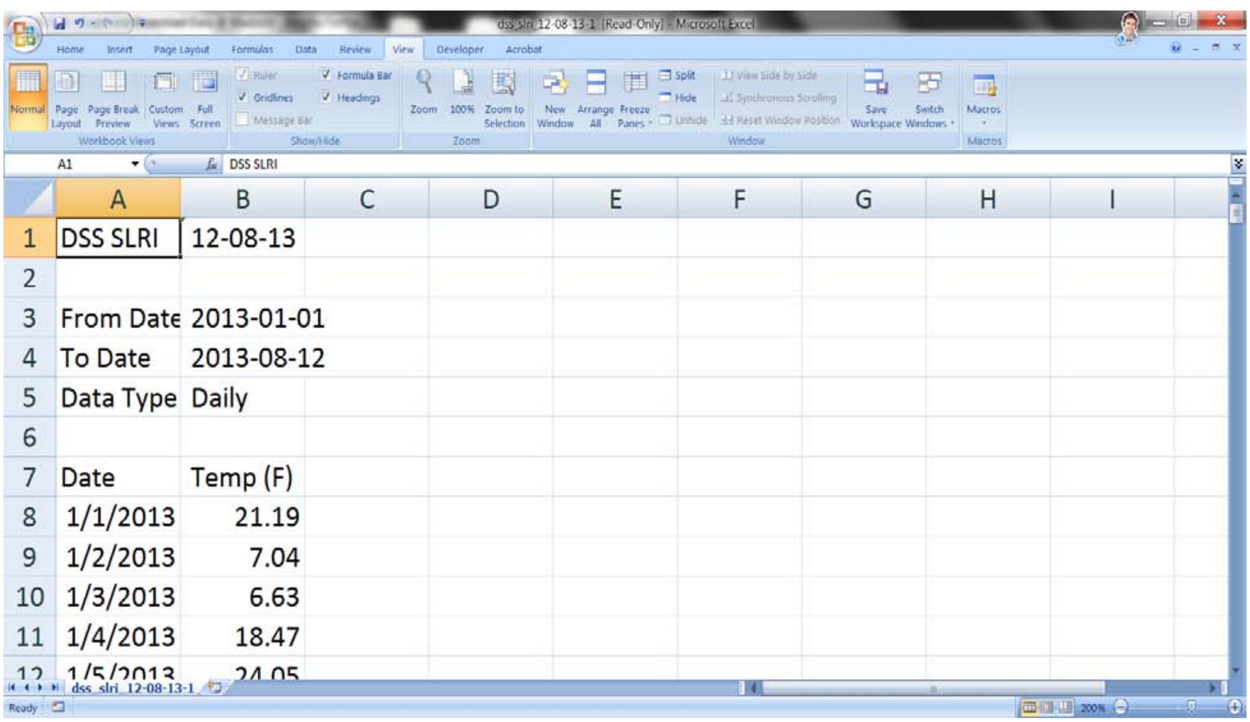

Generate Graph
Atmospheric
Subsurface
Select a Data Range
From date:
To date:
Temperature
Moisture
Watertable
Generate Graph

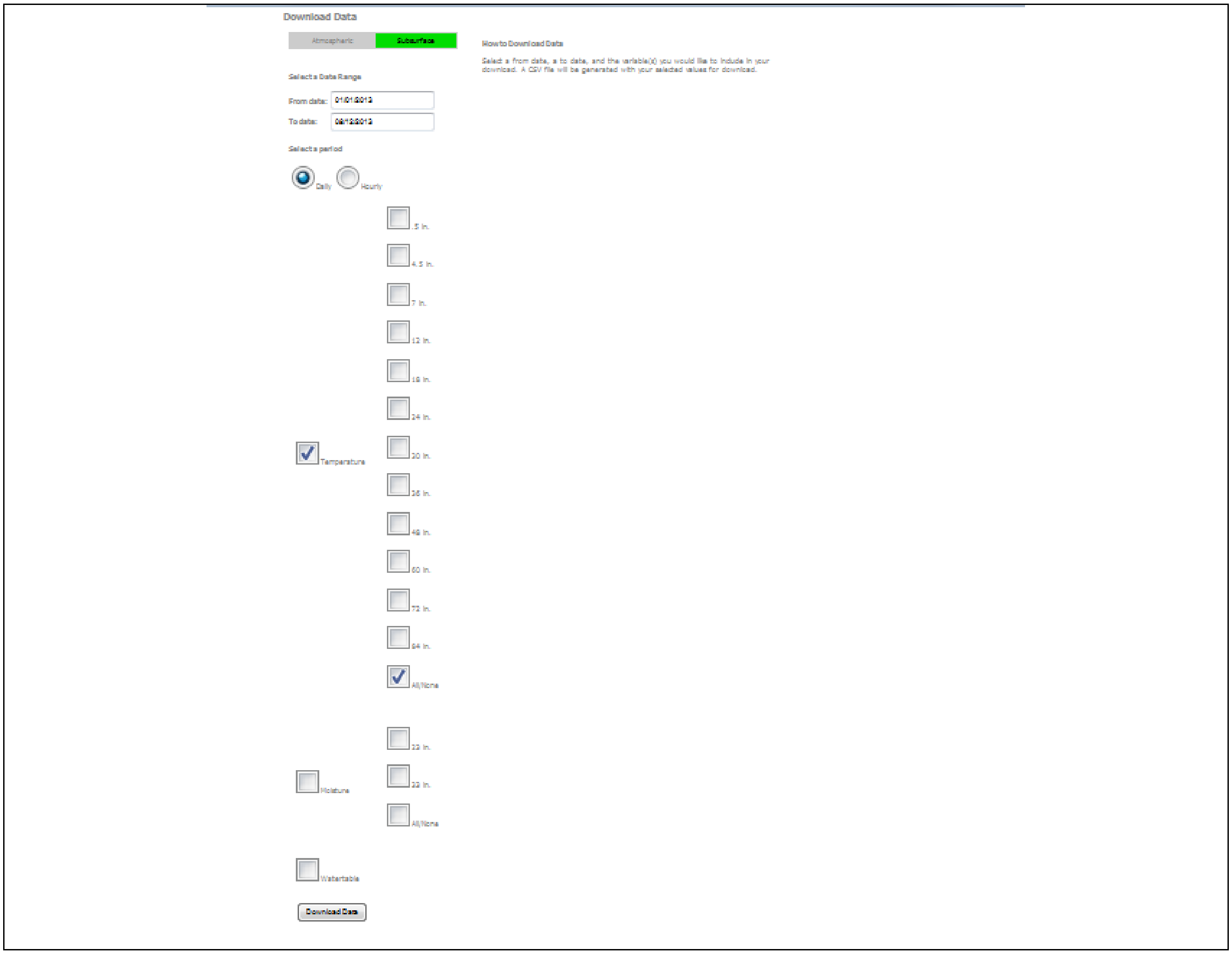


## 3.3 Download Data

Downloading is possible on the same page as the page that generates graphs. Users need to scroll down to view this capability. When downloading Atmospheric data into excel files onto a computer, users select one of the Measured Variables by clicking on the radio button in the list under Atmospheric Data and then clicking on Download Data. Similarly, users select one of the radio buttons in the list under Subsurface Data and then click on Download Data. To plot variable values at all available depths, users select the All/None radio button in the list.


Download Data
Atmospheric
Subsurface
How to Download Data
Select a from date, a to date, and the variable(s) you would like to include in your download. A CSV file will be generated with your selected values for download.
Select a Date Range
From date: 01/01/2013
To date: 08/12/2013
Select a period
Daily
Hourly
Measured Variables
Temp (F)
Rh (%)
Wind Speed (mph)
Bar. (inHg)
Solar Rad (W/m^2)
Rainfall (in)
Predicted Variables
CTI
CFI
DTI
DFI
FD
TD
Download Data

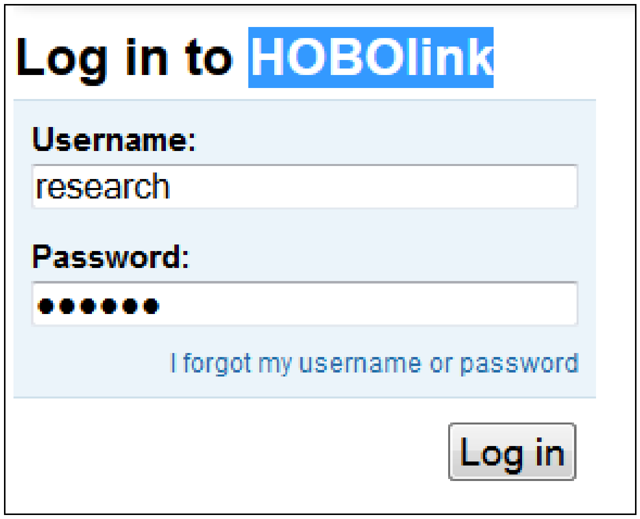

dss_slri_12-08-13-1 [Read-Only] - Microsoft Excel
DSS SLRI
12-08-13
From Date
2013-01-01
To Date
2013-08-12
Data Type
Daily
Date
Temp (F)
1/1/2013
21.19
1/2/2013
7.04
1/3/2013
6.63
1/4/2013
18.47
dss_slri_12-08-13-1
Ready



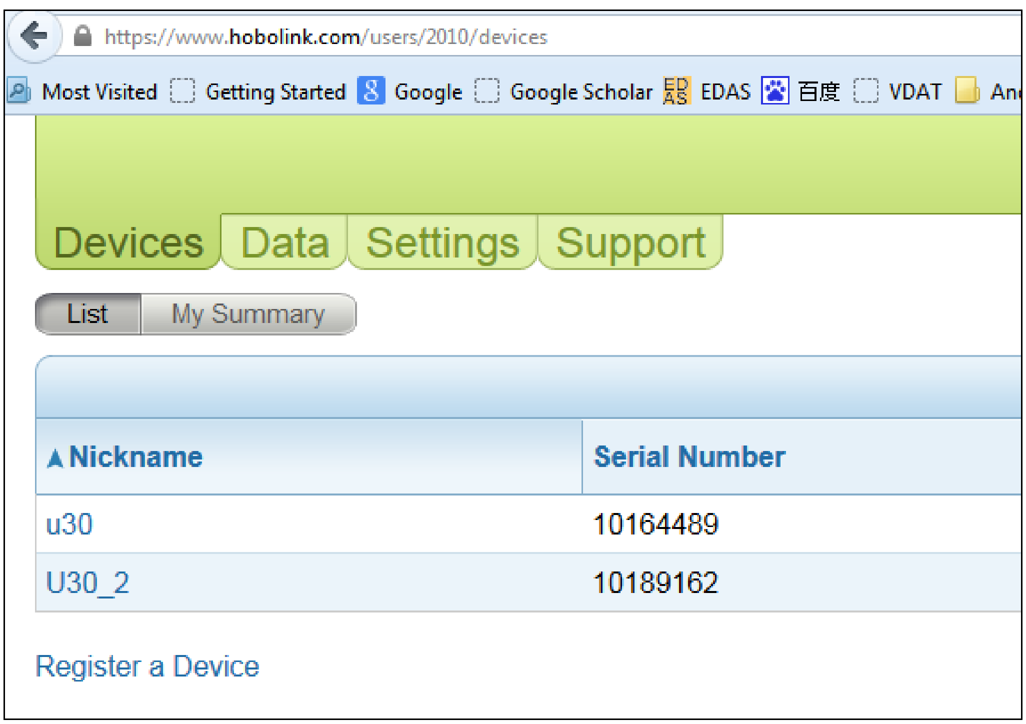
## 3.4 Use of the Prediction model for Frost-Thaw plots

## Section 4: Re-launching U30 Logger

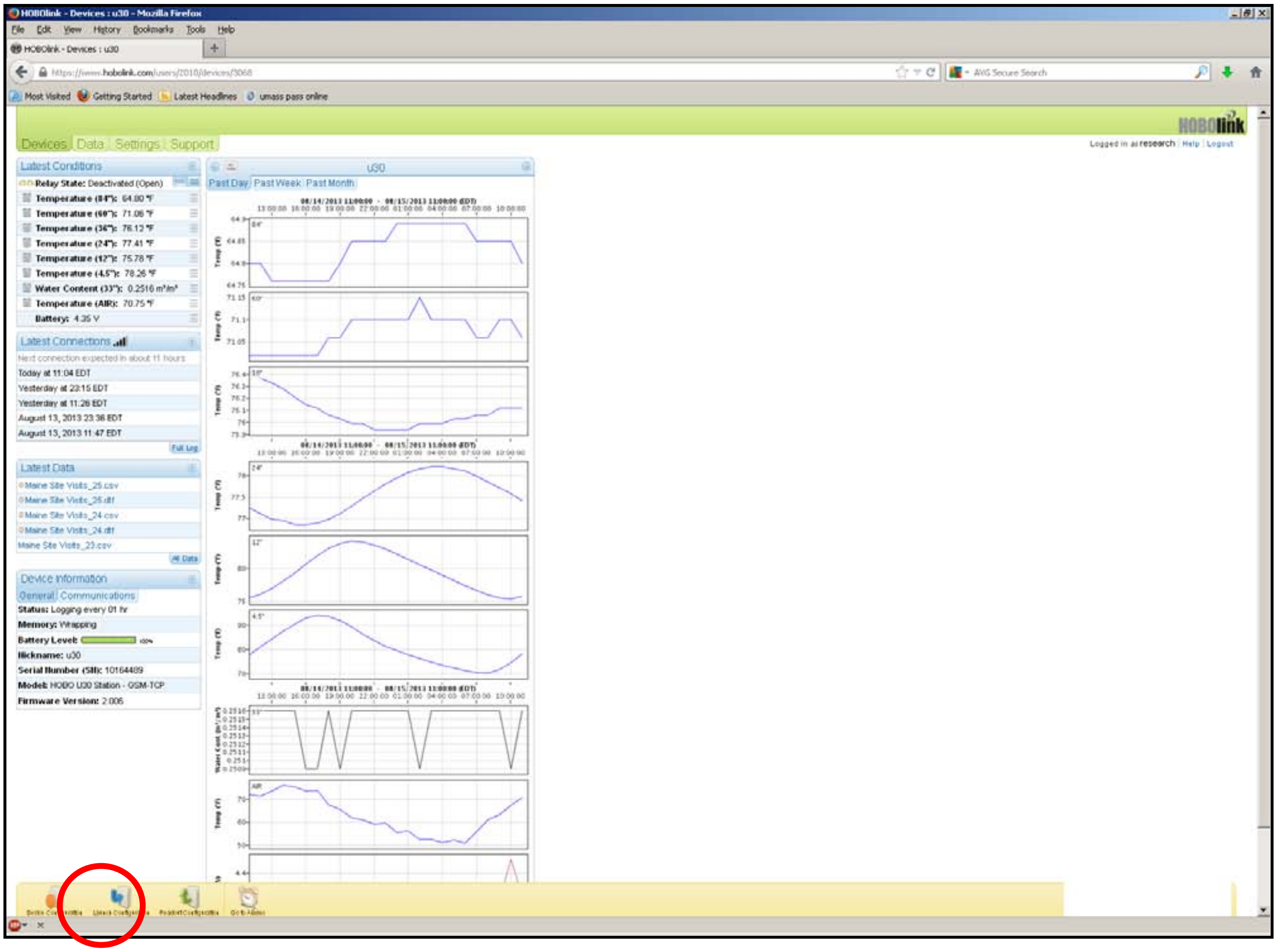
1. Log into hobolink account
   a) Visit www.hobolink.com
   b) Input username: research
   c) Input password: umassd
   d) Click log in

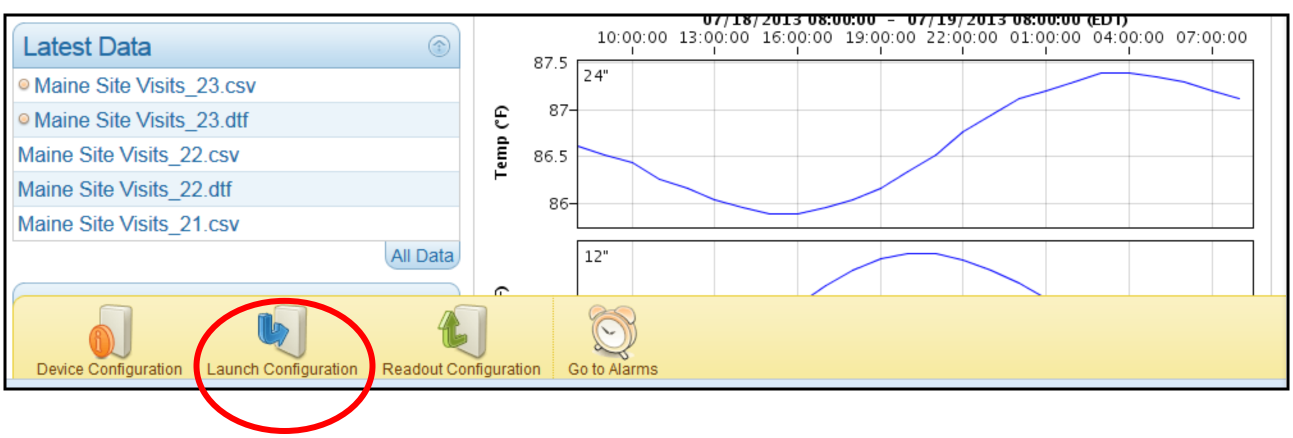



2. Choose and Click on device u30

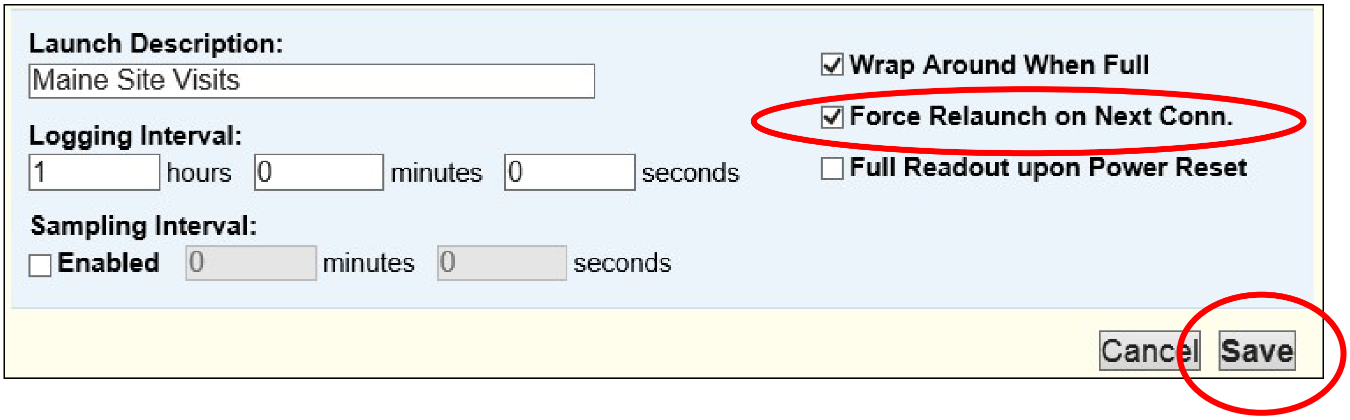


3. This brings up the following page. Click 'Launch Configuration' (the second icon at the bottom yellow bar)

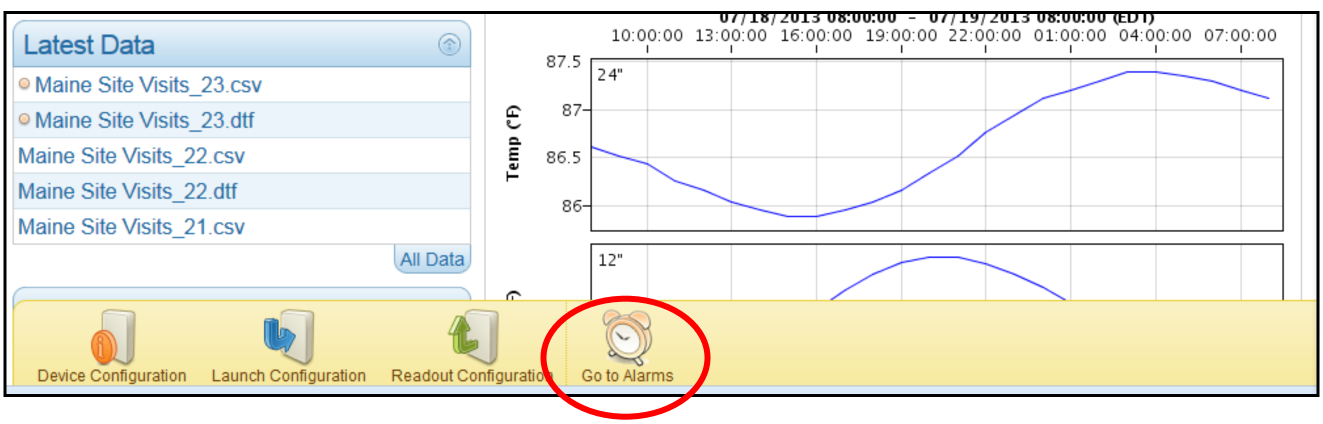


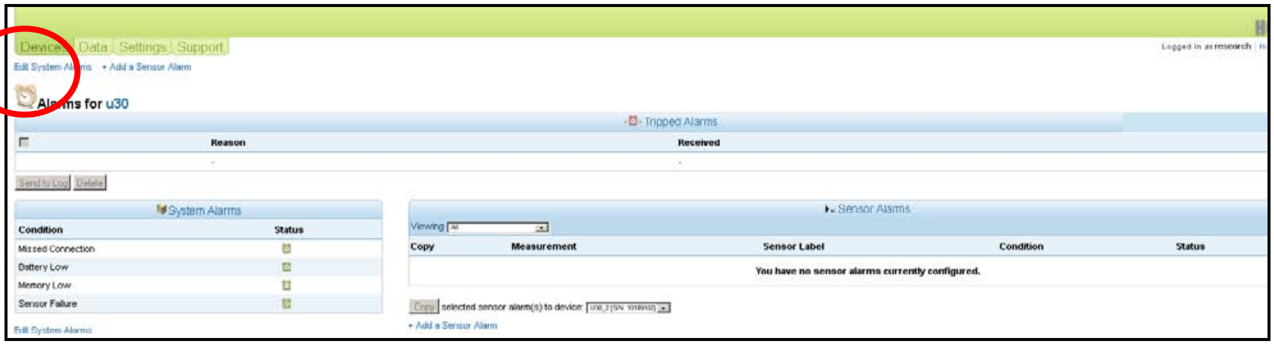
4. This brings up the following page. Choose the check box next to ‘Force Relaunch on Next Conn.’ and click 'Save'

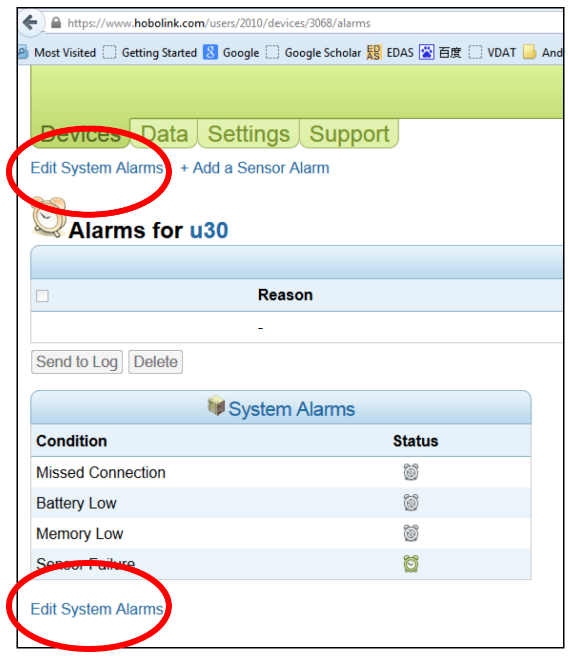



5. Return to the yellow bottom bar and click 'Go to Alarms'

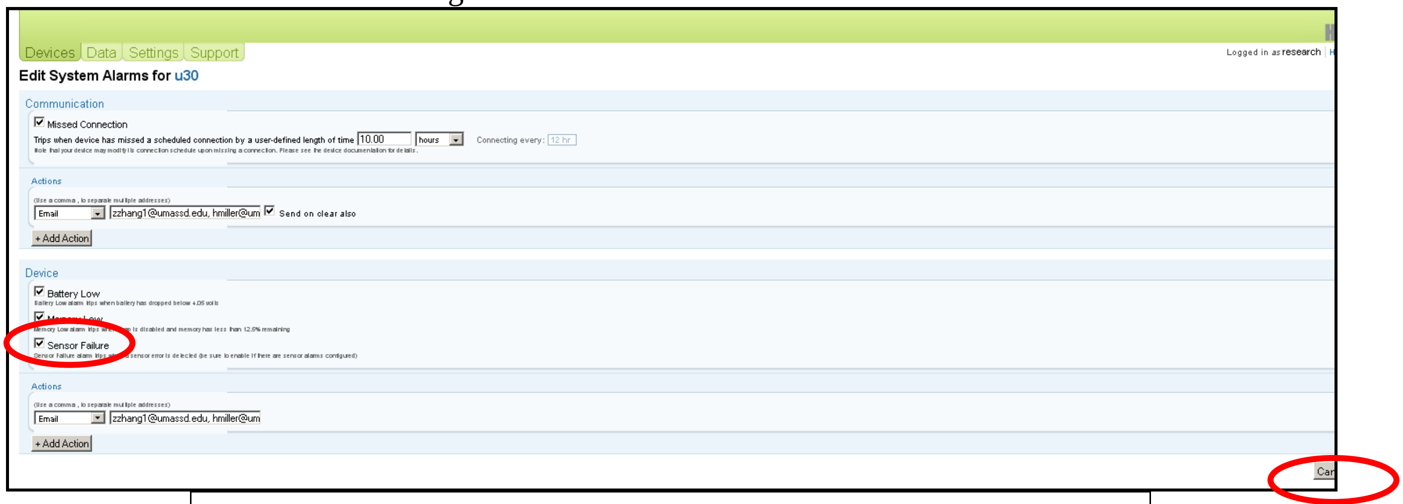


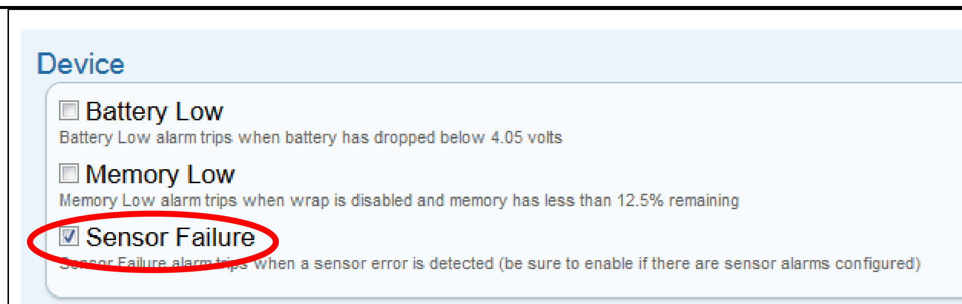
6. The following page emerges. Click 'Edit System Alarms'

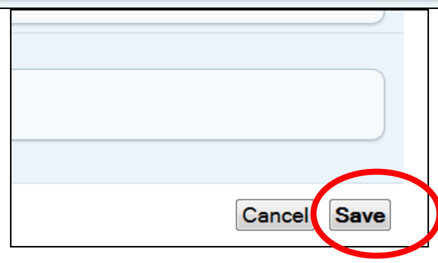


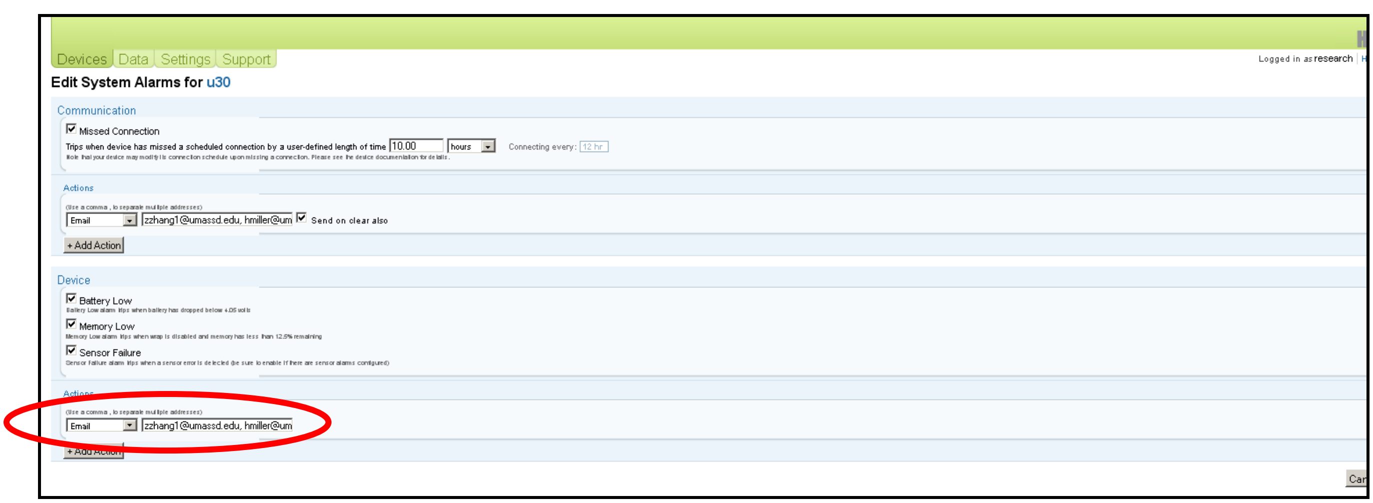
7. The following page emerges.
   Choose the check box 'Sensor Failure' under Devices.
   Click the 'Save' button at the right bottom corner.




8. Optional: Add your email address to this same page before saving.



# IMPLEMENTATION GUIDE

## EQUIPMENT DEPLOYMENT IMPLEMENTATION GUIDE

1) The first task in the deployment process is to identify and locate sites in which the state DOTs desire real-time information that could assist them with SLR postings. These identified sites, due to their remote locations and lack of cellular communication capabilities will benefit from satellite transmission. Information from sensors deployed at these sites include subsurface temperature and moisture data, which is used to generate Frost-Thaw plots, which in turn determines the SLR initiation dates and removal dates. Optional information transmitted from the selected sites could include water table depth and weather data such as air temperature, relative humidity, precipitation, barometric pressure, incoming solar radiation and wind speed. SLR Predictive Models require real-time weather data as input. These models are becoming more and more accurate and can be used to determine SLR initiation dates and removal dates weeks in advance. Once perfected, SLR Predictive Models using weather data will eliminate the need for subsurface temperature and moisture sensors, thus reducing deployment and instrumentation costs. In addition, some of the simpler SLR Prediction Models only require air temperature as input, although these models also require a lengthy calibration process to ensure accuracy. These simpler Models will reduce the costs even further.

2) State DOTs may also identify sites that have cellular communication capabilities, thus, eliminating the need for satellite transmission equipment. Not as remote, there are many of these sites in need of SLR postings. The transmission technology and instrumentation deployed at a cellular transmission site is different from a satellite transmission site, however, the required sensors deployed will be the same. Instrumentation cost at these sites is half the cost at the satellite transmission sites, approximately $6,000 rather than $12,000.

3) Latitude, longitude and elevation coordinates can be determined at the deployment sites by visiting the site with a Garmin GPS or similar navigation device.

4) There are different sensor technologies, data loggers and transmission systems on the market, however, the number of manufacturers to choose from is limited. Components should be evaluated in terms of sensor accuracy, installation issues, data transmission cost and power requirements. For the satellite transmission systems, three manufacturers can provide estimated cost quotes: Campbell Scientific, Inc., Sutron Corporation and Hoskin Scientific Limited in Canada. For the cellular transmission sites, quotes from Onset Computer Corporation, Davis and INWUSA are recommended.

5) In addition to the sensors, all systems require a transmitter, a data logger enclosed in a waterproof box, a solar panel for recharging the power supply and various miscellaneous cables and connectors. Components deployed by the demonstration project are listed in Tables 1 and 2 below. Note that manufacturers typically provide the specifications of their products on their websites.

6) Deployment sites must be located in a relatively open area in order to provide the solar panels with adequate sunlight exposure, which may result in insufficient energy available for data transmission. Open areas also ensure that there are no obstacles that might hinder satellite and cellular

transmission. In addition, shady sections of roadways should be avoided because frost/thaw patterns in shaded sections of roadway differ significantly from frost/thaw patterns in open areas.

7) A data transmission plan purchased from a transmission provider will have annual costs of approximately $300 for a cellular transmission site and $1000 for a satellite transmission site. Subscribers have a protected login over the internet to view raw data. DataGarrison provided satellite data transmission for the demonstration project and provided raw data viewing at the link https://datagarrison.com. The Onset Computer Corporation provided cellular data transmission for the demonstration project and provided raw data viewing at the link http://Hobolink.com.

8) A private website for the State DOTs for the demonstration project is named DSS-SLR, or the Decision Support System for Seasonal Load Restrictions, http://ne-slr.umassd.edu/redmine. It was constructed and programmed to download raw data automatically and periodically from these providers' raw data links. The websites' scripts graph the raw data over time and construct the desired Frost-Thaw plots. In the case of the demonstration project, downloads occur once every 24 hours after midnight, thus, the website plots an additional coordinate point to the graphs daily. Transmission charges increase with more frequent downloads and for longer transmission intervals during downloads.

9) The soil moisture "smart sensors" chosen for the demonstration's deployment combine the innovative ECH2O® Dielectric Aquameter probe, Decagon Devices, Inc. with Onset's "smart sensor" technology. All sensor conversion parameters are stored inside the smart sensor adapter so that data is provided directly in soil-moisture units without any programming or extensive user setup. They have a rated accuracy of $\pm 0.031$ $m^3/m^3$ or volumetric moisture content. Prior to installation in the field, a check of the sensor functionality can be conducted within the laboratory, checking sensor readings both in air and in distilled water to confirm that the readings are within the tolerances specified by the manufacturer.

10) At the satellite transmission sites, thermistors measure subsurface temperatures. The thermistors deployed in the demonstration project were produced by Yellow Springs Instrument, Inc., model 44007, and had accuracy within 0.2$^{o}$ C. Thermistor strings, produced by INW, placed the bottom 9 thermistors, of a string of 12, into a cable,as shown in Figure 1a.  The cable was buried completely at the transmission site. The deepest five sensors were placed at a spacing of 12 inches and four were placed at a spacing of 6 inches, in other words, at depths of 12, 18, 24, 30, 36, 48, 60, 72 and 84 inches. Additionally, 3 fly-out thermistors were included, branching off the cable as shown in Figure 1b. One of the fly-out thermistors was placed at the pavement surface, another at the bottom of pavement, and another within the granular base course, approximately at 6 inches deep. The thermistor strings were calibrated by Hoskin Scientic Limited prior to shipping, however, this calibration was again checked by the deployment team. The calibration process is described next.

11) At the cellular transmission site, twelve individual Onset Computer Corporation Temperature Smart Sensors measure subsurface temperatures. These also had accuracy within 0.2$^{o}$ C. Wrapping the individual sensors with electrical tape and attaching the sensors to a wooden dowel ensured depth spacing accuracy and provided support for the installation and placement in the borehole. To cut costs, State DOTs may elect to buy a smaller number of sensors. In addition, two separate data loggers / transmitters are required with 12 thermistors, which also require two solar panels and two subscriptions to data transmission providers, such as the one used in the demonstration project at the link http://Hobolink.com. Thus, State DOTs may elect to deploy 6 rather than 12 subsurface

moisture sensors. Furthermore, cost could be limited if the only weather sensor deployed at these cellular transmission sites is the air temperature sensor.

12) The twelve individual sensors at the cellular transmission site as well as the thermistor strings at the satellite transmission site were calibrated in an ice bath to determine freezing temperature offsets. These offsets were recorded for future use in the computation and prediction of SLR posting dates. Crushed distilled ice was placed in an insulated cooler, which was also then filled with distilled water. The thermistor strings and sensors were submerged long enough to acclimate. Swirling of the ice water mixture maintained its temperature at 32° C during this stabilization period. Once temperatures had stabilized, offsets from 32° C were recorded.

13) Deployment at the test sites requires a drill rig, backhoe and other miscellaneous tools. A State DOT crew drills a borehole in the pavement for the installment of the thermistor string, approximately 7 feet deep. If groundwater is not encountered in this borehole and if the soil is dense, then it is not necessary to encase the thermistor string in PVC conduit. However, it is recommended that the thermistor string at least be attached to a PVC dowel to prevent potential damage that might occur to the thermistor cable while experiencing differential frost heaving. If the thermistor string is encased in a PVC conduit, there is a danger that the air gaps between the thermistor string and the PVC walls alter actual soil temperature readings. Thus, Hollister sand must be poured into the PVC casing to fill in the air gap between the thermistor string and the PVC walls.

14) The crew drills a second borehole for installation of moisture sensors, approximately 3 feet deep. The crew also excavated a trench from the boreholes out beyond the roadway's edge for running cables to the pole or mast that supports the data logger and other associated instrumentation. The pole or mast is located off the edge of the road within the right of way. Utility poles or masts may already exist at the site, otherwise, installation may be necessary.

15) The placement of the soil moisture sensors may vary at each site, depending upon the thickness of the asphalt and base layers and existing moisture conditions. Typically, the maximum depth of the moisture sensors is 40 inches. As an example, the four moisture sensors deployed for the demonstration project at one of the satellite transmission sites had depths of 5, 9, 14.5 and 33 inches from the surface of the pavement. The sensors' distances from the roadway centerline were 99, 99, 97 and 108 inches, respectively. These location parameters are recorded and kept for future reference.

16) The reclaimed asphalt/gravel mix containing the four moisture sensors and two of the fly-out thermistors is used as backfill in the roadway portion of the trench. The reclaimed asphalt/gravel mix is compacted by hand with a tamper. The crew places atop, a layer of hot mix asphalt, HMA. Care must be taken while installing the upper two temperature sensors or thermistors, one just below the HMA and one 0.5 inches below the surface.

17) If desired, soil samples obtained from the boreholes may be collected and subjected to sieve analysis, moisture content determination, hydrometer analysis and Atterberg Limits tests. Parameters derived from tests' analyses can later be used as input to the more complex prediction models. If desired a pressure transducer for monitoring the depth to the groundwater table may also be installed off the edge of the roadway near the mast. This is also important input to the more complex prediction models.

18) To simplify the installation process of the weather sensors, some are attached to the mast while it lies horizontally on the ground. For example, it is easier to attach the wind and air temperature sensors, as well as the solar panel and barometric pressure sensor to the mast prior to hoisting up the mast onto the utility pole. Wooden spacers can be lagged bolted to the utility pole to secure the mast.

19) Other sensors, such as the rain gauge and pyranometer, or the sensor for measuring solar radiation, can be attached directly onto the wooden utility pole, rather than the mast. These two sensors must be adjusted to maintain a level position and attaching them to a solid utility pole is preferable over attaching them to a mast that may move with the wind. A bucket truck or ladder may be necessary.

20) To fasten the final bolt of the mast to the utility pole, located at the very top of the mast, a bucket truck or a long ladder may be necessary. After the mast is securely fastened to the utility pole, the data logger enclosure can be attached to the mast at a lower level where it is easily accessible. Note that the enclosure is locked with a key to prevent tampering and for security reasons.

21) At this point, the electrical cable connections can be made between the data logger and the sensors. PVC conduits from the ground up to the enclosure were use to protect cable wires emerging from the backfilled trench from the elements. Two completed satellite sites are displayed in Figure 2. A cellular transmission site with 12 individual subsurface temperature sensors, four moisture sensors and one air temperature sensor is displayed in Figure 3. Note that a mast was unnecessary for the cellular transmission deployment. Both data loggers, the two solar panels and the wind, rain and air temperature sensors are all mounted onto the utility pole.

Figure 1a) INW thermistor string, bottom 9 thermistors.

Figure 1b) Upper 3 fly-out thermistors. .

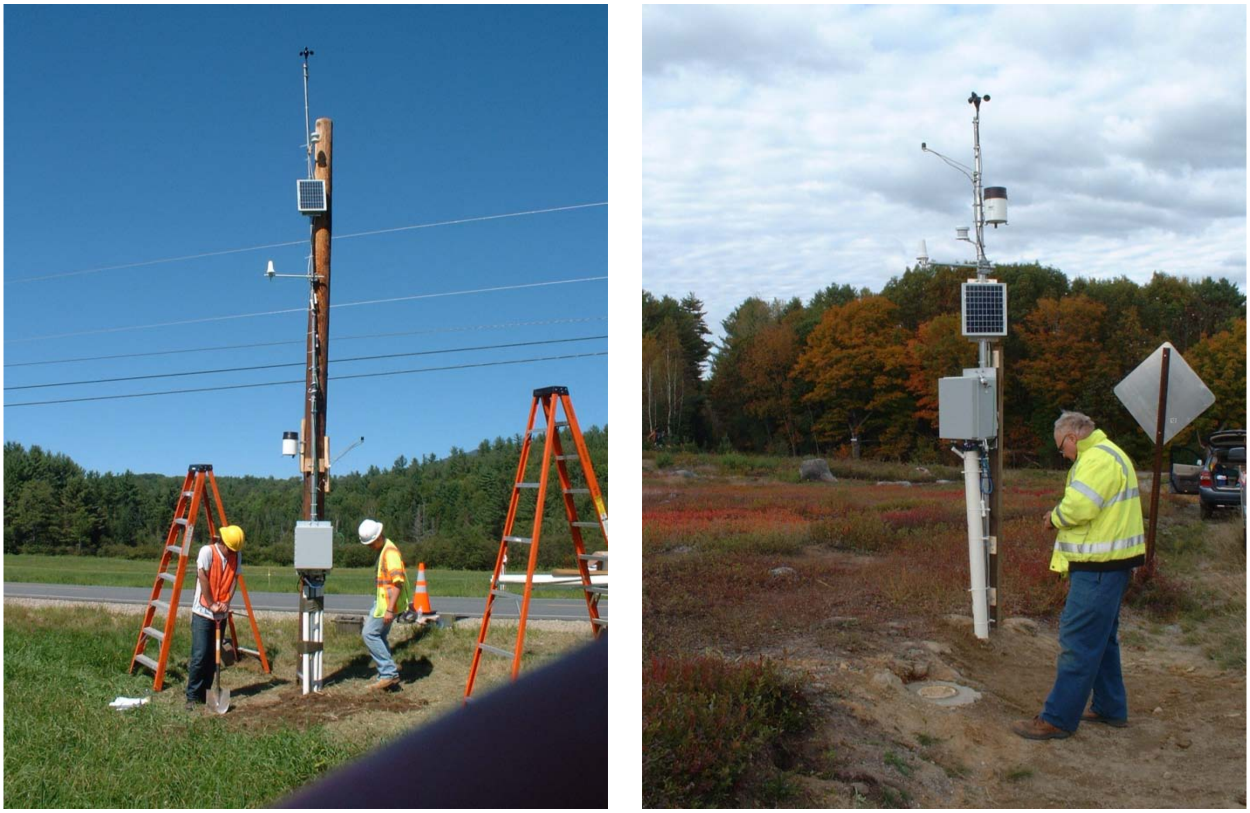


Figure 2: Two examples of completed deployment of satellite transmission sites.

Figure 3: An example of a completed deployment cellular transmission site.

Table 1. Equipment Purchased from Hoskin Scientific Limited for each of the Demonstration Project’s Satellite Transmission Sites.

| Part# | Quantity | Item Description and Associated Details |
|---|---|---|
| SSLOG-IRD | 1 | Solar Stream Data logger / Iridium Satellite Transceiver<br>Onset Smart Sensor Interface<br>Iridium 9602 Transceiver with Integral Iridium Antenna<br>Hoffman Nema 4 Enclosure 16"x14"x10"<br>Pole Mount Bracket for Enclosure<br>20 A/hr. Sealed Lead Acid Battery<br>10 Watt Solar Panel<br>Amphenol Military Circular Connector for Thermistor String<br>Integral Iridium Antenna (12’ Cable Length) |
| E317-3C395 T16 | 1 | Smart Sensor Control Box with Modbus Interface to SSLOG |
| TS-1272-3F-4407-66 | 1 | Thermistor String with 12 thermistors<br>YSI 44007 Thermistor 5K @ 25C, +/-0.2C Interchangeability<br>Polyurethane Injection Mold<br>72' total cable length (66' Tail Wire)<br>Amphenol Mating Connector for Satellite Enclosure<br>Kevlar Stranding<br>Water Block Cable Fill |
| E348-S-SMC-M005 | 4 | Soil Moisture Sensors - Decagon EC5 |
| E317-2B41824 | 1 | INW-Pressure Transducer (water table depth)<br>PT12, 5 PSIg<br>316 Stainless - Standard Calibration<br>Modbus Interface |
| E317-7A23540 | 1 | Sensor Cable for Pressure Transducer<br>PU 100 Submersible – 60 feet long |

| | | |
|---|---|---|
| E348-S-ADAPT-X5-10 | 1 | Smart Sensor 5-to-10 Input Expander Kit for SSLOG |
| E348-S-THB-M008 | 1 | Temp/RH Sensor (12-bit) w/ 8m Cable |
| E348-RS3 | 1 | Solar Radiation Shield (for use with temp/RH sensors) |
| E348-S-RGA-M002 | 1 | Rain Gauge (.01") with 2m Cable |
| E348-S-LIB-M018 | 1 | Silicon Pyranometer Sensor w/18m Cable |
| E348-M-LBB | 1 | Light Sensor Bracket |
| E348-S-BPA-CM10 | 1 | Barometric Pressure Sensor |
| E348-S-WSA-M003 | 1 | Wind Speed Sensor with 3m Cable |
| E348-S-EXT-M010 | 2 | 10m Smart Sensor Extension Cables for Rain & Wind Sensors |
| E348-S-EXT-CASE | 2 | Weatherproof Extension Cable Connector Housing |

Table 2. Equipment Purchased from Onset Computer Corporation for the Demonstration Project's one Cellular Transmission Site.

| Part # | Quantity | Item Description and Associated Details |
|---|---|---|
| U30-GSM-000-10-S100-204 | 2 | U30-GSM - Cellular communications |
| SOLAR-6W | 2 | 6 Watt Solar Panel |
| BHW-PRO-CD | 1 | HOBOware Pro Mac/Win Software |
| S-TMB-M017 | 12 | 12-Bit Temp Smart Sensor (17 m cable) |
| S-SMC-M005 | 2 | Soil Moisture Smart Sensor (Decagon EC 5) |
| S-TMB-M002 | 1 | 12-Bit Temp Smart Sensor (2m cable) for air temp. |
| RS3 | 1 | Solar Radiation Shield (for air temp sensor) |
| S-EXT-M010 | 2 | Smart Sensor Extension Cable - 10m length |
| S-EXT-CASE2 | 2 | Weatherproof Housing Units for Extension Cables |

## ADMINISTRATION & WEBSITE IMPLEMENTATION GUIDE

1. Establish an Advisory Board that minimally includes representatives from the following:
   - University Team Researchers that include expertise in Computer Science, Electrical Engineering, Civil Engineering (preferably geotechnical as well as traffic engineering) and a strong leader to guide, coordinate and record activities.
   - State DOT representatives and IT personnel
   - Field Consultants
   - Hoskin Scientific Limited IT personnel
   - US DOT RITA program management team
2. Interviewing and hire graduate students and assign each of them to one of the university team research members.
3. Organize and invite all partners listed above, including graduate students, to a kickoff meeting to acquaint members with the project objectives, project deliverables, project timeline and with each other. At this meeting, the delegation of responsibilities should be clarified as much as possible from the onset of the project. The option of conference calling for State DOT members that live great distances away should be provided. All power point slides and other kickoff meeting material to call-in participants should be sent ahead of time.
4. Weekly meetings should be held by the research team, including graduate students. Additional meetings between individual members may also be set up as the project activities require. Quarterly meetings with conference call capability should be set up with the advisory board members and all partners. Quarterly reports should be reviewed by all members and partners before submission.
5. A listing of the parameters or data collected by the weather station should be generated. This is useful to the vendors of the weather station as well as the team members designing the database of the DSS.
6. Vendor quotes can be acquired for the CRS& SI weather stations. The UMass Dartmouth team considered three quotes: from Sutron, from Campbell Inc. and Hoskin Scientific Limited. Discussion with partners and consultants will determine the components and sensors required to collect all the appropriate data for the DSS. Sensors should include subsurface temperature sensors as well as weather sensors above ground. Costs for each station typically ranged from $10K to $12K. Integration of the components, sensors and calibration is addition $3K each. Vendors work with their preferred satellite provider and Hoskin Scientic Limited works with DataGarrison. Subscriptions run around $1K each year for each station site. Delivery of the systems took 8 months from the date of the purchase order. This was not anticipated by the team and made planning difficult.
7. A test-bed, located near university research team members, such as on campus, should be established. This test-bed is required for testing the CRS&SI technology, but more important, is required to test satellite transmission and reception within the Decision Support System, DSS

database. This can reduce travel to and from the remote test sites where CRS&SI technology is later deployed.

8. It is prudent to hold early meetings with the university campus Data Center personnel and to construct a list of software modules needed to design the website.
9. Assemblage of historic data from various sources should be researched. Format within the database and appropriate units must be agreed upon. Sources of this historic data often have their own format and units, so conversion scripts and code must be written to convert all historic data into the agreed form. In addition scripts are needed to import this newly formatted data into the DSS-SLR database.
10. It is important to begin investigation of the preferred predictive model to be incorporated onto the DSS-SLR and important to identify input variables required by the model. Then, sensors can adequately acquire the needed input data for the prediction model. In the current case scenario, the DSS-SLR has incorporated the simple index prediction model that requires air temperature only. Thus, it was decided that WeatherUnderground would provide weather data to be connected to the database onto the DSS-SLR.
11. The research group hopes to integrate more sophisticated prediction models that require additional weather data, thus the two CRS&SI deployed weather stations are well equipped with the appropriate sensors to collect this data. Future validation of these prediction models will be necessary and this data will assist in that task.
12. Testing equipment was picked up from DataGarrison (in Falmouth, MA) to test satellite reception at the proposed installation sites in NH and ME and later returned to them. The results of these tests established that satellite coverage was quite adequate at these two sites for the proposed work. DataGarrison also provided login information to their internet links and the test data was downloaded successfully, however, not imported to the DSS-SLR, as the website was still undergoing development at that point.
13. The first draft of a user friendly GUI was designed within the first three months of the project. For the real time data, the concept included a Google Map which displayed the weather station locations. Once the computer mouse would be moved over the location of a station on the map, the frost-thaw-profile plots for that particular station would become visible to the user. Additional points on the frost-thaw-profile plots would be generated and added to the plots, each evening, for each station, from the data collected via the CRS&SI technology during the latest 24 hour period. The data points for the plots would be generated by an Seasonal Load Restriction Interpolation, SLRI, Tool which would then insert the new data point onto the plot. Script writing became intense in the 5$^{th}$ quarter and stayed intense until the completion of the project.
14. Although the delivery was delayed, much progress on the software side of the campus test-bed could made during this waiting time. For instance, the team worked on the development of a TCP/IP based communication software (Client-Server) to transmit the data collected from remote sites to the datacenter through real time satellite communications.

15. Upon arrival, July 2012, the equipment underwent testing in UMass Dartmouth ANDS Laboratory testbed site. Accounts were set up with a one-year subscription for two stations, purchased from Upward Innovations, Inc., at $770 each. The goal for the testing process was to ensure that the DSS, its database and the sensors collecting the data would communicate in a timely and accurate manner via satellite transmission.
16. At the time of delivery, the team underwent a one-day long training session on June 6, 2012, via conference call with Hoskin Scientific Limited Inc. Douglas Calvert. The training slide presentation was provided and the manual for the two CRS&SI weather stations and equipment was also provided.
17. At this point, the research team took the DSS-SLR website design to its first stage construction, specifically the programming and its GUI, now directly on the University's Data Center's server, and pushed the latest code to production. Some of the Asynchronous JavaScript and XML (AJAX) methods used to populate the views of the stored data were refined. Integration of JpGraph with the MVC progressed. This set the framework for future graph generation by given data arrays, historic or in real-time. JpGraph is an Object-Oriented Graph creating library. The library is completely written in PHP and ready to be used in any PHP scripts. PHP is a general-purpose server-side scripting language originally designed for Web development to produce dynamic web pages. It is one of the first developed server-side scripting languages embedded into HTML. Rather than calling an external file to process data, the code is interpreted by the web server's PHP processor module which generates the DSS website.
18. Tables of the database were modeled in the MVC architecture of the web application. Thus, general CRUD operations on each of the tables were possible. In addition, scripts established a real-time connection with Plymouth State University, PSU, where future real-time data could be transmitted to the DSS via the internet. Scripts to import PSU data, parse the data and display the data were created. Storage for this data was implemented as well. This included data from 12 separate site locations. This effort was in addition to activities previously mentioned in which the DSS database was being populated with PSU's historic data. In other words, expansion of the historic database continued and was ongoing throughout the duration of the project.
19. The DSS web server has the address http://ne-slr.umassd.edu and is named the *New England's - Seasonal Load Restrictions* website. Separately, a project website was established and provides a public description of the project along with key personnel information at http://mzgis.prod.umassd.edu/dssslri.
20. Many people assisted with the many deployment tasks as can be seen in the deployment report provided in the appendix of this final report. Tasks included traffic control and safety, road boring, trenching, placement of the well point and road subsurface temperature and moisture sensors, collection of soil samples, post setting and installing equipment onto the post. The UMass Dartmouth team and consultants installed the road hardware, installed the groundwater well pressure transducer and installed or mounted all of the equipment onto the mast/post. The team also tested it while state DOT drilled the waterwell, installed the post,

sawcut and removed the pavement, dug the trenches for the wires, obtained the soil samples, filled the trenches and patched up the road. In addition, at the Maine sites only, a string of HOBOs and surface HOBO were installed in a shady section of roadway nearby. During deployment, the team strived to ensure public safety and to remain on site as briefly as possible. There were several activities happening at the same time. Everyone was wearing ANSI safety vests, and hard hats. State DOT took care of the public notices regarding lane closure. The deployment also incurred unexpected and additional travel expenses to adjust the instrumentation, waterproofing, recharging the battery and replacement of damaged parts.

21. Debugging the code was a large part of the research team's focus during the last quarter of the project. For example, database columns were not always aligned with the correct sensors and adjustments in the scripts had to be completed. Validation of the data was also on-going and required more work than anticipated. To facilitate this, and in order to track the bugs, a bug-tracking system for the DSS-SLR with specific logins was set up for the UMass Dartmouth team members. It was and is still located at http://ne-slr.umassd.edu/redmine.
22. Also, during the last quarters of the project, communication between State DOTs and the UMass Dartmouth research team increased in frequency. Feedback on the GUI and its user friendliness became useful and crucial. A tutorial was under the planning stage for the final project meeting and the feedback assisted with the development of this tutorial.
23. DOT representatives, the project Advisory Board and Team members were invited to a final project meeting, August 22, 2013. A training tutorial was provided to NH DOT, ME DOT and US DOT at the final meeting. A flowchart of the project focused on all aspects of the project was also presented.

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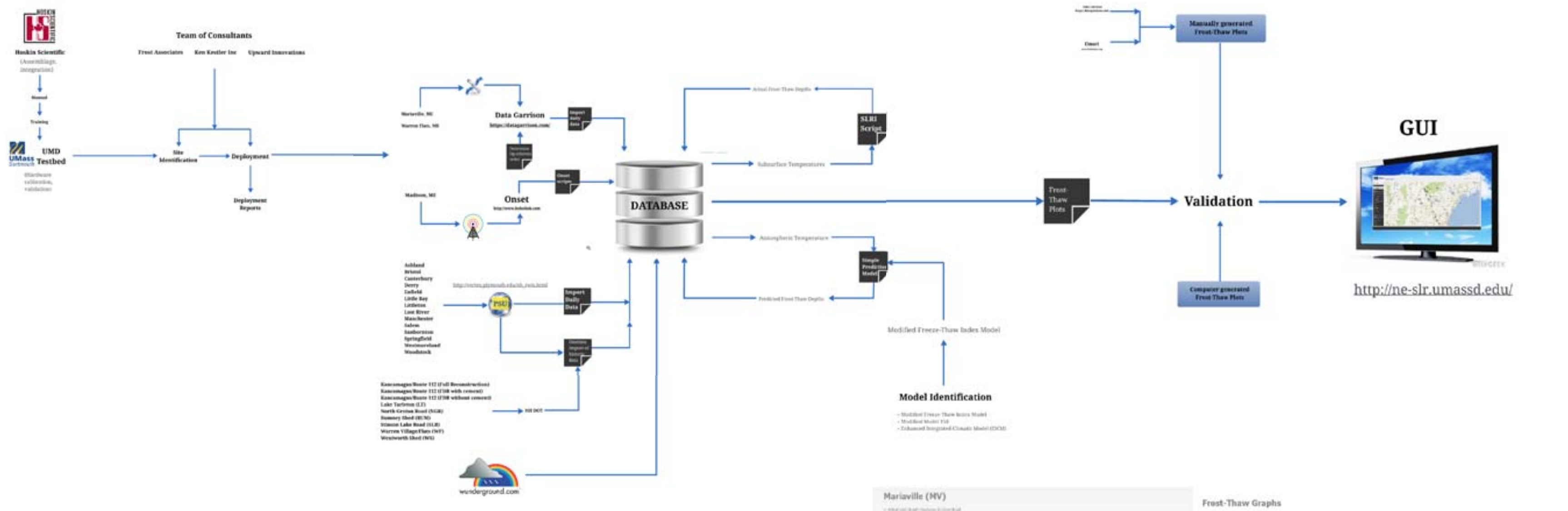
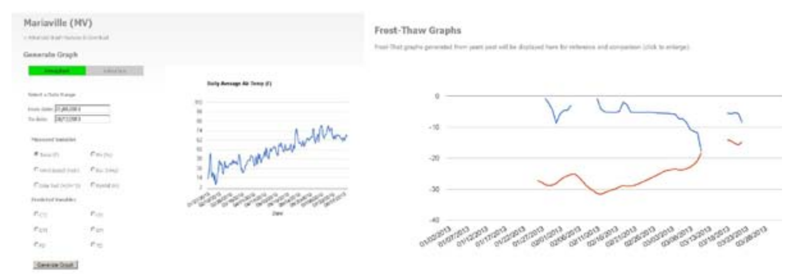
# Development of the DSS - SLR
# Decision Support System - Seasonal Load Restriction
# USDOT RITA Grant Award RITA ARS-11-H-UMDA

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### DSS-SLR System Goals
- Eliminate the need to manually collect roadway subsurface temperature data and replace it with remote sensing and spatial information, CRS &SI, technology.
- Collect atmospheric data via CRS&SI technology.
- Aggregate real-time data sources & historical data into one central database.
- Automate the processing of raw data into a more meaningful display for decision makers.
- Create Frost-Thaw depth plots from data.
- Design and build a Decision Support System, DSS, website with a user friendly Graphical User Interface for our DOT partners.
- Automate the collection of atmospheric data. Integrate a model on the DSS to predict Frost Thaw depths based on the forecast of atmospheric temperatures.

For a clearer picture, click on
http://prezi.com/53zyouvf_uq5/untitled-prezi/?utm_campaign=share&utm_medium=copy