Project # DHP-NH-4110 (156)
Key # 9294
Thorncreek Road to Moscow, Stage 1

Final Report
for
Weather Analysis of Proposed Realignments of U.S. Highway 95, Thorncreek Road to Moscow

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Introduction

This project was commissioned by the Idaho Transportation Department in order to evaluate the climatic conditions within a three mile wide, and six mile long study area south of Moscow, Idaho, which is traversed by U.S. Highway 95, as shown on the US95 Proximity Map and the Study Area Map in Appendix B. The study area is being evaluated to determine the possible realignment alternatives for Highway 95, as part of Project # DHP-NH-4110 (156) Key # 9294 Thorncreek Road to Moscow, Stage 1, in order to improve its drivability. ITD desires to characterize the climate of the study area with respect to variables which affect driving conditions and traffic safety. The primary variables of concern are precipitation, fog, and air temperature as it relates to production of road ice and frost. The following report describes the measurements and analysis which were carried out, and describes how the measurements relate to several different "characteristic" climate regimes within the study area. In addition, a comparison of the current measurements with measurements from a nearby long-term climatological station were used to place the study measurements in the context of the region's normal climate.

Study Objective

To collect and analyze weather data from within three anticipated "climate regimes" within the study area, to compare and contrast the three areas, and to present that information in distilled form to ITD.

Site Selection

As noted above, three climate regimes within the study area were anticipated based on orographic features present within and around the study area. The orographic factors considered to be important were: a) elevation above mean sea level (amsl), and b) proximity to Paradise Ridge. Elevation was anticipated to influence the study area by means of adiabatic cooling of air with increasing elevation under neutral or unstable atmospheric conditions, such as experienced during windy conditions or on sunny days with strong convection, which was anticipated to increase precipitation with increasing elevation. Conversely, under stable atmospheric conditions, often experienced at night especially during periods of low wind speeds, elevation gradients can guide cold air drainage into low-lying areas producing an inversion with much colder temperatures in those low-lying areas compared to higher-elevation surrounding areas.

The topography of the region is shown on the Study Area Map in Appendix B. Elevations within the study region range from a low of approximately 2540 feet amsl to a high of approximately 3000 feet amsl or slightly higher. For the most part, the southern third of the study area was dominated by elevations above approximately 2800 feet, and every possible alignment must attain an elevation above 2900 feet while traversing the southern third of the study area. Similarly the eastern corridor of the study area lies on rising ground, reaching a maximum elevation slightly above 3000 feet amsl, and remaining generally above 2800 feet amsl. The western corridor has some higher elevations exceeding 3000 feet amsl in the South, and also has a hill reaching 3000 feet amsl in the North, but drops below 2600 feet amsl in its central portion.

For the purposes of this study, lowland sites were considered to be areas lying below about 2600 feet amsl, and highland sites were considered to be areas above approximately 2800 feet amsl. In order to distinguish between lowland and highland sites, the 2700 foot amsl elevation contour has been highlighted in red on the Study Area Map, and then approximated by a series of line segments in blue. In order to capture the climate effects at the elevation extremes, it was determined that climate stations would be installed below 2600 feet and at or above 2900 feet.

In addition to these effects associated with absolute elevation of points within the study region, it was anticipated that proximity to Paradise Ridge could impose additional effects. Paradise Ridge lies outside and to the east of the study region. It runs roughly northeast to southwest, and reaches a maximum elevation of about 3703 feet amsl. Portions of the study region in the path of air flow moving over the top of Paradise Ridge might experience different climate effects from portions of the study region whose air flow could pass around Paradise Ridge, even for sites with the same elevation. This is due to the fact that air forced up over Paradise Ridge would cool as it was elevated, causing more water vapor to condense from the air. As a result, one might observe greater precipitation depths for sites whose airflow moved over Paradise Ridge, as opposed to sites whose airflow was able to move around Paradise Ridge.

The predominant air flow in the region is in the East-West direction. Given the extent of Paradise Ridge, this meant that the northern two-thirds of the study area was dominated by flow over Paradise Ridge, and the southern third of the study region generally experienced air flow which moved around the southern end of Paradise Ridge. The approximate demarcation between the flow-over versus flow-around portions of the study area is indicated by an east-west green line just to the south of Paradise ridge, as shown on the Study Area Mapin Appendix B. The flow-over/flow-around demarcation continues westward from the green line along the blue-line-approximation to the 2700 foot elevation contour.

In the context of the study region, these two factors were combined into a matrix to stratify the study area to determine the number of sampling areas required, as shown below:

	Highland	Lowland
Air Flow Over Paradise Ridge	√	√
Air Flow Around Paradise Ridge	√	None

The matrix indicates that three climate areas should be sampled. These are a “Lowland, Flow-Over Ridge” (LFO) area, a “Highland, Flow-Over Ridge” (HFO) area, and a “Highland, Flow-Around Ridge” (HFA) area. These regions are labeled on the Study Area Map. Accordingly, one climate station was established in each of the three climate regions of the study area. In the LFO area, a station was placed adjacent to Snow Road, west of the existing Highway 95. In the HFO area, a station was placed east of the existing Highway 95 on a bench butting up against the base of Paradise Ridge. Finally, an HFA station was located in the southern portion of the study area, slightly east of the existing Highway 95. The first two stations we refer to as the West Corridor (WC) Site and the East Corridor (EC) Site, respectively, in accordance with their position with respect to Highway 95. The third site in the south was located in the vicinity of Reisenauer Hill, near an existing cellular telephone tower, and we refer to it as the Reisenauer Hill (RH) Site. These stations are shown on the Study Area Map and a description of each of these sites is given below.

Site Descriptions

West Corridor Site

The WC site is located in the LFO region of the study area, 30 feet south of Snow Road, with a latitude of N 46° 40' 38", a longitude of W 117° 03' 00" and an elevation of 2520 feet amsl. The tower was placed slightly west of the western edge of the study area for logistical reasons, and is slightly north of the middle of the study area in the north-south direction. It is part of a broad drainage valley flowing from the southeast from within the study area, and is no more than ten feet below the elevation of the drainage valley within the western edge of the study area. Thus, it is representative of low elevation drainage valleys within the study area. The surrounding terrain is flat in the vicinity of the tower. One upstream tributary to the drainage channel flowing past the WC site, lies adjacent to the Eastern Corridor site, creating continuity of water and air flow between the two sites. About 100 feet to the east northeast there is a large storage shed, and about 60 feet to the northwest there is a row of trees. Both of these obstructions could influence wind speeds when wind is coming from those directions, but would not influence any of the other variables measured including precipitation, visibility (fog), and temperature. The WC site represents the “lowland, air-flow-over-ridge” condition.

East Corridor Site

The EC site lies in the HFO area, on a southwesterly facing plateau, on the eastern edge of the study area, slightly north of the middle of the study area in the north-south direction. It has a latitude of N 46° 40' 36", a longitude of W 116° 59' 39" and an elevation of 2950 feet amsl. Within a few hundred feet to the east of the tower, but outside the study area, there begins an abrupt ascent up Paradise Ridge. The two highest peaks of the ridge lie approximately one mile outside of the study area, nearly due east of the tower. Placement of the tower at this location maximizes the measurement of effects on climate of air flow over the Ridge. This is a “highland, air-flow-over-ridge” site. There are no obstructions to the tower to the north, west or south, but a few hundred feet to the east lies the upslope, which also has a number of large trees. Since the tower sits on the plateau, but near the beginning of the ascent up the ridge, wind speeds tend to be lower than measured at the other two tower sites.

Reisenauer Hill Site

The RH site lies in the southern HFA portion of the study area and is representative of the southern one-third to two-fifths of the study area. It has a latitude of N 46° 39' 12', a longitude of W 117° 00' 00" and an elevation of 2990 feet amsl. It sits on a west-facing slope, with an approximately uniform slope to both the east and west, approximately 250 feet south of the Reisenauer Hill cellular telephone tower. It has the greatest wind exposure of the three tower sites, but is similar to much of the southern two-fifths of the study area. This is a highland site whose dominant air flow pattern moves around the south end of Paradise Ridge.

Data and Instrumentation

Data Protocol

Measurements were collected with NTCIP compliant Road Weather Information System-Environmental Sensing Stations (RWIS-ESS) purchased from Vaisala, Inc. Measurements began on January 1, 2005 and are ongoing. This report includes results from the data measured between January 1, 2005 and May 31, 2005. Data was transmitted using CDMA cellular technology from each of the three sites to an ITD server located in Pocatello, Idaho. The ITD server polled and downloaded data from the three stations approximately every five minutes, however, the actual time of polling, and hence the time corresponding to each data value and the interval between pollings of a given station, varied depending on access waiting times, and download durations from sensors polled previously. ITD uploads the data to its public RWIS site where current weather conditions may be viewed on the Internet at http://164.165.237.41/Apps/RWIDS_Public/ by zooming to District 2 and looking for the Snow Road (WC), Paradise Ridge (EC), or Reisenauer Hill (RH) sites in the Moscow, Idaho area on the map.

In addition, a Vaisala, Inc. server in the United Kingdom temporarily archives the data in order for us to download it each day to the University of Idaho at Midnight Greenwich Mean Time (4:00 P.M. PST) to incorporate into our permanent archive.

For consistency between the data sets, we resampled all data by interpolation from the recorded data sets to a common five minute time increment corresponding to 0, 5, 10, 15, 20, etc. minutes after each hour.

Instrumentation and Measurements

The following measurements have been collected: Instantaneous, and 24-hour maximum and minimum air temperature (°F, °C), relative humidity (%), average and gust wind speeds/directions(mph, m/s; °), incoming shortwave radiation (W m^{-2}), precipitation type (no precipitation, slight, moderate or heavy rain, snow, or frozen precipitation), precipitation rate (in/h, mm/h), and accumulation (in, mm), visibility distance (33 – 6560 feet, 10-2000 m), and snow depth (in, cm). Wind speed/direction and incoming solar radiation on a horizontal plane were measured at 33 feet height; air temperature, relative humidity, precipitation , visibility distance, and snow depth were measured at approximately 6.5 feet height.

Precipitation Rate (inch/hr, mm/hr) and accumulation (inch, mm) are given in equivalent liquid water depths (i.e., snow is converted to melted depth of liquid water). This measurement is made using the PWD12 visibility distance sensor described below. The sensor measures the scattering of light by hydrometeors (raindrops, snowflakes, etc.) and converts this to volume of droplets within the sensing volume, and then to precipitation rate. It is able to distinguish between liquid and solid precipitation and convert to equivalent liquid water depth. In order to verify the accuracy of this sensor, we installed a standard eight inch tipping bucket raingage at the WC site at the beginning of February and allowed it to run continuously throughout the data collection period. Figure 1 shows that the rainfall accumulation reported by the PWD12 exceeded that of the tipping bucket raingage by 0.4 inches out of a total accumulation of 7.7 inches, which was within six percent of the tipping bucket raingage accumulation after four months of operation. Within this time period, the PWD12 tracked the tipping bucket raingage well, demonstrating that the difference between the two instruments was consistent over time. Tipping bucket raingages are known to under-catch rain in windy conditions. Furthermore, since the tipping bucket records precipitation in increments of 0.01 inches, up to 0.01 inches of precipitation may remain in the tipping bucket at the end of each rain storm. This excess amount may evaporate out of the tipping bucket prior to the next rainfall, and therefore never gets recorded. This also results in the under-catch by the tipping bucket raingage, indicating that the true precipitation accumulation should be larger than what is recorded by the tipping bucket. The record of the PWD12 exceeds that of the tipping bucket raingage, which indicates that it differs from the tipping bucket raingage in the correct direction; the true value of precipitation should exceed that recorded by the tipping bucket raingage.

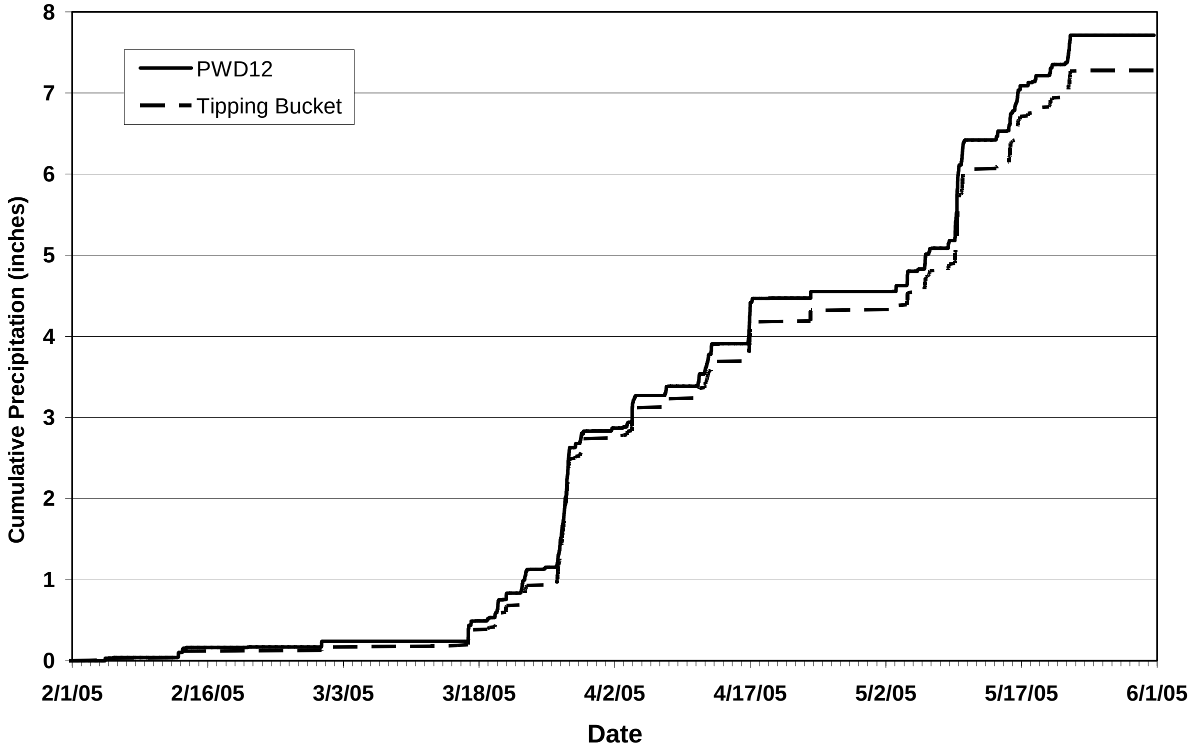

Figure 1. Comparison of Visibility and Present Weather Sensor (PWD12) with tipping bucket raingage at the WC site.

The visibility distance sensor measures the density of water droplet particles within a small volume near the instrument, by passing a beam of light through the volume, and then measuring how much light is scattered up toward a receiving sensor. Signal processing is used to convert this measurement to a visibility distance, reported in meters.

The snow depth sensor emits an inaudible sound pulse that bounces off the surface below the sensor and is reflected back to the instrument. The travel time of the signal is used to measure the distance to the surface below the sensor. This distance can be subtracted from the distance between the sensor and the ground surface to calculate snow depth.

In addition, wet bulb and dewpoint temperatures have been calculated from the temperature and humidity data. Information about the instruments used for these measurements appears in Appendix A.

Data Period

Measurements are ongoing. This report includes data from January 1, 2005 through May 1, 2005.

Analysis

The analysis of the data set incorporated both current and historical components. Each is discussed separately below.

Several variables were measured directly. These included precipitation type (no precipitation, slight, moderate or heavy rain, snow, or frozen precipitation), intensity (inch/hr, mm/hr), and accumulation (inch, mm), visibility distance (11-2200 yards, 10-2000 m), air temperature and relative humidity, snow depth, wind speed/direction, and solar radiation.

These direct measurements provide a wealth of information of the primary variables of interest to this study. The most significant variables with respect to this study are: Precipitation accumulation, visibility distance reduction due to fog, and freezing temperatures. We had originally planned to analyze snow at the three sites, however, there was too little snow during the measurement period to provide a meaningful comparison. Analysis of this data required organizing the data into formats which help to compare the three sites. We tabulate or graph the following:

- Monthly total depth of precipitation which falls at each of the three sites
- Hours per month (HPM) with fog
- HPM visibility lies within selected ranges (e.g., HPM with visibility 0-110 yards, 110-220 yards, 220-330 yards, etc. presented for each site within a histogram).
- HPM with freezing temperatures
- HPM with freezing temperatures simultaneous with 100% relative humidity as a surrogate for frost or ice on roadway.

ANALYSIS OF CURRENT DATA

Precipitation

Our analysis of precipitation at the three sites consists of a comparison of the depths which occurred at the three sites together with concurrent measurements at the University of Idaho Plant Sciences Farm (PSF). The PSF weather station lies 1.1 miles to the northeast of the northeast corner of the Study Area Map, and has a latitude of 46° 43’ 28”, a longitude of 116° 57’ 39” W and an elevation of 2660 feet amsl. The location of PSF with respect to the study area is shown on the US95 Proximity Map in Appendix B.

Table 1 below shows the monthly and total depths of precipitation that fell from January through May 2005, reported as liquid water equivalent depths, at the three study sites as well as at the University of Idaho Plant Sciences Farm. Table 1 also shows the 1971-2000, 30-year climatological normal depth and standard deviation for the Plant Sciences Farm.

Comparing current year PSF values to the 30 year normal shows that January and February were dry months, March and May were excessively wet months, and April was similar to the climatological norm. Using PSF as the reference, one can see that EC was similar to PSF each month during the current year (EC precipitation was slightly less than PSF during January through April, and slightly larger than PSF in May), with a total precipitation over the five months of 12.15 inches, compared to 12.00 inches at PSF. WC and RH exhibited precipitation depths which were about three-quarters that of PSF and EC for the current year.

Table 1: Monthly and Total Precipitation for 2005 at the West Corridor, East Corridor, Reisenauer Hill, and Plant Sciences Farm sites, and the 1971-2000, 30-Year climatological normal precipitation at Plant Sciences Farm. All values are given in inches of equivalent liquid water depth.

Site	January	February	March	April	May	Total
WC	1.22	0.22	2.59	1.72	3.16	8.92
EC	1.42	0.31	3.50	2.02	4.75	12.15
RH	1.20	0.22	2.79	1.43	3.62	9.26
PSF	1.80	0.32	3.52	2.36	4.00	12.00
PSF 30-Yr Norm	2.95	2.62	2.56	2.44	2.64	13.21
PSF 30-Yr StdDev	1.38	1.30	0.95	1.33	1.04	NA

Figures 2a-e below provide comparisons of within-month precipitation at the three study sites for January through May, 2005, respectively.

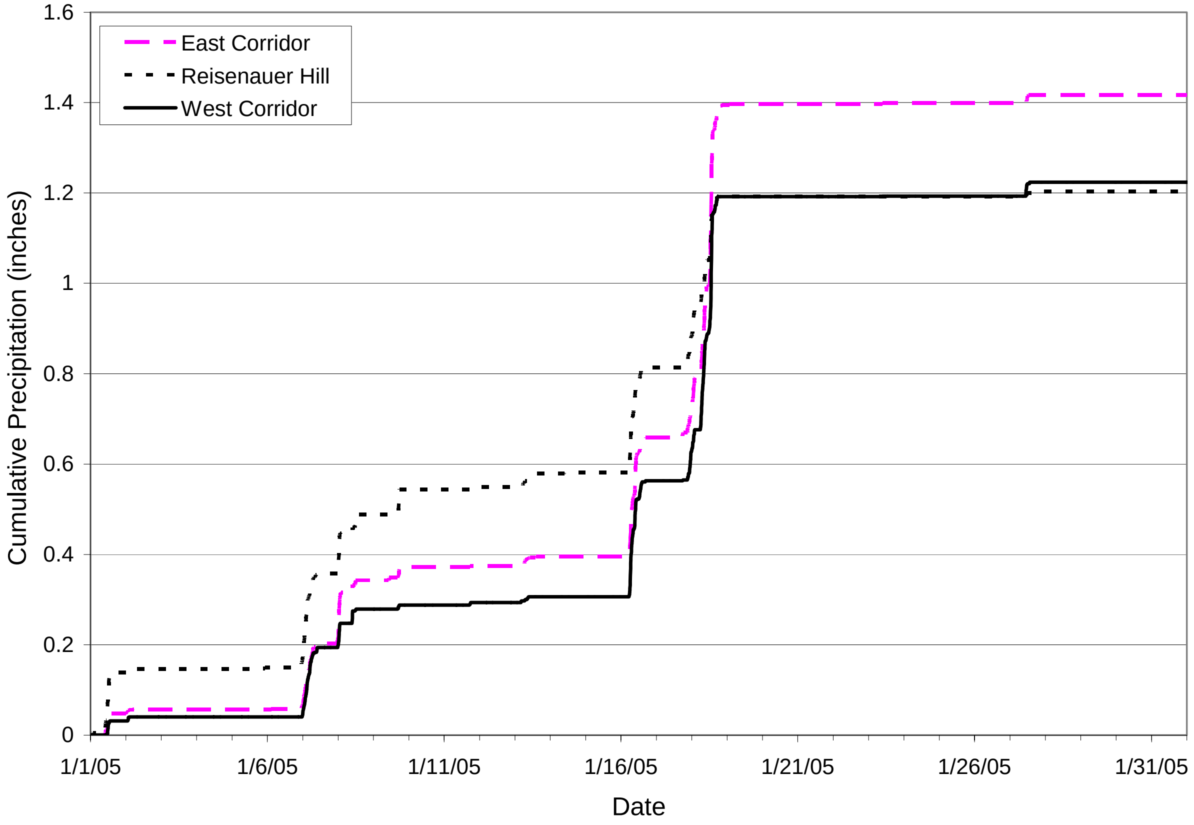

Figure 2a. Time Series of January precipitation at the three study sites. Note the different vertical scales among figures 2a-e.

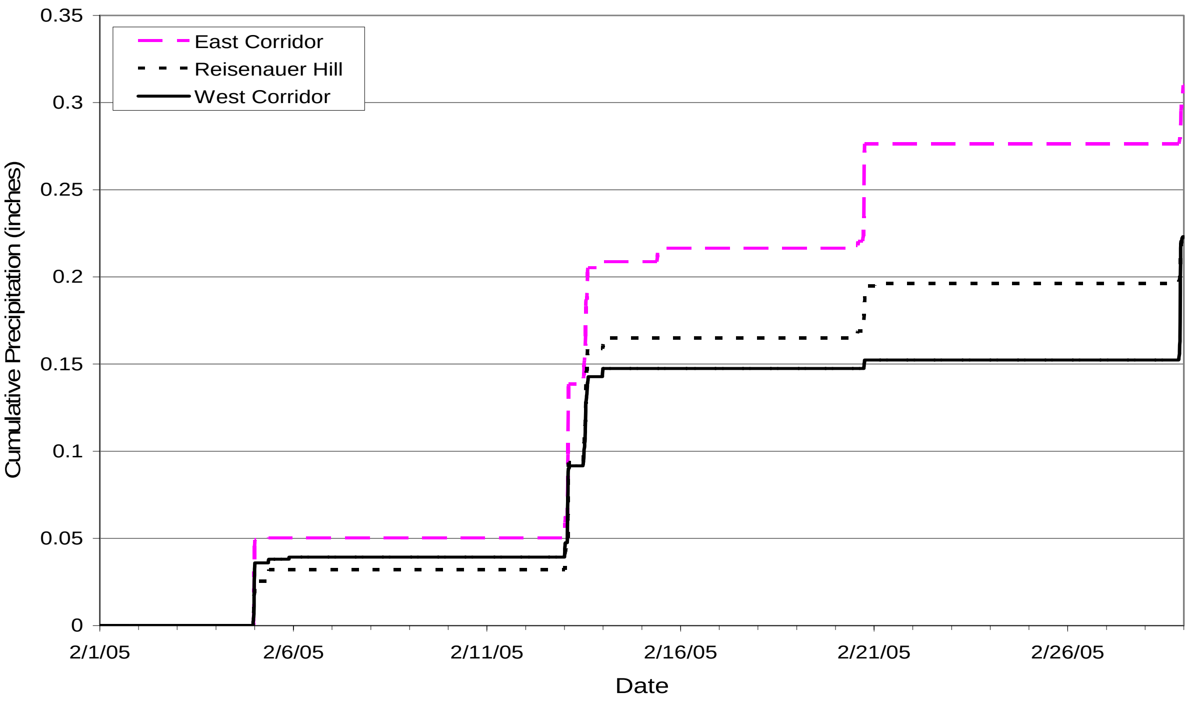

Figure 2b. Time Series of February precipitation at the three study sites. Note the different vertical scales among figures 2a-e.

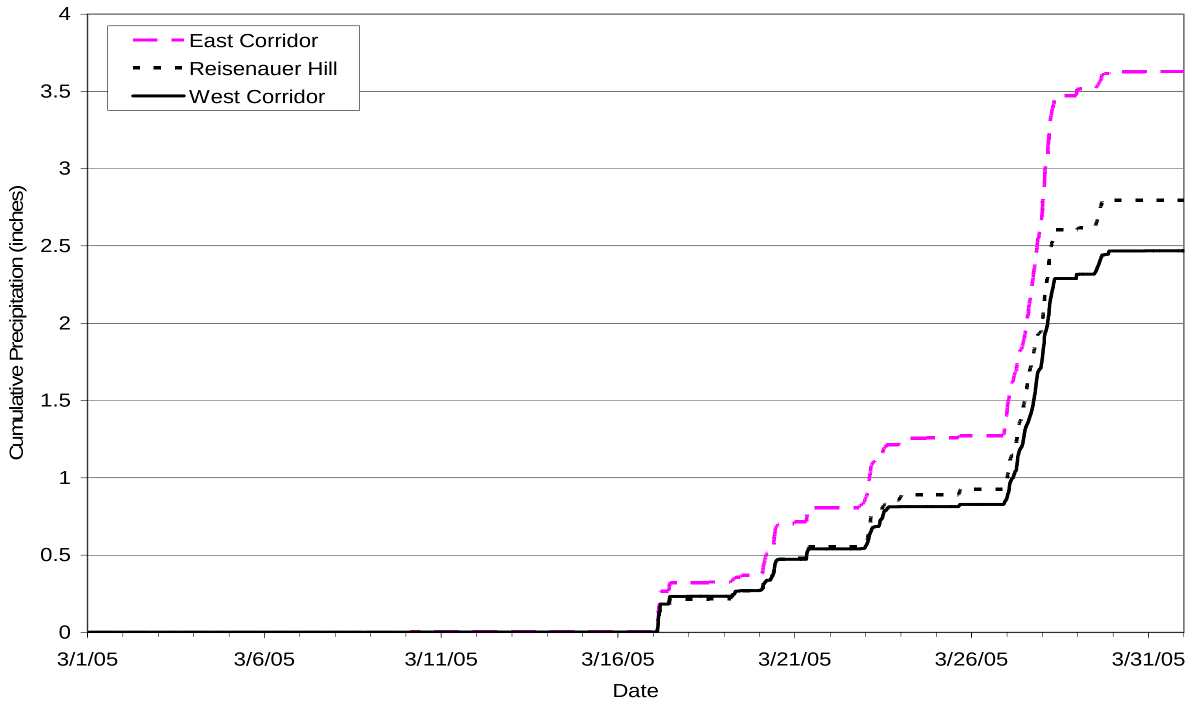

Figure 2c. Time series of March precipitation at the three study sites. Note the different vertical scales among figures 2a-e.

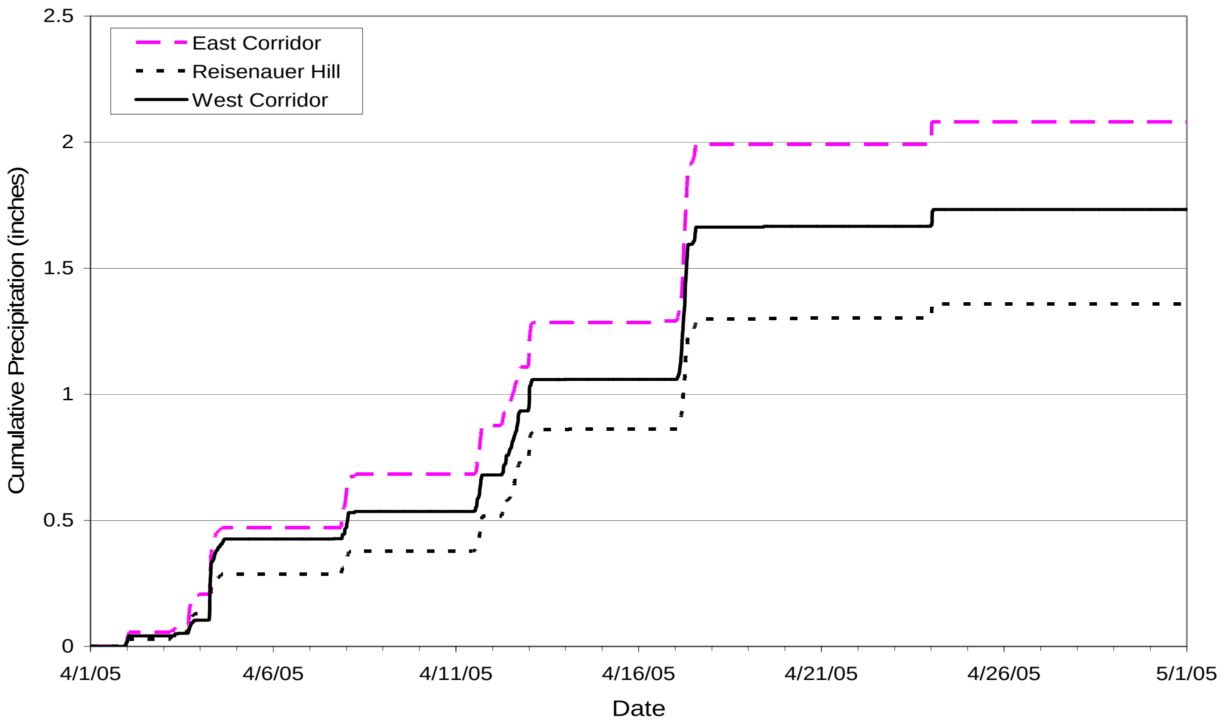

Figure 2d. Time series of April precipitation at the three study sites. Note the different vertical scales among figures 2a-e.

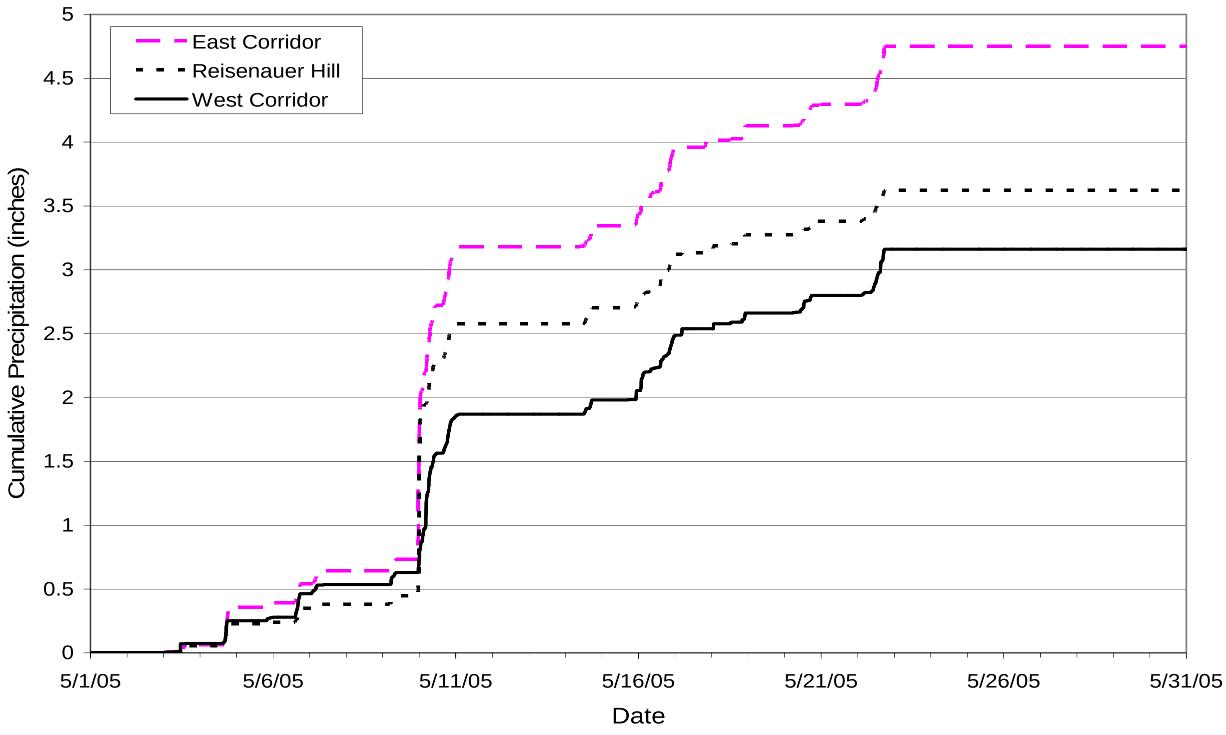

Figure 2e. Time series of May precipitation at the three study sites. Note the different vertical scales among figures 2a-e.

As noted earlier, the three measurement sites were selected to represent particular climate regimes, corresponding to lowland or highland, and flow over or flow around the ridge (LFO, HFO, and HFA). None of the three measurement sites represents a particular roadway alignment alternative over its entirety, since every possible alignment must traverse the HFA, and then one or the other of LFO or HFO. As a result, it is useful to distribute the measured data over an aggregated western corridor (AWC) and an aggregated eastern corridor (AEC) which reflect the relative distance spent traversing each of the climate regimes. To do this, the distances within the HFA, LFO and HFO climate regimes of two alignments were measured, one from the western corridor (W-2), and one from the eastern corridor (E-3), and the distance within each climate regime was divided by the total distance of the alignment. The climate elements from each measurement site (e.g., precipitation depth) were multiplied by the fraction of roadway distance within that climate regime for the eastern and western corridors and summed to produce the AWC and AEC climate values. The fractional distances were not significantly dependent on which road alignment was measured within a given corridor (e.g., W-3 versus W-2), and the use of W-2 and E-3 does not constitute a preference for these alignments over any of the other alignments within the corridor; they are simply representative of the western and eastern corridors. The fractional distances for the aggregated western corridor (AWC) are given in Table 2.

Table 2: Fractional distances within each of the climate regimes HFA, LFO, and HFO for road alignments representing the western and eastern corridors.

Aggregated Corridor	HFA	LFO	HFO
AWC	0.43	0.43	0.14
AEC	0.50	0.0	0.50

Precipitation is distributed through the aggregated western corridor and aggregated eastern corridor using these fractions. Table 3 presents cumulative data for the months of January through March, since these are the months most likely to have precipitation fall as snow. Results are reported as a fraction of Plant Sciences Farm (PSF) precipitation for these same months for both the measurements year 2005, and relative to the PSF 30-year averages for January through March. From Table 3, one can see that there is only about a six to eight percent difference in the amount of precipitation received by the Aggregated Western and Eastern Corridors.

Table 3: Percent of PSF precipitation for January through March within the aggregated western corridor and the aggregated eastern corridor for both the 2005 measurement year, and for the 30-year averages.

	% of PSF Precipitation	
Aggregated Corridor	2005	30-Year Average
AWC	76	74
AEC	84	80

Fog

Fog is a significant variable of concern in this study owing to its affect on visibility for drivers. The total hours of detectable fog (i.e., visibility less than the detection limit of 2200 yards) for each site and month are shown in Figure 3. As is common in this region, the greatest number of hours of fog during the study period occurred in January. February is often also foggy, however, owing to the dryness of the month this year, February had very little fog. Based on figure 3, Reisenauer Hill is foggy for a larger number of hours than either EC or WC, WC exhibits the least number of hours of fog, and EC lies about midway between RH and WC in terms of numbers of hours of fog.

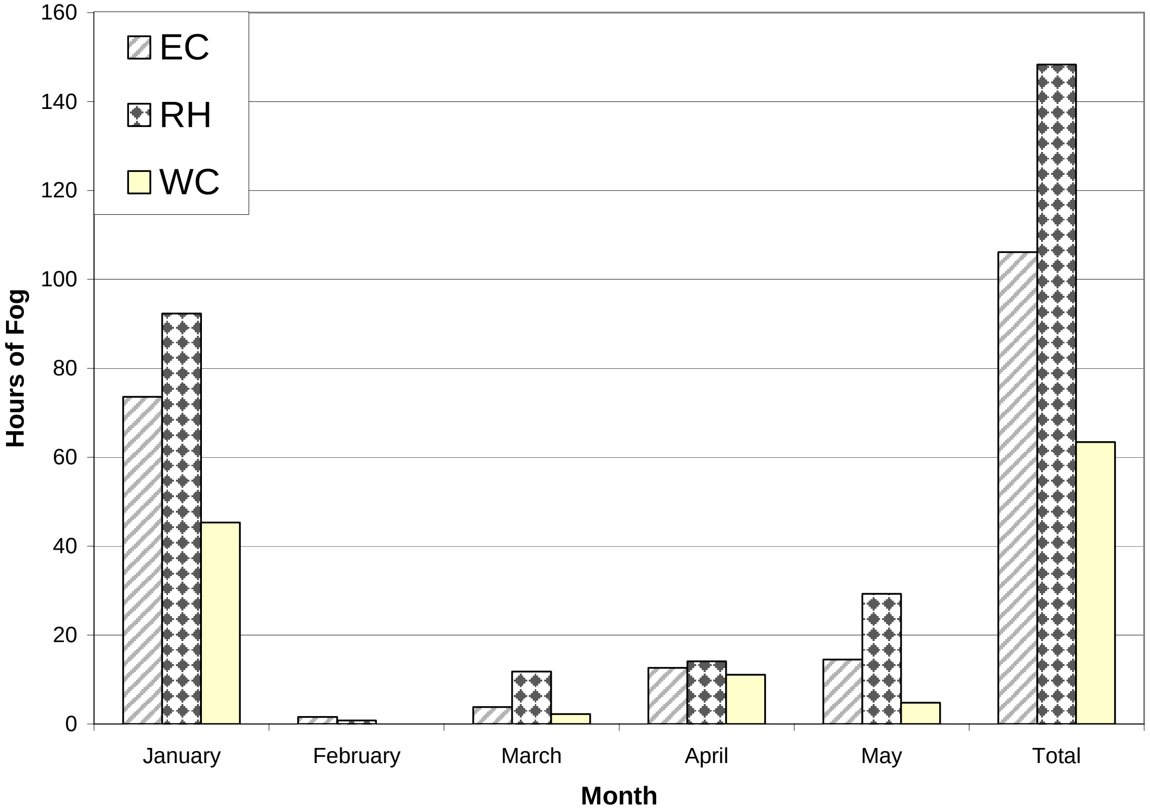

Figure 3. Total hours of detectable fog by site and month.

Although the PWD12 can detect reduced visibility ranging from 33 to 6560 feet (10-2000 m), reduced visibility affects drivability more severely at lower visibility distances than at longer visibility distances. To compare sites taking this into account, we present a histogram in Figure 4 of number of hours of visibility distance in ranges of 11-110 yards, 110-220 yards, 220-330 yards, etc. In order to condense the graph and focus attention on the shorter visibility distances, increments of 110 yards are used for the first five range categories from 0 to 550 yards. Above 550 yards, larger increments are used, ranging from 220 to 550 yards.

Figure 4 and Table 4 both exclude hours where the sensor detected no reduction in visibility (i.e., where visibility was equal to or greater than 2200 yards), since the number of hours in this "no visibility reduction" category greatly exceeds the data in all the other categories. The total number of hours during this five month period was 3624 hours, thus at RH, for example, the number of hours of fog was 148.25, leaving nearly 3500 hours during this same time period where no fog was present. In the visibility range below 330 yards, only 81.5 hours of fog were observed at RH over the five month study period. Thus fog was present only 2.2% of the time during this period. Fog was present only 1.6% and 0.4% of the time at EC and WC, respectively, during the study period.

Table 4 and Figure 4 both indicate that visibility distance is significantly reduced for the greatest number of hours at RH, followed by EC generally with half to three-quarters as many hours of fog as RH. There were few hours of reduced visibility in the smallest distance categories at the WC site.

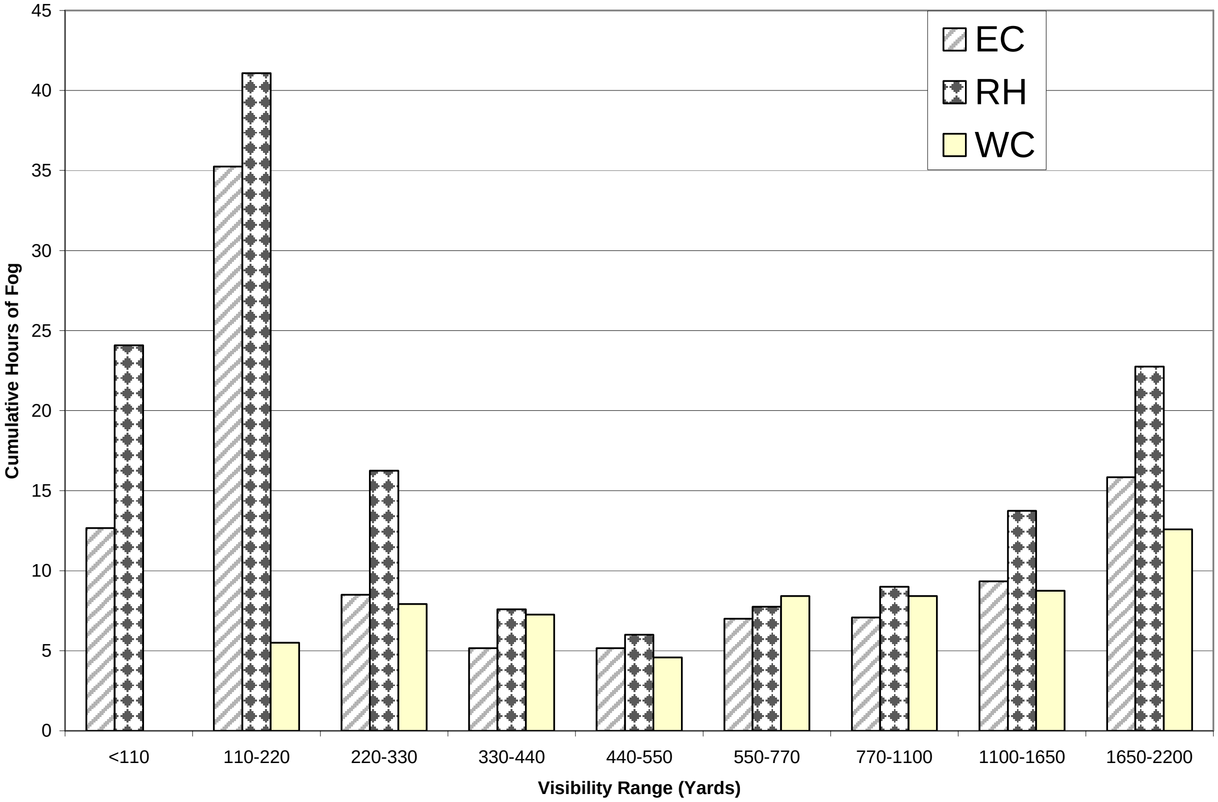

Figure 4. Number of hours of fog at each site in different ranges of visibility distance, for the period January through May 2005. Regarding drivability, only those ranges less than 330 yards are significant. This chart does not include hours for which no reduction in visibility was detected (i.e., when visibility distance was reported as 2200 yards).

It is important to note the particular locations where fog is more severe. RH exhibits the worst fog. It is a highland site, in the southern portion of the study site, for which the dominant air flow moves around the southern end of Paradise Ridge. From East to West across the width of the southern third of the study area, the topography is such that any selected roadway alternative must exceed a minimum elevation of 2920 feet amsl. The RH measurement site at 2990 feet amsl is representative of the conditions that any selected roadway alternative must traverse. Thus, all possible alternatives will traverse the portion of the study area in which fog is most severe; no alternative can avoid this. Accordingly, it is useful to distribute the fog by the fraction of road in each of the climate regimes for the eastern and western corridor, as was done for precipitation in Table 3 using the distance fractions from Table 2. These results are presented in Table 5.

Table 4. Number of hours of fog at each site in different ranges of visibility distance, for the period January through May 2005. Note that the ranges used in the table for visibility distances greater than 550 yards occupy larger increments than for the smaller visibility distances.

Range (yards)	RH	EC	WC
11-<110	24.1	12.7	0.0
110-<220	41.1	35.3	5.5
220-<330	16.3	8.5	7.9
330-<440	7.6	5.1	7.3
440-<550	6.0	5.2	4.6
550-<770	7.8	7.0	8.4
770-<1100	9.0	7.1	8.4
1100-<1650	13.8	9.3	8.8
1650-<2200	22.8	15.8	12.6
2200+	3401.4	3447.3	3490.0
11-<330	81.4	56.4	13.4
Total Fog Hours	148.3	106.0	63.4
Total Hours in Period	3624.0	3624.0	3624.0

Table 5. Cumulative Number of hours with visibility reduced below 330 yards from January through May in Aggregated Western Corridor and Aggregated Eastern Corridor.

Aggregated Corridor	Hours
AWC	48.7
AEC	69.0

Air Temperature

Air temperature is a concern in terms of its potential to cause icing of roadways, and because of its potential to cause precipitation to fall as snow or other frozen precipitation. In our analysis we consider the occurrence of freezing air temperatures alone, and the combination of freezing temperatures together with relative humidity values equal to 100%, which are indicative of frost and therefore produce slippery road surfaces.

Freezing air temperatures do not provide a perfect assessment of freezing surface conditions. Greater accuracy could be obtained with either some measure of the surface skin temperature, or by means of a complete surface energy balance. However, these other measures are not perfect either, since they would provide spot measurements, and surface temperature exhibits a great deal of spatial variability. Furthermore, pavement possesses different thermal and radiative properties than vegetation or soil, and no pavement was present at any of the measurement sites. At night, there is generally a net radiative energy loss from ground surfaces, which causes the ground to be colder than the air above it; the opposite is true during the daytime when the sun is shining on the ground. Usually relative humidity values of 100% occur either at night or under cloudy conditions, which eliminate or reduces the heating of the ground surface. Therefore, freezing air temperatures provide a conservative representation of frozen ground conditions, meaning that freezing air temperatures will not overestimate the occurrence of frozen ground.

The relationship among the air temperatures at the three study sites usually exhibited one of two characteristics. In one generalization, the air temperatures at the three sites tracked each other fairly closely. With this scenario, WC was usually the warmest by a couple of degrees Fahrenheit, owing to the 300 foot elevation difference, but not always. Figures 5a, b, and c show samples of this scenario measured in January, March and May, 2005.

The second general temperature characteristic occurred as a result of cold air drainage to low elevation valley sites, and resulted in the air temperature at WC dropping precipitously below that of the two highland sites, EC and RH, and the development of an atmospheric temperature inversion. This occurred when calm, stable atmospheric conditions existed. The longest period, wherein this phenomenon occurred almost nightly, ran from February 7 through March 16. There were also occurrences of this phenomenon of shorter duration in each of the other months within the study period. Figure 6 provides examples of this phenomenon. Frequently during the February through March event, the temperature in degrees Fahrenheit at WC dropped into the upper teens or low twenties, while remaining in the thirties at the other two sites, regularly producing at least a 15 degree Fahrenheit difference between WC and the other sites.

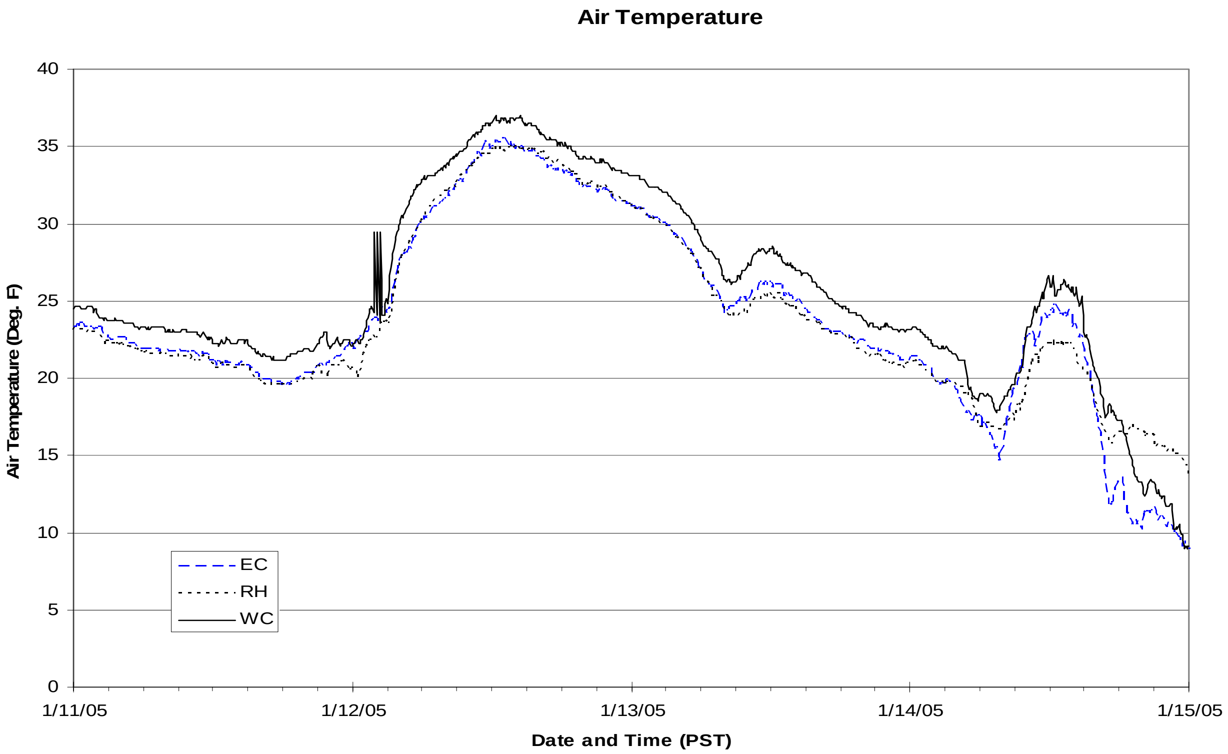

Figure 5a. Simultaneous air temperature measurements at the three study sites showing close tracking of one another.

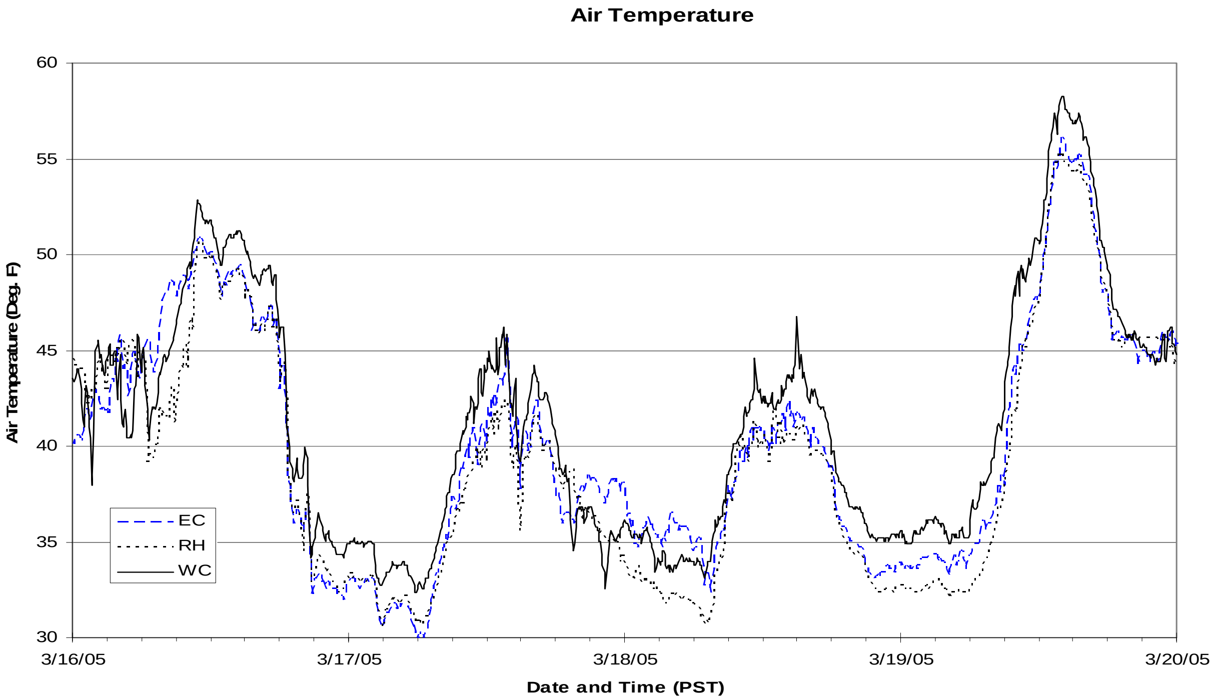

Figure 5b. Simultaneous air temperature measurements at the three study sites showing close tracking of one another.

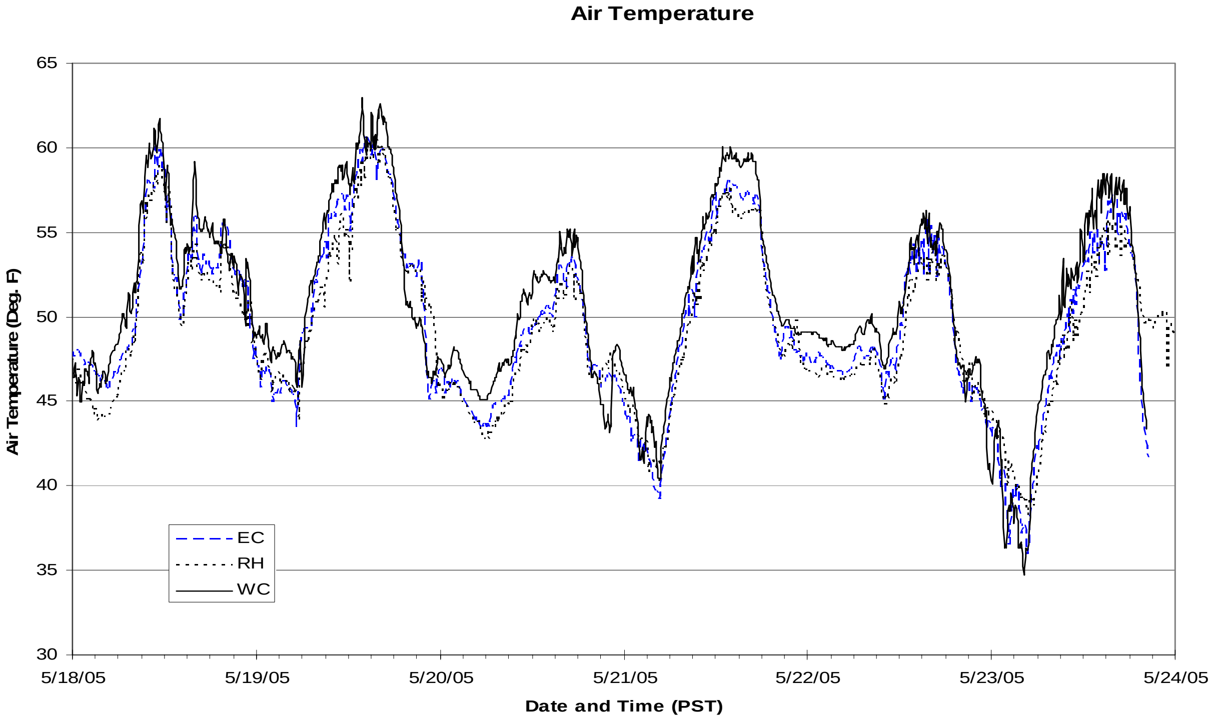

Figure 5c. Simultaneous air temperature measurements at the three study sites showing close tracking of one another.

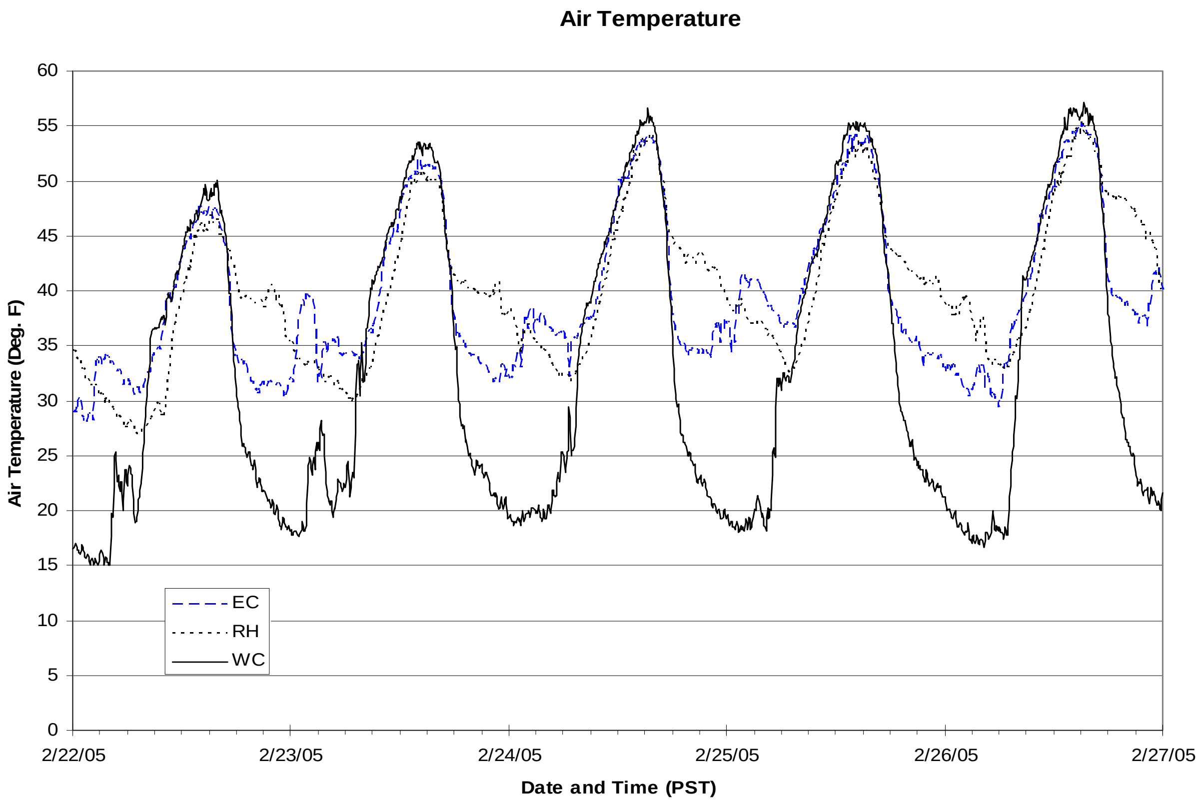

Figure 6. Examples of cold air drainage resulting in precipitous temperature drops at the lowland WC site (solid black line) compared to the other two sites, EC and RH.

In order to assess the relative severity of freezing temperatures at the three sites, we have tabulated the number of hours each month during which temperatures resided below 32 °F at each of the three sites and present the results in Figure 7. The figure shows that all three sites have similar numbers of hours of freezing temperatures in January, and in this particular year, approximately 50% of the time during the month temperatures were below freezing. Not shown is the fact that temperatures at all three sites remained below freezing almost continuously for the first half of the month, and then rose above freezing on January 17th and remained above freezing both day and night until the end of the month. The importance of the similarity in number of hours of freezing temperatures in January among the three sites is that it illustrates that *during stormy winter conditions*, one can expect similar durations of freezing temperatures across the study area.

In February, March and April, the lowland WC site clearly exhibits a larger number of hours of freezing temperatures compared to the highland sites, EC and RH. Although one cannot tell on the basis of Figure 7, Figure 6 shows that not only does WC have a greater number of hours of freezing temperatures, but the temperatures are much colder at WC than at the other two sites.

As noted earlier, the primary concern with freezing temperatures relates to icing of roadways. In this regard, freezing of dry, bare roadways does not pose a problem. Instead, the concern is with freezing of wet roadways. One of the ways that this occurs is from condensation of saturated air, which forms frost at sub-freezing temperatures. In the absence of sensors to detect frost directly, we rely on the combination of sub-freezing temperatures and relative humidity values equal to 100%.

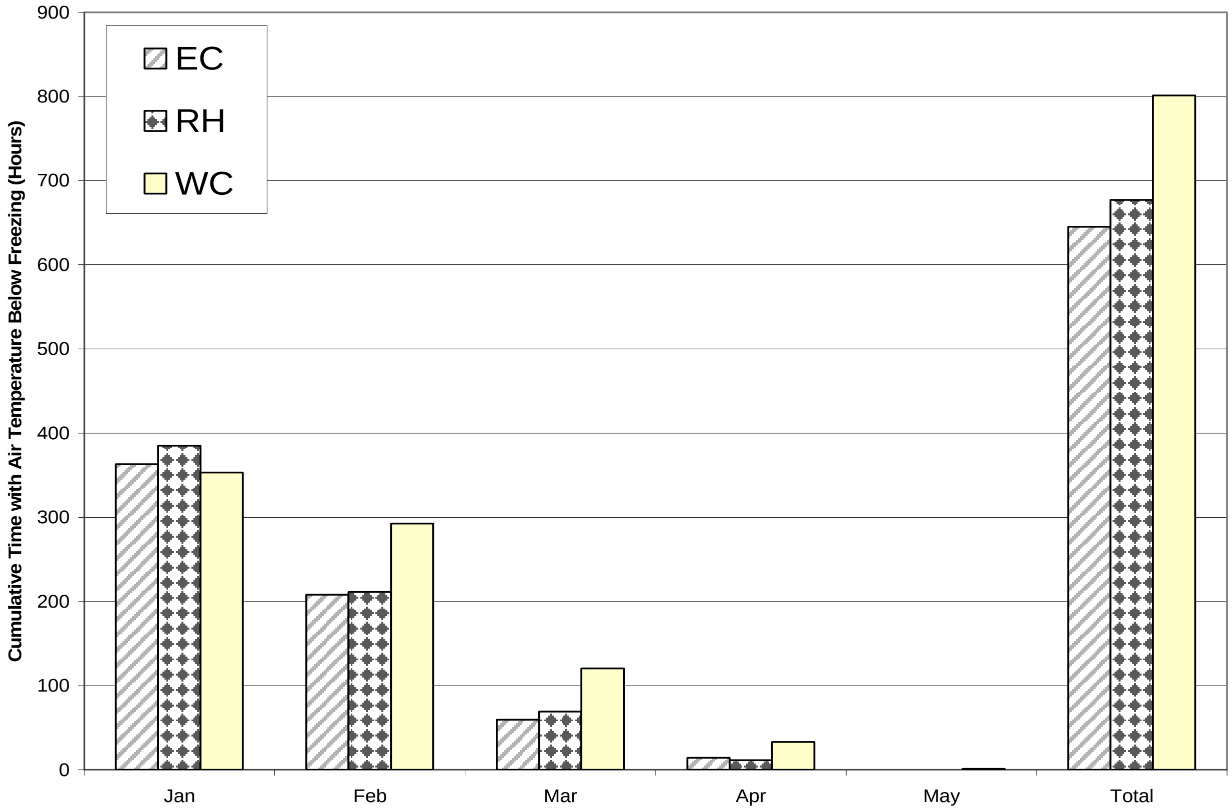

Figure 7. Number of hours per month during which air temperatures resided below 32 °F at each of the three sites.

Figure 8 is similar to figure 7 except that it presents the number of hours during which there was the simultaneous occurrence of sub-freezing temperatures and relative humidity values of 100%. This is indicative of the number of hours during which frost would be forming. In reality, frost could persist even after relative humidity rose above 100%, but in the absence of a good way to detect how long this might occur, we simply report the time where there is the potential for formation to occur.

Looking at Figure 8, one sees that in January, the most severe frost site was RH with 158 hours, and the least severe was EC with only 69 hours. WC lay near the midpoint between these two with 109.5 hours. In February, the only site with a measurable duration of frost conditions was WC. Despite the dry conditions of the month, the temperatures dropped so low, often into the upper teens or lower 20's as shown in Figure 6, that the dewpoint temperature was reached, forcing condensation in the form of frost due to the cold temperatures. The other sites lacked condensation because of their much warmer temperatures. Furthermore, the temperatures at EC and RH seldom dipped below freezing anyway, so that any condensation formed would likely have produced dew rather than frost.

All three sites exhibit similar durations of frost conditions in March, April shows only frost at WC again, and negligible frost conditions existed in May. Because of the dominance of frost conditions in January, RH has the highest total number of frost condition hours, followed closely by WC, whereas EC exhibits less than half the total duration of frost conditions as the other two sites. Thus with regard to frost conditions, the southern portion of the study area has the most severe conditions, and as with fog, all potential road alignments must traverse these conditions. A close second with regard to total number of hours with frost conditions is the WC site, thus any western corridor roadway alignments would be subject to these frost conditions. Furthermore, as documented earlier in this report, temperatures in the western corridor, were often much colder than in either of the other two climate regimes of the study area, providing the opportunity for much harder frosts in the western corridor than elsewhere.

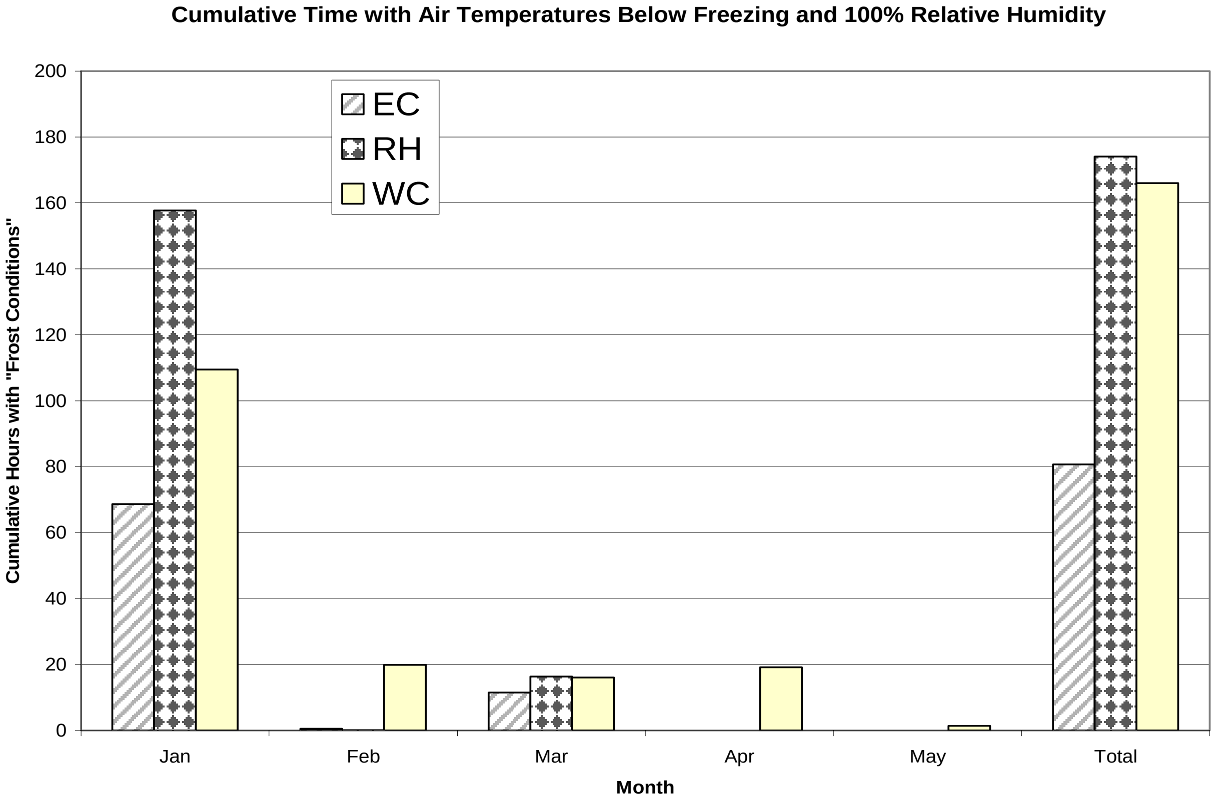

Figure 8. Number of hours per month during which air temperatures resided below 32 °F and relative humidity was at 100% at each of the three sites.

In order to consider how these frost conditions would impact roadway alignments within the eastern and western corridors, we distribute the hours according to road distances within each climate regime, as done for both precipitation and reduced visibility in Tables B and C. The results are presented in Table 6.

Table 6. Cumulative hours January through May with air temperature below freezing and 100% relative humidity (i.e., Road Ice Conditions).

Aggregated Corridor	Hours
AWC	157.5
AEC	127.5

Snow

There was insufficient snow during the study period to present a report on this variable.

HISTORICAL ANALYSIS

The data collected during the measurement period used in this study corresponded to a time period of relative drought. In this report, we are principally comparing the three sites with each other providing relative magnitudes of the different variables, rather than trying to specify mean absolute quantities at each site. Nevertheless, it is helpful to have a description of how the current measurement period relates to historical data in the region in order to have a rough idea of the magnitude of some of the variables that one might anticipate in an “average” or “normal” year. The following historical analysis relates to data collected at the University of Idaho Plant Sciences Farm Cooperative Observer climate station which has daily data nearly continuously back to February of 1893. As is the standard climatological practice, I present results based on the 30-year period from 1971-2000, and in some cases, 1971-present.

Historical Precipitation

The average annual precipitation over the period from 1971-2004 was 27.12 inches. In 2004, 24.65 inches fell, and over the twelve months leading up to and including May 2005, there was 23.25 inches of precipitation.

To provide an idea of the persistency of the current drought in Moscow, the Standardized Precipitation Index, SPI, is shown in Figure 9. This index was developed by the Colorado State Climatologist (http://ccc.atmos.colostate.edu/standardizedprecipitation.php) and provides a measure of how the previous 48 months’ cumulative precipitation compares to the average precipitation over a specified time period, which I am taking over the climatological “normal” period of 1971-2000, and extending it forward to the present. The 48 months, and total range of time period are user definable, but 48 months is sufficiently long to demonstrate persistence of a wet or dry period, but not so long as to average out the variability. Although this is somewhat of a simplification, the value of the index can be thought of as the number of standard deviations that the previous 48 months’ average annual precipitation, incrementing forward one month at a time, was above or below the mean annual precipitation over the 34 years. Positive SPI values indicate the previous 48 months have been wetter than average, and negative values indicate the previous 48 months have been drier.

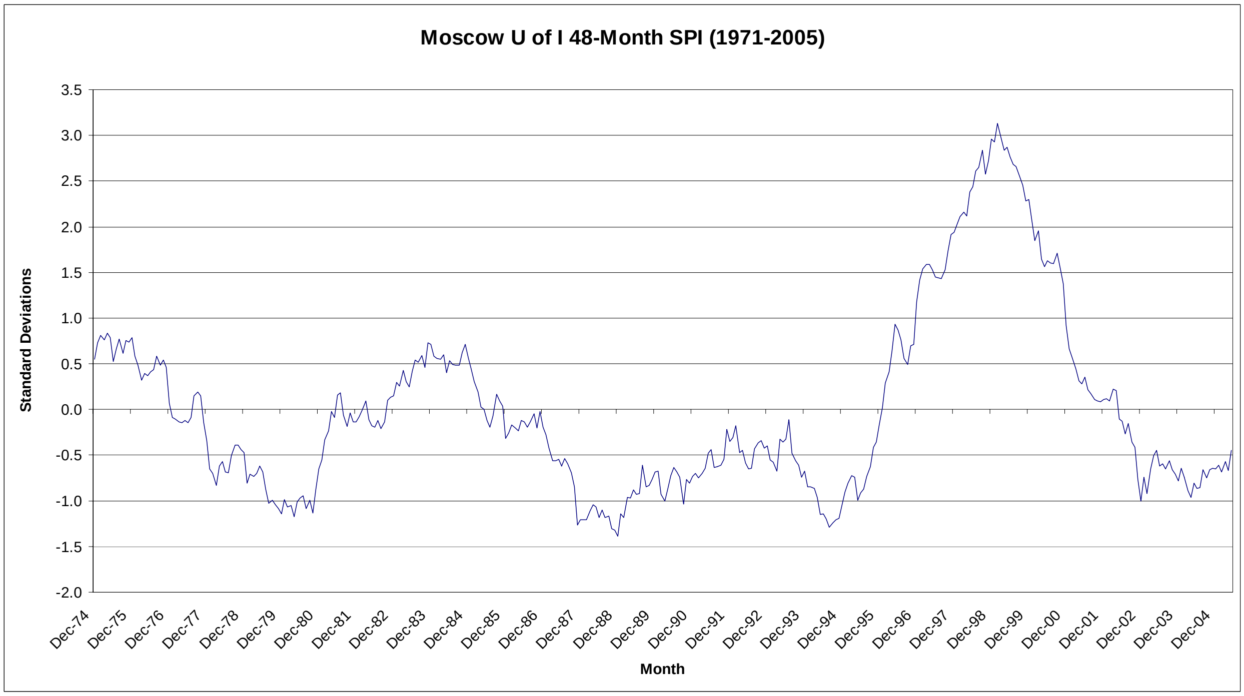

Figure 9. Standardized Precipitation Index for Moscow, Idaho, from data running from 1971-May 2005

The January through May 2005 range of the SPI is -0.681 to -0.446, meaning that over the 48 months preceding the first five months of 2005, cumulative 48 month precipitation has been about 0.5 standard deviations below the average cumulative 48 months precipitation over the period 1971-2005. There is an upward trend in the SPI value since April 2004, which means that the drought has lessened over the past year, compared to what it was like 48 months earlier. Also, the current drought is neither as severe as the drought of 1978-1980, nor as severe nor long lasting as the drought of 1987-1995, although until the drought ends a final comparison between this and earlier droughts cannot be made.

Despite the fact that the study site is presently in the midst of an extended drought, we can use the historical data from PSF together with current data from PSF and the three study sites in order to synthesize information about the typical or normal precipitation at the study sites. Figure 10 shows a scatter plot of PSF precipitation versus precipitation from each of the study sites paired by month of occurrence. There is a clear trend between the precipitation at each of the study sites and precipitation at PSF. Even though the data come from different months (e.g., each of the diamond symbols corresponds to a different month than each of the other diamond symbols), they provide a measure of the magnitude of precipitation at each of the study sites corresponding to a specified depth of monthly precipitation at PSF.

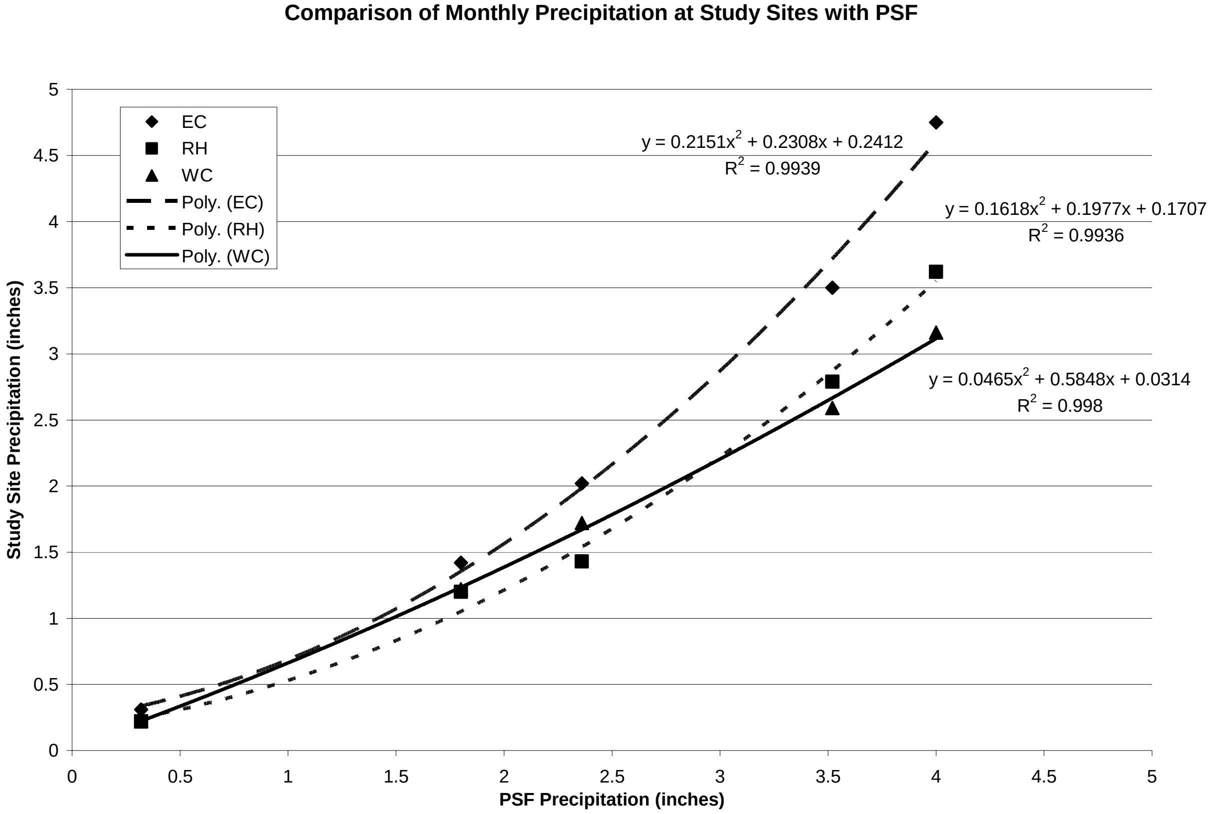

Figure 10. Monthly precipitation at each of the three study sites paired against precipitation depth at PSF for each of the corresponding months, January through May 2005 (symbols). The lines are polynomials fitted to the data from each of the study sites versus PSF. The fitted polynomial equations are shown next to their corresponding lines, as are the R-Squared values.

The trend between PSF and the study site precipitation depths is useful in order to estimate the mean or climatological normal monthly precipitation at each of the study sites. To illustrate how this may be done, consider that the January, 30-year normal precipitation at PSF is 2.95 inches, as shown in Table 1 presented earlier. If one was to fit a curve to the trend between PSF and EC in Figure 10, the value at EC corresponding to a PSF precipitation depth of 2.95 inches would be about 2.79 inches, as indicated by the long-dashed line corresponding to the diamond symbols. Since 2.79 inches precipitation at EC corresponds to 2.95 inches precipitation at PSF, we estimate the 30-year normal January precipitation depth at EC is 2.79 inches. Similarly, the January, 30-year normal precipitation at WC is estimated to be 2.16 inches, based on the solid, dark line in Figure 10. To assist in estimating 30-year normal precipitation values at each of the study sites, we have fitted 2nd order polynomials to the data to allow us to interpolate between data points. Each of the polynomials shown in figure 10 has an R-Squared value greater than 0.99 with respect to the measured data. Using these polynomials, we estimated 30-year normal monthly precipitation values for each of the study sites for October through May. These estimates are presented in Table 7. We could easily estimate values for the full year, but consider the October through May values to be most relevant with respect to impact on driving conditions. Furthermore, the fitted polynomials are based on only five months worth of data at each of the study sites. We anticipate continuing measurements at each of the study sites through the 2005-2006 fall, winter and spring, in order to increase the robustness of the curves.

Table 7. Estimated 30-year monthly normal precipitation for each of the study sites, presented together with the 30-year normal precipitation from PSF determined from the long-term climatological records at PSF. The last two rows give the total estimated normal precipitation over the eight month period, and the percentage that this total occupies of the total at PSF over the same eight month period. All values except percentages given in inches.

Month	PSF	EC	RH	WC
October	2.04	1.61	1.25	1.42
November	3.53	3.74	2.88	2.68
December	3.17	3.13	2.42	2.35
January	2.95	2.79	2.16	2.16
February	2.62	2.32	1.80	1.88
March	2.56	2.24	1.74	1.83
April	2.44	2.08	1.62	1.74
May	2.64	2.35	1.82	1.90
Total	21.95	20.27	15.69	15.96
% of PSF	100	92.3	71.5	72.7

There are several observations worth making about Figure 10 and Table 7. If one was to sketch the 1:1 line on Figure 10 (i.e., the line through the origin and point 5,5), all the data points in the figure except for the two points corresponding to EC where its precipitation is greater than 3.5 inches, would lie below the line. That is, all three study sites have precipitation less than the precipitation measured at PSF except for precipitation measured at EC when it exceeds 3.5 inches. Since the climatological normal precipitation at PSF only exceeds 3.5 inches in November, and then only barely, we anticipate that all monthly climatological normal precipitation values at the study sites should be below the corresponding monthly value at PSF, with the possible exception of November at EC. As a result, each of the study sites has an eight month normal precipitation less than that of PSF. This does not mean that none of the study sites can ever have monthly precipitation larger than that observed at PSF; in fact in May 2005, measured precipitation at EC of 4.75 inches exceeded May 2005 measured precipitation at PSF of 4.0 inches. However, statistical analyses show that PSF May precipitation only equals or exceeds 3.5 inches about 20% of the time, or about one year out of every five, therefore we anticipate that precipitation at EC should exceed that at PSF only about one year in five.

One may also draw conclusions about the RH site, based on the trendline between PSF and RH. Although no data was measured at RH which exceeded that of PSF, extrapolation of the trendline indicates that precipitation at RH would equal or exceed that of PSF for precipitation at PSF of about 4.3 inches. Statistical analysis indicates that this could be expected to occur in January about once every six years.

To summarize the historical precipitation analysis, measurements at PSF and the three study sites from January through May 2005 show clear relationships or trends between monthly precipitation depths at PSF and the study sites. These trends allow us to generate polynomials which simulate monthly precipitation depths at each of the study sites given the depth of precipitation at PSF. The R-Squared value for each of these trendlines is high, however the trendlines were developed from only five data points at each site. Additional measurements in the coming fall/winter/spring would reduce uncertainty in each of these trendlines.

Based on a combination of information from these trendlines and statistics of the historical data at PSF, we may conclude that on average, the precipitation at each of the three study sites is less than or equal to the precipitation at PSF with the possible exception of November precipitation at EC, which on average is only slightly higher than that at PSF. Thus, for the most part, precipitation and particularly snow, should be anticipated to be no worse than that found on Highway 8 between Moscow and Troy Idaho in the vicinity of the Plant Sciences Farm.

Historical Temperature Analysis

We have already described a current analysis of temperature at the three study sites, which indicates that RH has the most hours of temperature below freezing, followed relatively closely by WC. EC has significantly fewer hours of frozen temperature than either RH or WC. In addition, the lowland location of WC causes it to be subject to relatively frequent cold air drainage, and therefore much colder temperatures than either RH or EC. A multi-year study by Day (1968) of an East-West transect, running from the Snake River, up the South Fork of the Palouse River, approximately one mile north of the WC site, and then continuing eastward to the Clearwater Mountains across a number of hills and valleys, showed a similar temperature phenomenon as that found in this study. Namely, that low lying sites in drainage valleys such as the WC site exhibit severe drops in temperature, which are not found on highland sites. This concurs with our measurements and analysis that indicate the WC site exhibits the most severe cold within the study region. By extension, one can assume that even though these types of sites receive less precipitation, that snow that does fall in these low-lying areas would tend to persist longer.

Conclusions

Three sites within the U.S. Highway 95 realignment study area have been instrumented with weather sensors, and the data has been analyzed in order to provide a comparison of the three main climate types within the study area. These three sites represent “lowland, air flow over ridge” (LFO) in the Western Corridor (WC), “highland, air flow over ridge” (HFO) in the Eastern Corridor (EC), and “highland, air flow around ridge” (HFA) at Reisenauer Hill (RH) across the southern third of the study area. Measurements began at the beginning of January, 2005, and are ongoing, but the analysis was carried out over the months of January through May 2005. In order to augment this limited measurement and analysis period, data from a nearby long-term site at the University of Idaho Plant Sciences Farm (PSF) have been used. Historical measurements at PSF are used to establish the climatological normal conditions in the region, and determine how the current measurements compare to the local climatological norm. The principal variables addressed in this study and discussed in this report have been precipitation, fog and air temperature. The most significant findings of this report are summarized below:

- Monthly total precipitation at all three study sites is strongly correlated with that at PSF, and is generally lower than that measured at PSF, except at EC in months with an unusually large amount of precipitation. This is true both for the measurements during the study period, as well as for the climatological normal precipitation determined for each site compared to the climatological normal precipitation from PSF. The implication of this is that the precipitation in the study area is generally no more significant than on the existing U.S. Highway 8 between Moscow and Troy, Idaho near the Plant Sciences Farm.
- Among the three study sites, the largest amount of precipitation fell at EC, and approximately three-quarters of the amount measured at EC fell at each of the other two sites, WC and RH.
- Fog with visibility reduced below 330 yards, occurred for the greatest number of hours at RH. About half as many hours of fog in the most dense category (visibility < 110 yards) occurred at EC as at RH, and no fog in this category was observed this year at WC. In the second most dense category, 110-220 yards, EC experienced about 85% as many hours as RH, whereas WC experienced only 13% as many hours as RH. In the 220-330 yard category, both EC and WC experienced about 50% as many hours of fog as RH. Even at the worst site, RH, only 81.5 hours of fog were observed during the five month study period, which represents only 2.2% of the total time during this period. At EC and WC, fog was present only 1.6% and 0.4% of the time during the study period, respectively.
- Subfreezing temperatures coupled with 100% relative humidity, which is indicative of frost deposition, occurred for approximately the same number of hours at WC and RH. This combination of conditions occurred for less than half as many hours at EC.
- The coldest temperatures occurred at WC as a result of cold air drainage which produced marked temperature inversions. These conditions caused the temperature at WC to drop precipitously below that of EC and RH, often by as much as 15 °F. This phenomenon can cause icy road conditions to persist much longer at WC than at either EC or RH.

SUMMARY BY CORRIDOR

An alternate way to consider these results is to describe the climate characteristics of each corridor.

Western Corridor

The Western Corridor includes potential alignments W-1, W-2, W-3, and W-4 from the ITD July 2005 Preliminary Alignment Maps. All of these western alignments traverse both the HFA and the LFO climate regimes of the study area. Note that all possible alternative alignments, whether in the West, East, or Central corridors must traverse the HFA climate regime which lies across the entire southern third of the study area. Where the western alignments traverse the LFO region, particularly north of Eid Road through the drainage valley adjacent to and surrounding Snow Road, all western alignments would be subject to the LFO climate. The climate characteristics of the Western Corridor, including both the LFO and HFA areas, are summarized below. Items denoted by an asterisk (*) correspond to climate in the HFA regime, which is common to all possible alternatives.

- The coldest temperatures of the region occurred in the lowland LFO area, often reaching 15°F colder than the highland areas during times of cold air drainage.
- The most severe frost/icy road conditions existed in the lowland, LFO areas.
- Relatively uniform precipitation depths occurred along the entire western corridor (in both LFO and HFA portions), which equaled approximately three quarters of the precipitation which occurred in the HFO region of the eastern corridor.
- Fewer hours of dense fog, in the <110 yard, 110-220 yard, and the 220-330 yard visibility ranges occurred in the lowland areas, but the worst fog* of the study area, common to all alternatives, occurred in the southern HFA region.

Eastern Corridor

The Eastern Corridor includes potential alignments E-1, E-2, and E-3 from the ITD July 2005 Preliminary Alignment Maps. All of these eastern alignments traverse both the HFA and the HFO climate regimes of the study area, thus the entire length of the alignments lie on highland areas. As noted above, all possible alternative alignments, whether in the West, East, or Central corridors must traverse the HFA climate regime which lies across the entire southern third of the study area. Where the eastern alignments traverse the HFO region, approximately from Eid road, going north until the alternative alignments come down off the plateau, near where they rejoin the existing U.S. 95, the climate characteristics would be that of the HFO region. South of Eid Road, the characteristics of the Eastern Corridor correspond to the HFA climate, shared by all alternatives. Items denoted by an asterisk (*) correspond to climate in the HFA regime, which is common to all possible alternatives.

- Similar temperatures to most of the study area, except much warmer, often by 15°F, than the lowland areas during cold air drainage.
- Less severe frost/icy roads occur in the highland areas than lowland areas.
- The greatest amount of precipitation of the study area occurs in the HFO (northern) portion of the Eastern Corridor. The precipitation in adjacent areas, including the southern portion of the Eastern Corridor, is approximately three-quarters of the precipitation in the HFO area.
- The HFO (northern) portion of the Eastern Corridor is subject to fewer hours of fog than the HFA (southern) portion of the Eastern Corridor, where fog is the worst*. Fog is

worse in the HFO portion of the Eastern Corridor than in the LFO portion of the Western Corridor.

Central Corridor

The Central Corridor includes potential alignments C-1, C-2, and C-3. Alignments C-1 and C-2 can be described by the same characteristics given for the Western Corridor above. Alignment C-3 is described better by the climate description of the Eastern Corridor given above.

Final Summary

Each of the three study sites within the study area has particular climatological elements that are worse with respect to the impact on driving than at the other two study sites; Precipitation is worse at EC than at WC or RH, although not worse than at PSF, located near U.S. Highway 8; Fog is the worst at RH, and Temperature/Frost is the worst at WC. Furthermore, any road alternative selected for the Highway 95 realignment project will traverse the southern portion of the study area, for which RH is uniformly representative. Thus, the worst fog conditions of the study area will confront any selected road alternative. As a result, the most important areas to compare are the East Corridor and the West Corridor. In this comparison, each of the sites has climatological variables for which it exhibits more severe conditions than the other. As noted above, the West Corridor is subject to more extreme cold temperatures, leading to greater exposure to frost and icy road conditions. The Eastern Corridor is subject to heavier precipitation. The general conclusion that may be drawn from this is that each corridor has some climate characteristics that are worse, and some that are better than the adjacent corridor, suggesting that climate should not be the dominant factor used in selecting one alternative over another. Furthermore, given that there are roads in the region such as Idaho Highway 8 going past the University of Idaho Plant Sciences Farm which experience climate conditions worse than those found in the study area, none of the alternatives should be excluded solely on the basis of climate.

Reference

Day, R. L., A microclimatic profile between the Snake River Canyon and Clearwater Mountains, Idaho, Research Technical Completion Report, Project A-012-Ida, Water Resources Research Institute, University of Idaho, Moscow, Idaho, September, 1968.

Appendix A

Instrumentation

1. Solar Radiation ---- Kipp & Zonen QMS 101 SP *LITE* Pyranometer.

   http://www.kippzonen.com/pages/6/3/Pyranometers

2. Wind Speed & Direction ---- Vaisala WMS301 Combined Wind Sensors.

   http://www.vaisala.com/businessareas/instruments/products/wind/wm30

3. Temperature & Humidity ---- Vaisala HMP45D Humidity and temperature probe.

   http://www.vaisala.com/businessareas/solutions/roadandrailweather/products/roadandrailatmosphericinstruments/hmp45dhumidityprobe

4. Snow Depth ---- Campbell Scientific, Inc. SR50-L Ultrasonic Distance Sensor.

   http://www.campbellsci.com/sr50-l The snow depth sensor emits an inaudible sound pulse that bounces off the surface below the sensor and reflected back to the instrument. The travel time of the signal is used to measure the distance to the surface below the sensor. This distance can be subtracted from the distance between the sensor and the ground surface to calculate snow depth.

5. Precipitation and Visibility ---- Vaisala PWD12 Present Weather Detector.

   http://www.vaisala.com/businessareas/solutions/hydromet/products/sensors/sensorsformaws/presentweather/pwd Precipitation and fog were measured with a Vaisala Present Weather Detector (PWD12), which is a forward-scattering light sensor. The instrument emits light into a “detector volume” of air between its transmitter and its receiver. The direction of the beam of light is angled slightly off the axis between the transmitter and receiver. Under clear conditions, the beam of light passes through the detector volume unscattered and nothing is detected by the receiver. When water droplets from rain, snow, fog, etc., are present in the detection volume, light is scattered into the receiver. Signal processing algorithms distinguish between fog and precipitation, and together with ancillary measurements on the PWD12, the instrument distinguishes between different forms of precipitation. Output includes visibility distance (33 feet to 6560 feet) due to obstructions by fog or other particulate matter, precipitation type (slight, moderate, or heavy rain, snow, or frozen precipitation), intensity (in/hr, mm/hr), and liquid water depth accumulation (inches, mm).

6. Validation Raingage at WC---- Campbell Scientific, Inc. TE525WS-L Tipping Bucket Rain Gage. http://www.campbellsci.com/te525ws-l