Weather Forecasting Strategies for City and County Road Maintenance Operations

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This report describes the impacts of weather on roadway maintenance activities, with a focus on cities and counties, as obtained from interviews with road maintenance supervisors. The report further describes weather information technologies currently being used or investigated for use to reduce the impact of weather on maintenance activities and to reduce the costs of those activities. Recommendations presented include: implementing road weather information systems through interjurisdictional and interagency cooperation through the development of a regional staff weather advisory function; instituting a multi-agency weather "interest group"; documenting the societal benefits and costs of snow and ice control maintenance; developing guidelines for contracting for road weather information systems; and testing the utility to road maintenance organizations of a weather radar at Seattle-Tacoma International Airport.

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WEATHER FORECASTING STRATEGIES

FOR CITY AND COUNTY

ROAD MAINTENANCE OPERATIONS

by

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WEATHER FORECASTING STRATEGIES FOR CITY AND COUNTY ROAD MAINTENANCE OPERATIONS

SUMMARY

Many roadway maintenance activities are impacted by weather. These activities range from snow and ice control activities to paving operations; from vegetation control to painting and striping. Many maintenance decision makers are certainly aware of the impact the weather has on their activities. Very few, however, realize that certain critical values of certain parameters, or that specific weather events trigger action on their part. Nearly every decision maker has his or her own strategy to deal with the impact of the weather.

The Washington State Department of Transportation (WSDOT), in coordination with the Research Committee of the Washington State Association of County Engineers, initiated this research to determine the impacts of weather on city and county roadway maintenance activities. In 1987, the WSDOT contracted for a study to look at methods of reducing the impact of weather on state highway snow and ice control activities. This research highlighted weather information technologies and strategies that could be used to reduce the cost of snow and ice control. The research also pointed out that similar savings might be possible for cites and counties through the use of weather technologies, and that savings might be possible for maintenance activities other that snow and ice control. This paper describes the results of the extension of the earlier WSDOT research to the cities and counties.

A survey of current practices by selected municipal and county maintenance agencies indicates that various strategies are employed by maintenance decision makers to deal with changes in the weather. Some of the strategies are strictly reactive, i.e., the weather is causing the cancellation of an activity or the need to do something else. The other end of the spectrum involves proactive strategies. A few managers make decisions based on forecasts of weather conditions. In general, however, there is no formal process to incorporate weather forecasts into the maintenance decision process.

The survey also indicated that relatively few decision makers are aware of currently available technology for obtaining weather information. In like manner, not recognizing the opportunity for using weather information to an advantage, few decision makers have investigated the possibility of obtaining weather forecasting services to aid in the decision process. On the other hand, in one area of the State of Washington, municipal and county (and Washington State Department of Transportation) roadway maintenance people have weather forecasts provided to them by a private company which recognized the benefit to its operations by providing such information to people responsible for snow and ice control on roadways which carry people to and from the work place.

Except for the direct contact afforded by the in-person interviews conducted as a result of this contract, city and county roadway maintenance people were generally unaware of the weather-related research activities being conducted by the WSDOT. They are also not aware, as is the case also with WSDOT people, that there are sources of weather information available that might be used to the collective advantage of maintenance people. Unfortunately, no single repository exists which contains information dealing with weather data sources, either from State or other agencies.

Direct costs for snow and ice control activities (labor, equipment, and materials) for the United States and Canada exceed $2 billion; it is estimated that five to ten percent reductions in these costs might be possible through the use of weather information.[2] A five percent reduction in this figure means over $100 million could be available for other roadway maintenance. There are indications that savings are also possible for other roadway maintenance activities.

Finally, very little information is available on the indirect costs to the communities of snow and ice control activities. Highway vehicle flow data indicate significantly reduced volumes of traffic on snow-covered freeways. It is presumed the vehicle flow burden is then distributed among city- or county-maintained surface streets and roads. One hour of lost time due to reduced traffic flow can produce a large productivity loss for many employers, including the very local governments responsible for the roads. This suggests being prepared for and staying ahead of a snow or ice situation could help reduce both the direct costs of snow and ice control maintenance as well as the cost to the communities served.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Using weather information as part of the decision process in roadway maintenance organizations can save money and time through more timely, efficient, or prudent allocation of resources.

2. Few city and county roadway maintenance agencies use weather information to their advantage in making resource allocation and maintenance activity decisions.

3. At the resource allocation decision maker level, most supervisors are unaware of the research, testing, and evaluation efforts involving the use of weather information by roadway maintenance people. Indeed, few maintenance decision makers are aware of sources and the availability of weather information which could be of benefit in the decision process.

4. Even the handful of organizations which obtain weather forecasting services generally do not recognize that there is utility to using such services year around.

5. Weather service, tailored to the needs of city and county street and road maintenance organizations, can be implemented to improve the resource allocation decision processes, and save money which can be used to improve roads and streets. Such services can be acquired for far less cost than the savings to be realized.

RECOMMENDATIONS

1. The concept of regional Staff Weather Advisors (SWA) should be evaluated in Washington State to provide multi-jurisdictional "tailored" weather support. The evaluation of the SWA concept should be conducted in one climatological/geographical region for one year to evaluate its utility and to determine the level of effort required to provide the staff services.

2. The Washington State Department of Transportation should contact city and

county roadway maintenance personnel to seek their participation in the implementation of weather information and weather systems technology. The possible monetary savings to these agencies suggests that cost of implementation and the subsequent sharing of weather information should be borne by the participating agencies.

3. A study be initiated to determine the costs to society for snow and ice control activities. Governmental agencies, industry, and other appropriate and to-be-determined sources should be surveyed. The results of the investigation could be a basis for establishing cost-sharing of weather system technology, to include private funding in the realm of impact fees.

4. An evaluation should be conducted of the utility of weather radar data to city, county, and state road maintenance decision makers. The Port of Seattle at Seattle Tacoma Airport owns and operates an X-band, relatively short-wave, weather radar, which can detect light precipitation. The radar data can be provided to additional users with IBM-compatible PCs for the price of a telephone modem, telephone line charges, and the software required to format the images and to exchange the data.

5. A "guideline" should be prepared which describes suggested contracting procedures for acquiring weather equipment and/or services. Such a "guideline" would provide contractual boiler plate which would focus on the weather information needs of the maintenance organization and would allow tailoring of a request for proposal, for instance, to insure response by vendors to satisfy the stated needs. Such a guideline could also be used to establish evaluation criteria so that responders to a request for proposal would be evaluated for technical ability as well as for cost.

6. The WSDOT should take the lead to form and head and "interest group," similar to the Minnesota Weather Information Network (Mn/WIN). The group should be comprised of state, county and municipal agencies interested in the development of weather technologies to support all aspects of intra- and interagency use and sharing of weather information.

INTRODUCTION

RESEARCH OBJECTIVES

The objective of this study was to define ways to extend research efforts being conducted within the Washington State Department of Transportation on the use of weather technologies for roadway maintenance to city and county road maintenance agencies. In addition, the research was to seek other opportunities to use weather information to improve the management of roadway maintenance resources in activities impacted by weather. In order to achieve these objectives, the following tasks were accomplished:

1. A large quantity of literature was acquired and reviewed to both determine the impacts of weather on roadway maintenance activities and to define the state-of-the-art in weather technologies which can be used to assist in the resource allocation decisions in roadway maintenance organizations (previous research had focussed on snow and ice control activities);

2. In-person interviews were conducted with city and county roadway maintenance decision makers to determine the impacts of weather on roadway maintenance activities in Washington State, and to determine critical weather parameter thresholds which can be targets for tailored weather forecasts;

3. Information obtained from the literature review and the in-person interviews was analyzed to develop a matrix of weather impacts and maintenance activities as a basis for determining opportunities for using weather information to assist in resource allocation decisions, ultimately to reduce costs in roadway maintenance activities. The information was also used to determine areas where further research might lead to additional reductions in maintenance costs.

THE PROBLEM

Nearly all roadway maintenance activities are conducted out-of-doors where the weather can adversely affect the people performing the work, the quality and quantity of the work itself. The weather may also dictate what activities can or can't be performed, or may in fact be what causes the work to be done, as is the case with snow, ice, high winds, heavy rain, and severe temperatures.

Roadway maintenance activities overall are very expensive. According to 1987 Federal Highway Administration data [1], over $25 Billion were distributed in 1986 to roadways by municipalities, counties and townships. Over 40 percent, or over $10 Billion was spent on maintenance, namely for roads and bridges and for snow removal. The numbers in Washington State are similarly high. Washington's municipalities and counties spent over $548 Million on their roads, although only slightly over 34 percent, or $186 Million, went toward maintenance.

Weather impacts have typically been attributed primarily to winter. Consequently, the interest in reducing costs frequently centers on the cost of snow and ice control. For instance, nationwide, the costs for snow removal by cities, counties and municipalities in 1986 was over $700 Million. In Washington State, the cost was just over $9 Million, or about 5 percent of the maintenance costs (the figure was just under 7 percent for the nation).

The interest in reducing costs for snow and ice control is primarily associated with the notion that most of the money spent for snow and ice control is not available for other maintenance activities. In other words, no constructive roadway maintenance is being performed with that money, even though there may be societal benefits derived from performing snow-or-ice control activities. However, opportunities may also exist to save money from other maintenance activities through improved management decision making. That improvement could result in reduced costs from less wasted effort and materials for weather impacted procedures.

Too often, maintenance managers recognize that the weather has an impact on their activities, but make decisions that are a result of, or reactive, to the weather. Very few such managers make decisions proactively by using weather information, in particular weather forecasts, to their advantage. Having knowledge about what the weather will be can be extremely valuable information.

The Research Committee of the Washington State Association of County Engineers (WSACE) recognized that there may be utility in the use of weather information to assist road maintenance decision makers. With the approval of the Research Committee, the WSDOT Research Office contracted with the Matrix Management Group to investigate opportunities for reducing costs for all city and county road maintenance activities, not just snow and ice control, through the use of such weather information in the resource allocation decision process. A copy of the agreed-to scope of work is included at Appendix I.

The Committee's objective was to identify innovative practices to reduce costs and to improve the efficiency city and county road maintenance organizations. Opportunities found as a result of this project are documented in this report. The project has defined procedures or philosophies which can be implemented immediately, as well as provided recommendations for further study.

REVIEW OF CURRENT PRACTICE

OVERVIEW

This section summarizes the results of the literature search and in-person interviews with city and county road maintenance people. The purpose of the literature search was to determine what weather impacts on roadway maintenance activities have been reported and/or documented, and what decision processes and maintenance practices are employed to deal with the impacts. In addition, the search was used to determine the state-of-the-art in this country, as well as others, of the use of weather information to assist decision makers in their allocation of resources.

Interviews were conducted with city and county road maintenance people in order to:

- document the impact of weather on their maintenance activities in the State of Washington;
- document the critical weather-related thresholds for decision making;
- determine their knowledge of or working relations with WSDOT weather research activities;
- document roadway maintenance practices of the cities and counties; and
- find opportunities for implementing the use of weather information into the resource allocation decision processes.

Interviews were also conducted with non-roadway maintenance people as information obtained in the above interview process or the literature review pointed to availability and use of weather equipment and information in Washington State.

A literature review was conducted to determine the impact of weather on roadway maintenance activities, to identify technologies available to reduce those impacts, and to discover and document sources of weather technologies. The review consisted of reading trade periodicals and professional journals. In addition, pertinent reports were identified using automated searches through the University of Washington Libraries and, especially, the Washington State Department of Transportation Library. Most of the discussions and descriptions of weather impacts on roadway maintenance activities center on winter weather, namely snow and ice. This is understandable considering the large amount of money spent nationwide each year on winter maintenance for materials and equipment, as well as labor costs.

WEATHER INFORMATION TECHNOLOGIES

Within the last two years, considerable interest has been focussed on the use of weather technologies to assist in snow and ice control. The use of weather information by roadway maintenance decision makers ranges from monitoring local forecasts to using sensor systems and specially tailored forecasts designed to be used in the decision process. A few examples of road weather information system usages are described in the literature.

The state of Wisconsin has the most extensive network of sensors in the United States [13], [28]. Wisconsin is also unique in that the State contracts with the counties to perform snow and ice control maintenance activities. Their road weather information system consists of a network of sensors and remote processing units which are connected to central processing units in maintenance district headquarters and in county headquarters. Data from the sensors, acquired from Surface Systems, Inc. (SSI), provide measurements of atmospheric and roadway parameters. In addition to sensor readouts, decision makers have access to forecasts of certain parameters for specific locations. The forecasts are provided by SSI. Meteorological products, such as satellite imagery and radar information are also available through the computer system.

Typical parameters measured in road weather information systems include: air temperature, dew point temperature or relative humidity, wind direction and speed, the occurrence of precipitation, pavement surface temperature, pavement surface conductance and capacitance for salinity and wetness, and subsurface temperature at sub base depth. Forecasts for use by decision makers are usually for the time of occurrence of frost, onset, duration and accumulation of precipitation (freezing rain, snow, rain), air temperature, pavement surface temperature, and wind speed and direction. It should be pointed out that the pavement temperature is the critical parameter for snow and ice accumulating or forming on pavement.

Lists of vendors of meteorological equipment in general, and road weather systems in particular, are provided in appendices. It should also be noted that meteorological services can be acquired and used successfully without having sensors in place. This has been the typical practice for general meteorological support in the past. In Washington State, a few examples of the users of such support include the WSDOT, Thurston County, and the City of Spokane. However, in regions of variable terrain elevation, weather and roadway conditions, sensors can help the meteorological forecasters and the decision makers for snow and ice control. The amount of assistance appears to be related to maintenance practices, especially for snow and ice control (e.g. use or non-use of deicing chemicals).

Acquiring road weather system hardware can be costly. A typical sensor installation can cost $40-50,000; processing computers and proprietary software near $30-40,000. Meteorological products and services are in addition to hardware costs. Because of the high initial costs, multi-agency procurement appears to be a method of distributing the costs. Examples of share systems can be found in Missouri (St. Louis city and Missouri DOT; Kansas City, Missouri DOT, and Kansas DOT), Colorado (Denver, Thornton, and Colorado DOH), and the Washington, D.C. area (D.C., Virginia DOT, National Parks Service). Efforts are nearly complete to effect a multi-agency procurement in Washington State between Spokane (city and county), the Washington DOT, and the Spokane International Airport. Included in the appendices is a list of sensor system installations as provided by the vendor with the most installations.

Of interest also is the fact that in some states, the aeronautics side of the department of transportation is acquiring weather equipment in the form of automated weather stations. Data from these automated stations could be used by road maintenance people. In Washington, the Aeronautics Division of the DOT has purchased automated systems for Bremerton and Deer Park airports. These sensors have voice synthesizers and can be called by telephone for the latest weather information. The Aeronautics Division also has a computer system with weather observations and forecasts available to persons with a computer and a modem. Telephone numbers for the sensors and the computer system should be available from the WSDOT Aeronautics Division.

The aviation community has recognized the need for years for weather information to minimize the effect of weather on aviation operations. This includes runway maintenance activities. The current weather technologies being developed for use by road maintenance organizations have resulted from efforts to provide better support for aviation. For example, pavement sensors were first used in runways; weather radars are primarily sited at airports; nearly all weather observations come from airports; and many NWS forecast offices are located at or near airports.

The road maintenance community has its own needs, some of which can be satisfied by joint use of equipment. The Michigan DOT and the NWS at Lansing jointly purchased a weather radar. Pennsylvania DOT decision makers in the Erie district tap NWS radars in that area to monitor Lake Erie-effect snow showers in the winter and rain showers year round. Seattle-Tacoma International Airport (SEATAC) has purchased a short wave length weather radar to monitor precipitation onset and termination in the SEATAC area. The operations personnel at SEATAC have been very pleased with their ability to track precipitation patterns and to anticipate the onset of precipitation at SEATAC. The possibility exists of road maintenance agencies using these radar data at nominal cost.

WEATHER IMPACTS

There are also research efforts underway to seek ways to reduce costs in snow and ice control. These include efforts by the Federal Highway Administration (FHWA), the Strategic Highway Research Program (SHRP), the National Cooperative Highway Research Program (NCHRP), and numerous separate efforts in states and metropolitan regions. The research covers developing new equipment, such as snow plow blades and chemical or abrasive spreading equipment. It also covers developing new materials, such as the use of non-chloride or non-corrosive de-icing chemicals. SHRP, as well as some individual states, is also investigating weather-information-gathering technologies to assist their snow and ice control maintenance activities. Little of the research, except for SHRP, focusses on the resource allocation decision process, and usually not on the critical thresholds of weather parameters that one needs to know will occur in order to make timely decisions. Also, little of the research even mentions weather impacts other than for snow and ice control.

Some of these other critical weather parameter thresholds are documented, however. An NCHRP report described the impact of weather on roadway construction and some maintenance activities [30]. Figure 1 shows those effects of the weather.

	PRECIPITATION			TEMPERATURE		WIND		
	Rain	Snow	Sleet	Hot	Cold	0-10 Low	10-30 Med	30 + High
Work	S	S	S	L	M-S	L	M	M
People	S	S	S	L-M	M-S	L	M	S
Equip	M-S	S	S	L	M	L	L	M
Mater-ials	M	S	S	L	M	L	M	M

L = Low M = Medium S = Severe

Figure 1. Effect of weather on highway construction

Interviews with city and county roadway maintenance people in Washington indicate similar impacts on their activities from weather. However, the key is to determine critical thresholds of weather parameters that produce the impact. The purpose of determining the thresholds is to insure that if weather service is acquired, that the service provides information centered on the information which is critical to the decision process.

The interview process is one way of eliciting critical thresholds. Typically, when initially asked to list some kinds of weather impacts, people don't recognize that impacts exist. However, in the interview process, the interviewer can lead the interviewee into a thought process that fosters the recognition that impacts do exist. Once an impact is recognized, then the interviewer can guide the discussion toward finding the "true" impact, that critical threshold that if exceeded will cause one to take action. One example occurred during an interview where a public works superintendent indicated what had turned out to be a poor overlay most likely resulted from not properly monitoring pavement and ambient temperatures during the application. Other cases involved wasted time and materials preparing for or even conducting an overlay only to have rain occur in the process or with tank trucks full of oil and no where to store the oil when it couldn't be used.

Such critical thresholds are frequently not documented. Reasons for the lack of documentation range from not realizing that a threshold is critical and therefore not paying attention to its occurrence, to operating in a strictly reactive fashion to the weather. However, following interviews with maintenance people, critical values can be assigned to some of the weather impacts shown in Figure 1. Rather than in a research project, the same interview process can occur with a meteorologist. Most of the firms providing meteorological services, however, provide a menu of products or a checklist on which a client fills in blanks. In order to ascertain weather impacts and establish critical thresholds, a consultant arrangement is appropriate, i.e., when an intermediary who understands roadway maintenance and meteorological service capabilities can work with both parties. Such a consultant can either be a staff person, such as a staff weather advisor (SWA), or a consultant hired for the specific purpose.

The Minnesota DOT has recognized the utility of having such a person on their staff and has hired a meteorologist to help identify meteorological needs and to see that those needs are satisfied. The principal is the same as is common in the military. Few commanders commit resources without knowing that the impact of weather is or is going to be on operations. Each commander usually has access to weather service in one form or another to provide the information. That service is arranged for and "tailored" to the operation by a staff weather person. When making resource allocation decisions on activities that have weather impacts, weather advice can be critical.

ROADWAY MAINTENANCE ACTIVITIES

The various maintenance activities performed by road/street maintenance authorities are well known, although the implementation of the practices may vary significantly from one location to another. Table 1 lists the typical maintenance responsibilities for a roadway maintenance function.

Following the review of literature and interviews with maintenance people, we found that the weather impacts most of those maintenance activities in one way or another. The analysis of those impacts is presented in Table 1. The weather phenomena listed can either affect the ability to perform or prevent the performance of certain activities. In addition, the weather may also specify the need to perform a certain activity.

Table 1. Weather Impacts on Roadway Maintenance Activities

	Weather Parameter							
	Precipitation		Temperature (Air)	Humidity	Wind		Temperature (Surface)	Surface Condition
	Rain	Snow			Speed	Direction		
Vegetation Control								
Spray Herbicides	X		X		X	X		
Downed Trees					X	X		
Burning Debris					X	X		
Painting								
Structures	X	X	X	X	X	X	X	
Roadway Markings	X	X			X	X	X	
Thermoplastics	X	X					X	
Clean-up								
Routine Sweeping	X	X			X			X
Post Storm	X	X			X			X
Roadway Repair								
Overlays	X							
Pot Holes	X	X						
Crack Sealing	X	X						
Seal Coating	X							X
Dirt Roads			X		X			X
Gravel			X		X			X
Drainage Systems								
Catch Basins	X	X			X			
Culverts	X	X						
Storm Drains	X	X						

Table 1. Weather Impacts on Roadway Maintenance Activities (cont.)

	Weather Parameter							
	Precipitation		Temperature (Air)	Humidity	Wind		Temperature (Surface)	Surface Condition
	Rain	Snow			Speed	Direction		
<u>Flood Control</u>								
Inspections:								
Bridge	X	X						
Culvert	X	X						
Storm drains	X	X		X				
<u>Construction</u>								
Structures								
Concrete	X	X	X	X	X			X
Roads								
Ballast	X	X					X	X
Asph. sfc trtmnt	X		X		X	X	X	X
Asph. prime coat	X		X				X	X
<u>Snow and ice Control</u>								
Plowing		X			X	X	X	X
Blowing		X			X	X		
Hauling		X						
Deicing	X	X	X		X		X	X
Traction	X	X	X					X
Closures	X	X			X	X		X
Restrictions	X	X			X	X	X	X
Avalanche	X	X	X		X	X		
<u>Load Restrictions</u>			X				X[1]	

[1] Need temperature measurements below the road surface.

The list of maintenance activities in Table 1 is intended to be comprehensive, in that it lists most, if not all, maintenance activities that road or street authorities perform. It is recognized that not all agencies may perform all of the activities and that there may yet be additional activities performed by some. The Table does illustrate, however, that the weather can and does influence a broad spectrum of maintenance activities.

These maintenance activities require significant expenditures by the cities and counties. The FHWA Highway Statistics 1987 indicate that over $186 million were spent for maintenance alone in Washington State, including over $11 million on snow and ice control; over $190 million were spent for construction [13]. The counties and municipalities of Washington State spent over $375 million on roadways in 1986.

Information acquired in support of a Strategic Highway Research Project indicate that for snow and ice control, five to ten percent of the costs can be eliminated through the use of weather information in the resource-allocation decision process [4], [13]. This is primarily based on reducing waste in materials, eliminating unnecessary road patrols, and reducing labor costs for overtime and callouts/callbacks.

There is every reason to believe that savings can be realized for maintenance activities other than snow and ice control. If in fact even five percent of the money spent by the cities and counties can be saved, then close to $20 million can be returned to maintain, improve, or build roadways.

USES OF WEATHER INFORMATION

Based on interviews conducted with city and county highway maintenance people, weather information is obtained (or not obtained) from many sources and is used (or not used) in many ways. Weather information can be categorized as observations or forecasts. The observations tell what the current weather conditions are; the forecasts tell what the expected weather conditions are at some future time. Typical sources of weather forecasts are:

- radio and television station forecasts, some of which are retransmissions of National Weather Service (NWS) forecasts, while the others are developed by private meteorologists, either employed or contracted by the station;

- o NWS forecasts, obtained either from National Oceanic and Atmospheric Administration (NOAA) Weather Radio, or rebroadcast by the "Weather Channel" on cable TV;

- o Private meteorological service-provided forecasts, either directly or indirectly.

Some road maintenance facilities have installed cable television for the sole purpose of obtaining The Weather Channel, taking measures to ensure that that is the sole use of any video equipment in an office. In order to provide NOAA Weather Radio, some organizations have installed an appropriate crystal in or programmed multichannel radios to acquire the signal. Other vehicles with scanners will look monitor the NOAA frequencies (three VHF channels from 162.45 to 162.65 MHz, one channel in one area). Some offices also purchase a desk-top radio. These can be acquired in two versions. One is designed for constant receipt of NOAA broadcasts; the other has an alert mode and will be activated by a NOAA-transmitted 1000 MHz signal when severe weather is anticipated.

Roadway maintainers also use weather observations, too. Weather observations can be described as formal or informal. Informal observations include:

- o on-the-job weather reports provided by road crews. These can be passed from crew to crew or back to central offices;

- o reports obtained indirectly from road users by monitoring radios or scanners. In areas with heavy truck traffic, monitoring CB radio broadcasts can keep maintenance crews apprised of conditions;

- o reports provided directly by other government entities, such as public safety agencies (police, fire, etc.);

- o monitoring or weather instrumentation, such as thermometers placed in locations either known as or thought to be strategic for determining weather conditions. Maintenance people have been known to place thermometers on sign posts and bridges. Some vehicles have been equipped with external sensors to measure air temperature;

Formal weather observations would be those obtained directly from sensor systems designed for the specific purpose of acquiring weather information, or indirectly from agencies who process the information and provide it to people who need or are interested in the information. The observations are also categorized as in situ, i.e., measured in place, or as remote, i.e., measured from some distance away. Examples of remote observations are data from weather satellites or weather radar.

The formal in situ weather observations are generally considered to be NOAA or Federal Aviation Administration (FAA) observations. Other observations are frequently taken in support of environmental monitoring or agricultural activities. Unfortunately, these are not generally available to the public. Finally, there is a network of volunteer Cooperative Observing Stations whose observations are used to build climatological records. (Appendix F lists those stations reporting in Washington State.) Again, these observations are not provided for "operational" use and are collected by the NOAA/NWS. Some of the NOAA and FAA observations are provided as a public service, such as from NOAA Weather Radio. Additionally, some of these same observations are relayed by The Weather Channel which requires fee for cable TV, or by private meteorological service agencies, some of whom can provide NOAA and FAA observations.

In the earlier investigation on this project, it was discovered that the Port of Seattle had purchased a weather radar for their use in making decisions for snow and ice control as well as other precipitation-impacted maintenance activities. Discussions with airport operations personnel indicated they were satisfied with the ability of the system to help them pinpoint precipitation events in the Puget Sound area. They also indicated they would be amenable to other agencies accessing the radar data. According to the radar vendor, additional access can be provided for the cost of appropriate software and the availability of an IBM PC or compatible and a telephone modem.

A new type of observation capability is beginning to be used and tested in support of highway maintenance activities, usually for snow and ice control. Sensor systems are being installed alongside roadways and in the travelled way to measure atmospheric and pavement parameters. These systems usually contain a mixture of atmospheric and pavement sensors. A typical installation might include instruments to measure:

- wind speed and direction;

- temperature and relative humidity;
- precipitation occurrence;
- pavement temperature;
- pavement condition (wet, dry, frost, etc);
- chemical factor (amount of deicing salts on surface); and
- subsurface temperature (depth varies, but usually at sub base).

The same companies who sell the sensing equipment frequently offer services to provide forecasts of pavement and weather conditions to the maintenance organization. The combination of observations and forecasts is called a Road Weather Information System (RWIS). RWISs have been in use for some years in Europe and are now being used and tested in some locations around the United States. A test installation was recently completed in WSDOT's District 1, Area 5. Four sets of sensor systems will provide data on atmospheric and pavement conditions to the DOT as well as to the meteorological services provider who will use the data in making forecasts. The forecasts and observations will be used to make decisions for assigning maintenance resources.

The placement of the sensors and assistance in providing pavement condition forecasts to the WSDOT has been partially based on road thermography data collected and processed to show thermal profiles of road surfaces in the Area under various atmospheric conditions. Part of the evaluation of the WSDOT installation of weather technologies will include determining the utility of the use of the road temperature profiles. It has been stated that in Vancouver, B.C., the snow and ice plan was altered based on similar thermal data. The data indicated that warm road segments were being plowed first, cold segments last. Reversing the plowing routes could improve plowing efficiency.

PROACTIVE WEATHER STRATEGIES

The key aspect in the use of weather information, including RWISs, is for the maintenance organization to become proactive based on the weather information. If a maintenance supervisor relies on current conditions to make decisions, then the supervisor is reacting to conditions. Meteorologists frequently say, "a look out the window is good for 30 minutes." Weather systems and weather move and the atmosphere changes. To be proactive, supervisors need to make decisions based on forecasts.

It is true that some decisions have to be based on observations. Typically, maintenance action is required if ice has formed, snow is falling, or a culvert is plugged. If the associated maintenance activities are not planned for, crews must be called out and frequently penalty costs are incurred. Knowing, or having reasonable assurance, that an event is going to occur allows a supervisor to plan for that occurrence, or plan around other activities.

It is important that the road maintenance organizations and the meteorological community understand each others' information needs. A line of communication must be opened and critical decision thresholds need to be understood and agreed to. Even if a maintenance organization decides to become proactive and to use weather forecasts in their decision processes, too often the forecasts used are public NWS forecasts which provide general information for an area, or private meteorological service-provided forecasts which are advertised to be "better" or "more accurate." A roadway maintenance supervisor needs specific weather information in order to make maintenance decisions. The meteorological information needs to be tailored to the maintenance supervisor's needs.

STAFF WEATHER ADVISORS

One way to facilitate the "tailoring" process is to employ, as Minnesota has done, a meteorological advisor. Such advisors can play a key role. As part of an organization's staff, or in a support role, a staff weather advisor (SWA) can sort out the organizations' weather information needs. The SWA also understands the capabilities of the meteorological community. By functioning in an intermediary capacity, the SWA can arrange or provide for the needs of the maintenance community. Numerous typical roles can be assigned to a SWA.

The SWA can work to improve meteorological capabilities through the collection and analysis of meteorological data. The conduct of local forecast studies can be key to developing forecast capabilities which will directly benefit the organization by providing more timely and more accurate information.

The SWA can also work within the maintenance organization to assist in the recognition of weather impacts, the establishment of critical thresholds, and the implementation of RWISs or weather information. The SWA can also provide quality control and quality assurance for the weather information acquired.

The initiation of a Staff Weather Advisor function that would be available to city and county road maintenance organizations would provide a excellent mechanism to reduce costs in roadway maintenance and would be an excellent return for the investment in terms of greater effectiveness in the use of scarce road dollars. A number of alternatives for implementing a state-wide SWA function can be envisioned. One alternative would be to assign a SWA in each climatological-similar areas.

The WSDOT operational organization is divided into six districts which approximate climatological areas of the state. A logical implementation scheme would then suggest funding for up to six SWAs, one per WSDOT district, to be a geographical-area resource for both the WSDOT and for the other jurisdictions. Participation by other jurisdictions would be based on providing a share of the cost of the SWA. It is envisioned that each SWA would be a contract employee. Some of the functions of a "District SWA" would include:

- o train road operations and construction personnel in the advantageous use of enhanced meteorological services;

- o provide seasonal weather and climatological briefings for each participating entity within the geographical region to support the maintenance and construction planning;

- o provide for (or provide) weather forecasts tailored to each participating agency's locale and needs, for example

  - calling storm characteristics and thresholds to their attention in response to the meteorologists' developed knowledge of their areas of exposure

- in response to an agency's alerting the SWA that a particular weather sensitive activity will be occurring at a particular place and time

o provide a dedicated source with whom a road and street official could collaborate in deciding on a course of action in a particular weather situation;

o undertake local area weather forecast studies to advance the ability to deal with recurring and expensive weather impacts;

o further develop and institutionalize effectiveness of this new, but rapidly evolving function in road and street management; and

o advise the various agencies on Road Weather Information System technologies which would have benefit (exceeding the RWIS cost) in the particular climate zone and facilitate the multijurisdictional involvement in the procurement and implementation of RWISs.

The cost of such an undertaking may appear overwhelming at first glance. As indicated above, the potential for savings to the WSDOT alone could be close to $1 Million, based on five percent savings for snow and ice control alone. The savings to the cities and counties would approach half that amount. If each district contracted for a SWA, much like the WSDOT does now for avalanche forecasters, at perhaps 1000 hours of work per annum, the cost could go as high as $300,000. But that would be a 5:1 ratio of return on investment. This doesn't even consider additional benefits which possibly may accrue through other-agency interest, such as the WSDOT's aeronautical function, or the State's energy, environment or agricultural meteorological needs.

Efforts are underway across the country to decrease the expenditures and improve the efficiency of road maintenance activities. The use of weather information is becoming more and more the center of attention.

o Minnesota has implemented a weather information sharing function (Mn/WIN ... the Minnesota Weather Information Network), and has hired a part-time meteorologist to interface with the state maintenance personnel and meteorological service and hardware providers;

- multi-agency installations of RWISs are in place in St. Louis and Kansas City, MO., Denver, CO., Washington, DC., Boise, ID., and Chicago, IL; and

- testing of RWISs is being monitored by the FHWA and SHRP, and state tests are being conducted in Minnesota, New Jersey, Idaho, and Oregon, as well as Washington, among others.

Of interest perhaps, is that in Washington State, the Boeing Company has recognized the effects of reduced functioning of roads on their own productivity and has contracted with a private meteorological service to provide forecasts of weather conditions which could pose hazardous roads. The Boeing Company then provides these forecasts to county and state road maintenance units in order to insure timely and efficient snow or ice clearing activities.

It is important to recognize, though, that although it is believed the implementation of SWA support would greatly benefit the participating agencies, a formal evaluation and careful monitoring of the activities envisioned will be required to document both the costs and benefits.

ALTERNATIVES

There are a number of alternatives through which a SWA function could be made available to cities and counties. The first alternative might be the development of a "road weather center" which is manned 24 hours per day, year around. The "center" might be set up to focus on the climate zones, WSDOT District geographical regions, or participating jurisdictions, or combinations thereof. The staffing could consist of four or five meteorologists who respond to the needs at hand, with the flexibility to have more than one person available during inclement weather.

The second alternative could be to assigned SWAs in each climate region or geographical area. These are envisioned as "day-time" staff people. The focus would be on the needs of each region, although during bad weather periods, one SWA would be augmented by a neighboring SWA, for instance. Also, synergistic benefit would accrue to the customers through cross-border conferencing.

A third alternative might be SWAs contracted from multiple, pre-approved or screened, sources, by individual jurisdictions, with overall guidance provided centrally on how to determine needs, acquire services, effectively use services and how to evaluate the services obtained. This central guidance could be provided by a WSDOT-level SWA who would also provide overall evaluation and develop means to improve effectiveness of using weather information, especially in the early years.

The last alternative might be to encourage the various agencies and jurisdictions to acquire road weather information technologies and/or services, but without providing central guidance. In effect, this would be telling everyone that this is a good idea, but it's up to them how to figure out what to do.

The last two alternatives run the risk of having jurisdictions in the same geographical locale obtaining weather information from different sources and getting different information for basically the same place. Although it is most important to obtain accurate information, it is also important to make decisions from consistent information. Information from different sources may be accurate, but can be interpreted differently. Consistent information will tend to ensure consistent actions. The last alternative also runs the risk of agencies acquiring the services of less-than-qualified sources and obtaining services that don't or can't satisfy the needs.

RECOMMENDATIONS

The potential for reducing roadway maintenance costs through the use of tailored weather support approaches 10 per cent for snow and ice control; perhaps similar cost reductions are possible for other weather-impacted maintenance activities. Potential cost reductions are possible at every jurisdictional level: cities, counties and at state level. It is therefore recommended that the Washington State Department of Transportation, in conjunction with other jurisdictions, evaluate the use of a Staff Weather Advisor to assist in the development of tailored weather support.

It is recommended that the second SWA alternative, developing regional SWA functions, be implemented in one climate area for a minimum of three years. Three years should be used as the evaluation period to ensure that sufficient weather events occur in which activities would be monitored. One year may contain no "significant" weather.

In order to test the recommendation, two possibilities can be explored. First, since a cadre of State-funded meteorologists already exists to provide avalanche forecasting support, contract for additional services from this same group, although focussed on road weather support in a particular climate zone, could be explored. The other possibility would be to contract with a private forecasting service to provide the inter-jurisdictional tailored weather support. Instead of a private service contracting with many different agencies, for example, the service could contract with one agency to provide services within a geographical/ climatological area.

It also recommended that the WSDOT contact city and county roadway maintenance organizations. A meeting of managers from each organization would review the recommendation and, if they decide to proceed, devise a participation formula. A first guess could be a *pro rata* share based on the participants' snow and ice control budget.

Given the perceived value of the SEATAC weather radar by the airport operations personnel, it is recommended that a test be conducted to test the utility of the radar data to road maintenance agencies. The short wavelength radar has the ability to detect light precipitation, which is the most common type in the Puget Sound area. Typical "storm" weather radars are designed to detect the large water drops in severe storms. Being able to monitor the areal coverage and movement of precipitation patterns should provide considerable additional insight to decision makers on the onset and duration of precipitation events.

Interviews with maintenance personnel pointed out the difficulties they frequently have in first recognizing the utility of weather information to their decision processes. Once that need is recognized, it is often difficult to define the specific needs and also to acquire meteorological services and/or sensing hardware to satisfy those needs. Problems arise in evaluating the ability of offerors to satisfy needs. Additionally, there is a tendency to acquire such services or hardware on a low-cost bid basis. Guidelines are needed for the procurement of meteorological services. The services should be considered professional services and evaluated on the basis of technical merit as well as cost. It is recommended that the WSDOT prepare guidelines for the use of roadway maintenance agencies to use in contracting for meteorological services.

Literature received from other state agencies has pointed to the benefit of multi-agency involvement in discussions about the needs for, benefits of and acquisitions of meteorological services and hardware. The Minnesota Weather Information Network appears to be an appropriate model and vehicle to generate mutual interest and cooperation. The acquisition of meteorological hardware can be expensive. Since the climate and weather "know" no boundaries, equipment purchase by one agency can certainly provide useful information to included or adjacent jurisdictions. There is benefit to sharing information and to cooperating in purchasing equipment. It is recommended that the WSDOT take the initiative to form a weather "interest group" comprised of private, federal, state, county and municipal agencies who have an interest in the gathering, providing or using meteorological information. Such a group has value in just providing the opportunity for communication.

The report has focussed on the potential value of weather information in reducing costs of road and street budgets. The value of roadway maintenance to society is generally recognized but not quantified. It is therefore also recommended that surveys or other instruments be developed which could measure these benefits to society, especially for snow and ice control activities. As pointed out above, the Boeing Company recognizes the importance of snow and ice control and pays to provide weather information to insure that maintenance is timely and efficient.

It should be pointed out that throughout this report, that the ideas noted herein will have comparable value to the WSDOT and state roadways. The implementation of these concepts within the WSDOT will provide increased coverage of meteorological data and attention, and economies of scale in providing services to the benefit of all concerned.

EVALUATION

There are a number of ways to evaluate the effectiveness of the recommendations. Evaluation will be the most important element of any further research. We believe a state-wide initial implementation, rather than a small, isolated sample, inevitably not fully representative in this extremely diverse state, is warranted for testing the SWA concept. This is out of the conviction that the essence of every alternative, and in every region, will be beneficial aside from research; that reaching for the benefits is immediately warranted; and that the evaluation phase will allow improvements and institutionalization in three to five years -- rather than undertaking additional alternatives then or presuming to overlay results from one zone onto others that are different in their weather or in the number and types of participants. However, we recognize that fiscal and political realities and reluctance to participate without formal evaluation preclude such a state-wide test.

The means of evaluation is all-important and should include developing an all-encompassing evaluation instrument that establishes a baseline, then use recurring surveys of actual uses of weather information, some of which would be subjective, but if done frequently enough, could compensate for any errors when analyzed statistically. In addition, if recommendations are implemented for evaluation, such evaluations should take place for a sufficient duration to insure significant weather events take place.

Finally, the location for such evaluations is key to validating the concepts. The weather radar test could take place within local telephone call distance of SEATAC to minimize costs. The weather interest group implementation should take place at WSDOT headquarters. The SWA concept should probably be implemented and evaluated in a location where meteorological hardware is or will be installed. This could be in either WSDOT District 1 Area 5 (Bellevue) which has had meteorological equipment installed or District 6 Area 1 (Spokane) which may have equipment installed. These areas are shown in Appendix H. If the Spokane installations take place, this would be the preferred location, since the hardware purchases have been through joint procurement, maintenance will be handled through an interlocal agreement, and other agencies are monitoring the progress for possible future participation. In addition, the probability of having significant weather, especially snow and ice situations, is higher in Spokane than in the Seattle area.

ACKNOWLEDGEMENTS

We wish thank all the maintenance supervisors and managers we interviewed as part of this research. These included people in Grant, Spokane, King and Snohomish counties, and the cities of Spokane, Moses Lake, Pullman, Seattle, Lynnwood and Mountlake Terrace.

We would also like to thank Ms. Barbara Russo, WSDOT Librarian, for her diligent work in obtaining a number of important documents used in the literature review for this project.

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Appendix A

List of Acronyms

DOH	Department of Highways
DOT	Department of Transportation
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FTE	Full-time Equivalent
Mn/Win	Minnesota Weather Information Network
NCHRP	National Cooperative Highway Research Program
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PC	Personal Computer
RWIS	Road Weather Information System
SEATAC	Seattle-Tacoma International Airport
SHRP	Strategic Highway Research Program
SSI	Surface Systems Incorporated
SWA	Staff Weather Advisor
WSACE	Washington State Association of County Engineers
WSDOT	Washington State Department of Transportation
WWWS	Wisconsin Winter Weather Network

Appendix B

Major Road Weather Information System Sensor Manufacturers marketing in the U.S.

SSI (Surface Systems, Inc.)
10420 Baur Boulevard
St. Louis, MO 63132
1-800-325--SCAN

Vaisala, Inc.
100 Commerce Way
Woburn, MA 01801
1-617-933-4500

Climatronics/FFV Aerotech
140 Wilbur Place
Bohemia, NY 11716
1-516-567-7300

Boschung Company, Inc.
12777 W. Silver Spring Road
Butler, WI 53007

Appendix C

Sample of Meteorological Sensor Manufacturers
(from exhibitors at the annual American Meteorological Society Convention)

AAI Corporation
P.O. Box 126
Hunt Valley, MD 21030
Contact: "Mac" McClernan

Atmospheric Instrumentation
Research, Inc. (AIR)
8401 Baseline Road
Boulder, CO 32905
Contact: Robert Munio or Jim Roby

Belfort Instrument Company
727 South Wolfe Street
Baltimore, MD 21231
Contact: Jim Ferner

Campbell Scientific, Inc.
P.O. Box 551
Logan, UT 84321
Contact: Betsy Dastrup

Handar, Inc.
1188 Bordeaux Avenue
Sunnyvale, CA 94089
Contact: Katie Andrews

Magnavox
1313 Production Road
Fort Wayne, IN 46808
Contact: Martha Carlson

R.M. Young Company
2801 Aero-Park Drive
Traverse City, MI 49684
Contact: John Campbell

Rotronic Instrument Corp.
160 East Main Street
Huntington, NY 11743
Contact: Catherein Tenebruso

Scientific Technology, Inc.
2 Research Place
Rockville, MD 20850
Contact: Donald Williams

Seta Systems, Inc.
45 Nagag Park
Acton, MA 01720
Contact: Larry Griffin

Sofrel, Inc.
7685 Commerce Way, Suite 105
Eden Prairie, MN 55344
Contact: James Goodall

Sunsor
22333 Pacific Coast Hwy.
Malibu, CA 90265
Contact: Susan Bergsma

Teledyne Geotech
3401 Shiloh Road
P.O. Box 496007
Garland, TX 75046-9007

UCAR/Unidata
P.O. Box 3000
Boulder, CO 80307
Contact: Susan Kassinger

Appendix D

Sample of Meteorological Services Providing Forecasts to Highway Maintenance Organizations

ACCU-WEATHER, INC.
619 W. College Ave.
State College, PA 16801

AIR SCIENCE CONSULTANTS, INC.
347 Prestley Rd.
Bridgeville, PA 15017

COMPU-WEATHER, INC.
P. O. Box 1122
Flushing, NY 11354

FREESE-NOTIS WEATHER, INC.
1453 NE 66th Ave.
Des Moines, IA 50313

METRO WEATHER SERVICE, INC
Hangar #11 @ JFK Airport
Jamaica, NY 11430

NORTHWEST WEATHER NETWORK
4564 168th AVE SE
Issaquah, WA 98027

SURFACE SYSTEMS, INC.
2605 S. Hanley Road
St. Louis, MO 63144

WEATHERBANK, INC.
2185 South 3600 West
Salt Lake City, UT 84119

WEATHER CORPORATION OF AMERICA
5 American Industrial Dr.
St. Louis, MO 63043

WEATHERDATA, INC.
833 North Main St.
Wichita, KS 67203

WEATHER NETWORK, INC.
dba NOWCASTING
an Oceanroutes Company
3760 Morrow Lane, Suite F.
Chico, CA 95928-8865

Appendix E

List of SSI SCAN System Installation, U.S.
(provided by SSI)

California DOT	San Francisco
Colorado DOH, Alamosa	Alamosa
CO State DOT	Denver
Colorado DOH, Pueblo	Pueblo
DC Metro (Washington DC DPV)	Washington
Iowa DOT	Des Moines
Idaho DOT	Boise
Chicago City Streets	Chicago
IL State Toll Hwy	Oak Brook
IL DOT	Peoria
Illinois DOT District 1	Schaumburg
City of Indianapolis	Indianapolis
City of Overland Park	Overland Park
City of Wichita	Wichita
Massachusetts Turnpike	Cambridge
MA DOT at Braga Bridge	Taunton
Michigan DOT Oakland County	Detroit
Michigan DOT Kalamazoo	Kalamazoo
Michigan DOT Lansing	Lansing
Michigan DOT Saginaw	Saginaw
Minnesota DOT District 1	Duluth
Minnesota DOT District 5	Minneapolis
Metro Kansas City (City of KC)	Kansas City
Missouri DOT	Kirkwood
St. Louis City Streets	St. Louis
Montana DOH	Missoula
Grand Island	Grand Island
NJ DOT Cherry Hill	Trenton
Nevada DOT	Reno
NY DOS (Brooklyn Bridge)	New York
NY DOT	Rochester
Verrazano Bridge	Triborough
Columbus DOT	Columbus
Oregon DOT	Bend
Oregon DOT	Medford
Oregon DOT	Milwaukie
Penn DOT District 1	Franklin
South Carolina DOH, (Columbia)	Columbia
South Carolina DOH, (Greenville)	Greenville
Nashville DPW addition	Nashville
Utah State University	Logan
Utah DOT Ogden	Ogden
Utah DOT	Price
Richmond-Petersburg	Richmond
WSDOT District 1	Seattle Area

WSDOT Snoqualmie Pass	Hyak
WI DOT District 6	Eau Claire
WI DOT District 3	Green Bay
WI DOT District 5	La Crosse
WI DOT District 1	Madison
WI DOT District 7	Rhinelander
WI DOT District 8	Superior
WI DOT District 2	Waukesha
WI DOT District 4	Wisconsin Rapids
West Virginia Turnpike	Charleston
Wyoming DOH	Rock Springs

Vaisala System Installations, U.S.

Minnesota Road Test Facility	40mi NW Minneapolis

Appendix F

List of Companies Providing Road Thermography
(Associated company providing the service)

Vaisala, Inc
(bought Thermal Mapping International, Ltd)
100 Commerce Way
Woburn, MA 01801

Climatronics
(uses Bergab of Sweden)
140 Wilbur Place
Bohemia, NY 11716

Donahue and Associates
1020 N. Broadway
Milwaukee, Wisconsin 53202

STATION INDEX

WASHINGTON 1988

STATION	INDEX NO.	DIVISION NO.	COUNTY	LATITUDE	LONGITUDE	ELEVATION FEET	YEARS OF RECORD: TEMP.	YEARS OF RECORD: PRECIP.	YEARS OF RECORD: EVAP.	OPENED DURING YR: MONTH	CLOSED DURING YR: MONTH	SEE REFERENCE NOTES
WASHINGTON												
ABERDEEN	0008	01	GRAYS HARBOR	46 58	123 49W	10	85	98	0			M
ABERDEEN 20 NNE	0013	01	GRAYS HARBOR	47 16	123 42W	435	31	60	0			C M
ANACORTES	0176	02	SKAGIT	48 31	122 37W	30	78	96	0			M
APPLETON	0217	06	KLICKITAT	45 49	121 16W	2336	29	29	0			M
ARLINGTON	0257	03	SNOHOMISH	48 12	122 8W	100	0	50	0			M
ASOTIN 14 SW	0294	10	ASOTIN	46 12	117 15W	3500	0	13	0			
BARING	0456	04	KING	47 46	121 29W	770	19	19	0			M
BATTLE GROUND	0482	04	CLARK	45 46	122 32W	284	45	50	0			
BELLINGHAM FAA AP	0574	03	WHATCOM	48 48	122 32W	149	45	48	0			M
BELLINGHAM 3 SSW	0587	02	WHATCOM	48 43	122 31W	30	4	4	4	AUG		M
BICKLETON	0668	08	KLICKITAT	46 0	120 18W	3000	51	55	0			M
BLAINE	0729	03	WHATCOM	49 0	122 45W	60	82	87	0			C M
BOUNDARY DAM	0844	09	PEND OREILLE	48 59	117 21W	1800	21	21	0			M
BREMERTON	0872	03	KITSAP	47 34	122 40W	162	36	90	0			M
BUCKLEY 1 NE	0945	04	PIERCE	47 10	122 0W	685	76	76	0			M
CARSON FISH HATCHERY	1160	05	SKAMANIA	45 54	121 57W	1134	12	12	0			C M
CATHLAMET 6 NE	1205	04	WAHKIAKUM	46 16	123 18W	180	0	29	0			M
CEDAR LAKE	1233	05	KING	47 25	121 44W	1560	83	88	0			C M
CENTRALIA	1276	03	LEWIS	46 43	122 57W	185	88	91	0			M
CHELAN	1350	07	CHELAN	47 50	120 2W	1120	88	97	0			
CHEWELAH	1395	09	STEVENS	48 17	117 43W	1670	62	63	0			L M
CHIEF JOSEPH DAM	1400	07	DOUGLAS	48 0	119 39W	820	36	38	0			C
CHIMACUM 4 S	1414	02	JEFFERSON	47 57	122 47W	140	0	60	0			M
CLEARBROOK	1484	03	WHATCOM	48 58	122 20W	64	80	85	0			
CLEARWATER	1496	01	JEFFERSON	47 35	124 18W	80	52	60	0			L M
CLE ELUM	1504	06	KITTITAS	47 11	120 57W	1930	81	86	0			M
COLFAX 1 NW	1586	10	WHITMAN	46 53	117 23W	1955	81	99	0			M
COLVILLE AIRPORT	1650	09	STEVENS	48 33	117 53W	1885	46	47	0		APR	L
COLVILLE 5 NE	1654	09	STEVENS	48 35	117 48W	3000	1	1	0			L
CONCONULLY	1666	07	OKANOGAN	48 33	119 45W	2320	80	89	0			
CONCRETE PPL FISH STN	1679	04	SKAGIT	48 33	121 46W	195	66	71	0			M
CONNELL 1 W	1690	08	FRANKLIN	46 40	118 53W	1020	28	28	27			C
CONNELL 12 SE	1691	08	FRANKLIN	46 30	118 46W	1078	0	37	0			
COUGAR 6 E	1760	05	SKAMANIA	46 4	122 12W	659	29	52	0			
COULEE DAM 1 SW	1767	07	GRANT	47 57	119 0W	1700	53	52	0			
COUPEVILLE 1 S	1783	02	ISLAND	48 12	122 42W	50	74	86	0			M
CUSHMAN P H 2	1939	01	MASON	47 22	123 10W	21	16	16	0			M
DALLESPORT FAA AP	1968	08	KLICKITAT	45 37	121 9W	240	47	47	0			M
DARRINGTON RANGER STA	1992	04	SNOHOMISH	48 15	121 36W	550	48	65	0			L M
DAVENPORT	2007	07	LINCOLN	47 39	118 8W	2440	74	81	0			M
DAYTON 1 WSW	2030	10	COLUMBIA	46 19	118 0W	1557	88	89	0			M
DIABLO DAM	2157	04	WHATCOM	48 43	121 9W	891	55	57	0			L M
DOTY 3 E	2220	04	LEWIS	46 38	123 12W	260	0	20	0			
ELLENSBURG	2505	08	KITTITAS	46 58	120 33W	1480	89	96	0			L M
ELMA	2531	04	GRAYS HARBOR	47 0	123 24W	70	45	47	0			M
ELTOPIA 8 WSW	2542	08	FRANKLIN	46 24	119 10W	700	15	15	15			
ELWHA RANGER STATION	2548	04	CLALLAM	48 2	123 35W	360	42	45	0			
EPHRATA AIRPORT FCWOS	2614	08	GRANT	47 19	119 31W	1259	45	47	0			M
EVERETT	2675	03	SNOHOMISH	47 59	122 11W	60	74	74	0			L
FORKS 1 E	2914	01	CLALLAM	47 57	124 22W	350	67	78	0			M
GLENOMA 1 W	3177	04	LEWIS	46 31	122 10W	870	63	65	0			M
GLENWOOD 2	3184	06	KLICKITAT	46 0	121 17W	1850	10	10	0			M
GOLDENDALE 2 E	3226	08	KLICKITAT	45 49	120 46W	1800	17	17	0			

SEE REFERENCE NOTES FOLLOWING STATION INDEX

STATION INDEX

STATION	INDEX NO.	DIVISION NO.	COUNTY	LATITUDE	LONGITUDE	ELEVATION FEET	YEARS OF RECORD TEMP.	YEARS OF RECORD PRECIP.	YEARS OF RECORD EVAP.	OPENED DURING YR MONTH	CLOSED DURING YR MONTH	SEE REFERENCE NOTES
GRAPEVIEW 3 SW	3284	04	MASON	47 18	122 52W	30	80	80	0			H
GRAYLAND	3320	01	PACIFIC	46 48	124 5W	10	35	35	0			H
GRAYS RIVER HATCHERY	3333	01	PACIFIC	46 23	123 34W	100	27	27	0			H
HARRINGTON 4 ENE	3515	07	LINCOLN	47 29	118 11W	2260	27	27	0			C H
HARTLINE	3529	07	GRANT	47 41	119 6W	1910	50	55	0			
HATTON 9 SE	3546	08	ADAMS	46 44	118 39W	1510	78	83	0			
HOLDEN VILLAGE	3730	06	CHELAN	48 12	120 47W	3220	27	27	0			H
HOQUIAM FAA AP	3807	01	GRAYS HARBOR	46 58	123 55W	12	42	42	0			H
HUMPTULIPS SALMON HATCHER	3826	01	GRAYS HARBOR	47 14	123 59W	140	2	2	0	JULY		H
ICE HARBOR DAM	3883	08	WALLA WALLA	46 15	118 52W	368	31	31	0			
IRENE MT WAUCONDA	3975	09	OKANOGAN	48 49	118 54W	2700	0	77	0		OCT	H
KAHLOTUS 5 SSW	4077	08	FRANKLIN	46 35	118 36W	1550	0	73	0			
KALAMA FALLS HATCHERY	4084	04	COWLITZ	46 1	122 43W	310	0	22	0			
KENNEWICK	4154	08	BENTON	46 13	119 6W	390	80	98	0			
KENT	4169	03	KING	47 24	122 14W	30	63	71	0			
LA CROSSE	4338	10	WHITMAN	46 49	117 53W	1480	80	80	0			H
LAKE WENATCHEE	4446	06	CHELAN	47 50	120 48W	2005	0	74	0			C H
LANDSBURG	4486	04	KING	47 23	121 58W	535	69	85	0			C H
LEAVENWORTH 3 S	4572	06	CHELAN	47 34	120 40W	1128	55	67	0			H
LIND 3 NE	4679	08	ADAMS	47 0	118 35W	1630	74	81	63			C H
LONG BEACH EXP STA	4748	01	PACIFIC	46 22	124 2W	25	22	22	0			H
LONGMIRE RAINIER NPS	4764	05	PIERCE	46 45	121 49W	2762	70	70	0			C H
LONGVIEW	4769	04	COWLITZ	46 9	122 55W	12	64	64	0			C H
MATLOCK 8 S	5086	04	MASON	47 9	123 24W	110	0	4	0	OCT		H
MAYFIELD POWER PLANT	5110	04	LEWIS	46 30	122 35W	280	0	10	0			
MAZAMA	5133	06	OKANOGAN	48 37	120 27W	2170	25	25	0			C H
MC MILLIN RESERVOIR	5224	03	PIERCE	47 8	122 16W	579	47	47	0			C H
MC NARY DAM	5231	08	BENTON	45 57	119 18W	361	34	34	0			
MERWIN DAM	5305	04	COWLITZ	45 58	122 34W	224	0	42	0			H
METHOW 2 S	5326	07	OKANOGAN	48 6	120 1W	1170	20	20	0			H
MILL CREEK DAM	5387	08	WALLA WALLA	46 5	118 16W	1175	0	40	0			
MONROE	5525	03	SNOHOMISH	47 51	121 59W	120	58	58	0			H
MOUNT ADAMS RANGER STA	5659	06	KLICKITAT	46 0	121 32W	1960	54	64	0			C
MOUNT VERNON 3 WNW	5678	02	SKAGIT	48 26	122 23W	14	33	33	0			H
MOXEE CITY 10 E	5688	08	YAKIMA	46 31	120 10W	1550	42	41	0			H
MUD MOUNTAIN DAM	5704	04	KING	47 9	121 56W	1308	49	49	0			C H
NASELLE 2 ENE	5774	01	PACIFIC	46 23	123 45W	50	0	54	0			H
NESPELEM 2 S	5832	07	OKANOGAN	48 8	118 59W	1890	63	70	0			
NEWHALEM	5840	04	WHATCOM	48 41	121 15W	525	63	65	0			
NEWPORT	5844	09	PEND OREILLE	48 11	117 3W	2135	69	71	0			H
NORTHPORT	5946	09	STEVENS	48 55	117 47W	1320	69	73	0			C H
OAKVILLE	6011	04	GRAYS HARBOR	46 50	123 14W	80	60	66	0			
ODESSA	6039	07	LINCOLN	47 19	118 41W	1570	77	85	0			H
OLGA 2 SE	6096	02	SAN JUAN	48 37	122 48W	80	97	99	0			H
OLYMPIA WSO AP	R 6114	03	THURSTON	46 58	122 54W	192	47	47	0			C H J
OMAK	6121	07	OKANOGAN	48 25	119 32W	851	10	10	0			
OTHELLO 6 ESE	6215	08	ADAMS	46 48	119 3W	1190	42	43	0			
PACKWOOD	6262	04	LEWIS	46 37	121 40W	1060	32	49	0			H
PALMER 3 ESE	6295	04	KING	47 18	121 51W	920	64	64	0			C H
PLAIN	6534	06	CHELAN	47 47	120 39W	1940	37	43	0			
POMEROY	6610	10	GARFIELD	46 28	117 37W	1810	74	88	0			
PORT ANGELES	6624	02	CLALLAM	48 7	123 26W	90	85	111	0			L H
PORT TOWNSEND	6678	02	JEFFERSON	48 6	122 46W	70	90	111	0			
PRIEST RAPIDS DAM	6747	08	GRANT	46 39	119 54W	460	28	32	0			

SEE REFERENCE NOTES FOLLOWING STATION INDEX

STATION INDEX

STATION	INDEX NO.	DIVISION NO.	COUNTY	LATITUDE	LONGITUDE	ELEVATION FEET	YEARS OF RECORD TEMP.	YEARS OF RECORD PRECIP.	YEARS OF RECORD EVAP.	OPENED OR CLOSED DURING YR MONTH OPENED	OPENED OR CLOSED DURING YR MONTH CLOSED	SEE REFERENCE NOTES
PROSSER 4 NE	6768	08	BENTON	46 15	119 45W	903	63	65	0			
PULLMAN 2 NW	6789	10	WHITMAN	46 46	117 12W	2545	35	35	0			C G H
PUYALLUP 2 W EXP STN	6803	03	PIERCE	47 12	122 20W	50	73	73	27			G H
QUILCENE 2 SW	6846	04	JEFFERSON	47 49	122 55W	123	67	68	0			
QUILLAYUTE WSCMO AP	6858	01	CLALLAM	47 57	124 33W	179	23	23	0			C H J
QUINCY 1 S	6880	08	GRANT	47 13	119 51W	1274	43	44	0			
RAINIER OHANAPECOSH	6896	04	LEWIS	46 44	121 34W	1950	0	48	0			C H
RAINIER PARADISE R S //	6898	05	PIERCE	46 47	121 44W	5427	46	52	0			H
RANDLE 1 E	6909	04	LEWIS	46 32	121 56W	900	0	56	0			C
RAYMOND 2 S	6914	01	PACIFIC	46 39	123 43W	30	10	10	0			H
REPUBLIC	6974	09	FERRY	48 39	118 44W	2610	66	72	0			H
RICHLAND	7015	08	BENTON	46 19	119 16W	373	44	44	0			H
RITZVILLE 1 SSE	7059	08	ADAMS	47 7	118 22W	1830	69	76	0			H
ROSALIA	7180	10	WHITMAN	47 14	117 22W	2400	92	93	0			
ROSS DAM	7185	05	WHATCOM	48 44	121 3W	1236	28	28	0			H
ST JOHN	7267	10	WHITMAN	47 6	117 35W	1945	26	26	0			
SAPPHO 8 E	7319	01	CLALLAM	48 4	124 7W	760	32	42	0			C
SATUS PASS 2 SSW	7342	06	KLICKITAT	45 57	120 39W	2610	21	21	0			C
SEATTLE STATE EMSU	R 7458	03	KING	47 39	122 18W	19	17	17	0			C H
SEATTLE SAND POINT WSFO	7470	03	KING	47 41	122 15W	60	3	3	0	OCT		H
SEATTLE-TAC WSCMO AP	R 7473	03	KING	47 27	122 18W	450	44	44	0			C H J
SEDRO WOOLLEY	7507	03	SKAGIT	48 30	122 14W	60	84	92	0			H
SEQUIM 2 E	7544	02	CLALLAM	48 5	123 3W	50	10	10	0			H
SHELTON	7584	04	MASON	47 12	123 6W	22	57	57	0			
SKAMANIA FISH HATCHERY	7696	04	SKAMANIA	45 38	122 13W	440	24	24	0			H
SMYRNA	7727	08	GRANT	46 50	119 40W	560	34	34	0			
SNOQUALMIE FALLS	7773	04	KING	47 33	121 51W	440	86	84	0			C H
SPOKANE WSO AP //	R 7938	09	SPOKANE	47 38	117 32W	2356	107	107	22			C H J
STAMPEDE PASS WSCMO //	R 8009	05	KITTITAS	47 17	121 20W	3958	44	44	0			C H J
STARTUP 1 E	8034	04	SNOHOMISH	47 52	121 43W	170	58	59	0			
STEHEKIN 4 NW	8059	06	CHELAN	48 21	120 43W	1270	67	69	0			C H
STEVENS PASS	8089	05	KING	47 44	121 5W	4070	36	40	0			C H
SUNNYSIDE	8207	08	YAKIMA	46 19	120 0W	747	92	94	0			C
TACOMA NO 1	8278	03	PIERCE	47 15	122 25W	25	7	9	0	JAN		
TOLEDO	8500	04	LEWIS	46 28	122 51W	325	26	26	0			
TOLT SOUTH FORK RESVR	8508	05	KING	47 42	121 41W	2000	0	27	0			
TONASKET 4 NNE	8520	07	OKANOGAN	48 46	119 25W	960	5	5	0	JULY		
UPPER BAKER DAM	8715	05	WHATCOM	48 39	121 41W	690	24	24	0			C H
VANCOUVER 4 NNE	8773	04	CLARK	45 41	122 39W	210	93	104	0			H
WALLA WALLA FAA AP	8928	08	WALLA WALLA	46 6	118 17W	1166	40	40	0			H
WALLA WALLA WSO CI #	R 8931	08	WALLA WALLA	46 2	118 20W	949	116	115	0		MAY	C J
WAPATO	8959	08	YAKIMA	46 26	120 25W	841	68	72	0			H
WATERVILLE	9012	07	DOUGLAS	47 39	120 4W	2620	83	99	0			H
WAUNA 3 W	9021	03	PIERCE	47 22	122 42W	20	0	47	0			
WELLPINIT	9058	09	STEVENS	47 54	118 0W	2490	29	65	0			
WENATCHEE	9074	08	CHELAN	47 25	120 19W	640	72	76	0			H
WENATCHEE EXP STATION	9079	08	CHELAN	47 26	120 21W	800	18	18	18			C H
WENATCHEE FAA AP	9082	08	CHELAN	47 24	120 12W	1229	29	29	0			H
WHITMAN MISSION	9200	08	WALLA WALLA	46 3	118 27W	632	26	26	26			C
WILBUR	9238	07	LINCOLN	47 45	118 40W	2230	78	87	0			
WINTHROP 1 WSW	9376	06	OKANOGAN	48 28	120 11W	1755	71	75	0			H
YAKIMA WSO AP //	R 9465	08	YAKIMA	46 34	120 32W	1064	79	79	10			C H J

SEE REFERENCE NOTES FOLLOWING STATION INDEX

REFERENCE NOTES

DEFINITIONS

STATION NAMES: Name of the city, town or locality. Figures and letters following the station names indicate the distance in miles and direction from the post office or town community center.

DIVISIONS: Areas within a state of similar climatological characteristics. Division averages are calculated using data from stations that record both temperature and precipitation (ie: not precipitation alone).

NORMALS: The average value of the meteorological element over the time period - 1951-1980. The normals for National Weather Service localities have been adjusted so as to be representative for the current observation site.

TEMPERATURE EXTREMES AND FREEZE DATA: Spring minimum dates are obtained from data for January through June; Fall dates are from July through December data. "NONE" indicates temperature threshold not reached. "MSG" indicates available data insufficient to determine date.

MONTHLY DEGREE DAY TOTALS: One heating (cooling) degree day is accumulated for each degree that the daily mean temperature is below (above) 65 deg. F.

SOIL TEMPERATURE EXTREMES: The highest and lowest MAX and MIN temperature for each month and the year.

WIND: (As shown in "Evaporation and Wind" table) The total wind movement in miles over the evaporation pan as determined by an anemometer recorder located 6-8 inches above the pan.

SYMBOLS AND LETTERS USED IN THE DATA TABLES

- \- No record. Data not recorded, determined unreliable by quality control checks, or not received in time for publication.
- * Rain gage not read. Precipitation is included in the amount following the asterisks. Time distribution not known.
- // Rain gage equipped with a windshield.
- A Amount of precipitation is the total of observer's entries for the current month. It may include precipitation that occurred during the previous month. Refer to monthly bulletins to determine date of last reading. (HAWAII stations)
- B Estimated total value for wind, evaporation, or cooling degree days.
- M Insufficient or partial data. M is appended to average and/or total values computed with 1-9 daily values missing. M appears alone if 10 or more daily values are missing.
- R Amounts from recording rain gage.
- T Trace. An amount too small to measure.
- V Includes total for previous month(s). (See * above)
- Z Same as M but the Z has overprinted a Negative sign or leading digit (eg. Z14.6 = M-14.6, Z08.2 = M108.2).

SYMBOLS AND LETTERS USED IN THE STATION INDEX TABLE

- \# Thermometers located in a rooftop shelter.
- C Station is equipped with a recording rain gage (R) but values in this bulletin are from a non-recording rain gage unless indicated by an R.
- G Observations appear in "Soil Temperatures" table.
- H Observations appear in "Snowfall and Snow on Ground" table in Monthly "Climatological Data" publications.
- J Station also published as a "Local Climatological Data" bulletin.

Seasonal Tables: Monthly and seasonal snowfall and heating degree days for the 12 months ending with the June data are published in the July issue of "Climatological Data".

Cooling degree days for the calendar year are published in the "Climatological Data Annual Summary".

Additional precipitation data are contained in the "Hourly Precipitation Data" bulletin for each state, except Alaska.

The graphic displays appearing in this publication were first produced for the 1986 annual. The types of graphs and the information they portray may vary from year to year and from state to state in order to highlight climatic features of state, regional, and historical interest. Some graphs present information for "clusters". A cluster is a group of up to four (4) adjacent divisions that comprise an area of similar climate.

Information concerning the history of changes in locations, exposure, etc. of substations is kept on file at the National Climatic Data Center. Similar historical information for regular National Weather Service Offices is available from the "Local Climatological Data" annual bulletin.

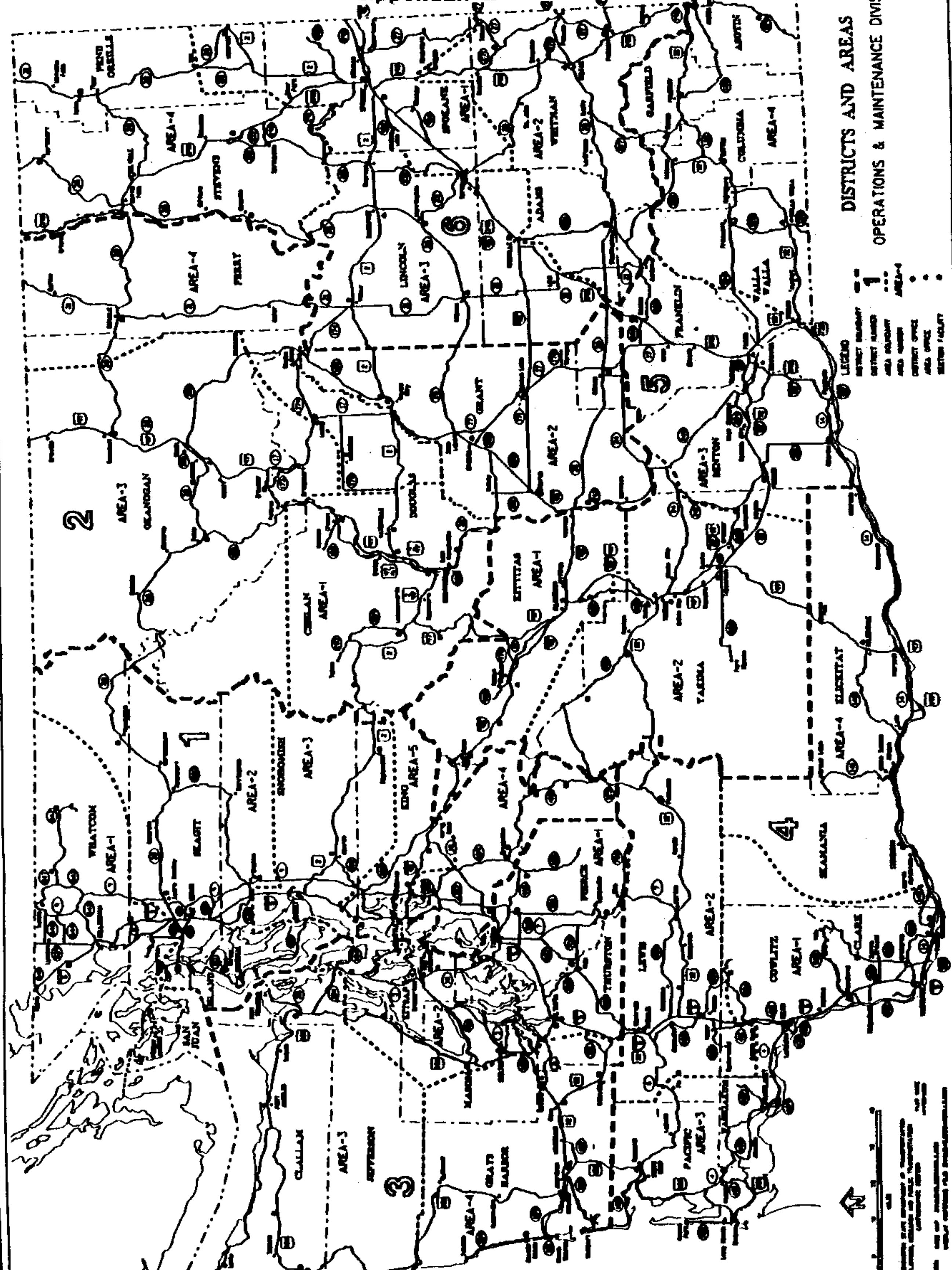
Additional Information regarding the climate of this state may be obtained by writing to the address below or to any weather service office near you. The contents of this publication may be reprinted or otherwise used freely with proper credit to the National Climatic Data Center. The data are also available in digital form on magnetic tape and diskette.

SUBSCRIPTION, PRICE AND ORDERING INFORMATION AVAILABLE FROM

NATIONAL CLIMATIC DATA CENTER
FEDERAL BUILDING
ASHEVILLE, N.C. 28801-2696

USCOMM-NOAA ASHEVILLE, N.C. 1988 0770

Appendix H



Appendix I

WORK PLAN

Document current county and city uses of weather information in highway operations and the meteorological skills in support of thereof.

A. Determine current county and city practices relative to weather-sensitive actions.

1. Interdisciplinary consulting team identifies likely target areas through initial inquiry with Snohomish, Spokane and King counties and selected "lead" cities within those counties. Example target study areas are:

   a. Weather-sensitive operations.
   b. Management decisions requiring weather-related judgments.
   c. Activities that could be positively affected by better ways to predict the weather.
   d. Information sources now used for weather-sensitive decisions.
   e. Alternative sources for weather information and advice.
   f. Extent of legal exposure due to weather-related conditions, and the adequacy of county and city positions or preparations for same.

2. Consulting team collaborates to establish an interview guide and interview list; then through in-person and telephone interviews with cities and counties, establishes a reliable description of current situations and practices.

   a. The interview and data gathering would have the following perspectives in the prepared interview guide:

      (1) County and city road and street operations--knowledge of road construction, maintenance and operations, what is done, how it is done, why it is done, its consequences, and effects.

      (2) Meteorology--what weather information is available, how to get it, reliability, what parameters and products are

appropriate.

(3) Travelling public interests--anticipation of legitimate expectations of motorists for information requiring a weather-related judgement.

3. Conduct interviews, to a large extent in person. Time is of the essence in undertaking this step, because it will be ideal to perform such interviews during the winter foul-weather months; and to combine with the interviews some observation (however brief) of weather-impacted activities and to have some interaction with City and County weather fighting personnel beyond the designated interviewees. Through the visit process the consultants will informally observe activities getting and using weather information, and visit sources of meteorological information locally in use.

4. Integrate the findings and draw tentative conclusions.

5. Make follow-on inquiries by telephone as necessary for clarification.

B. Prepare written report to serve primarily as a complete, objective description of current uses of weather information in county and city operational decision making, and to describe prospective pilot programs that will test and/or demonstrate meteorological technologies and communications that could reduce weather impacts.

The report will also identify any recommendations for change that are possible to be made solely as a result of the level of effort to this point in the undertaking. It will also outline any further investigation or development needed to optimize weather-related actions.