AN EVALUATION OF WEATHER INFORMATION TECHNOLOGIES FOR SNOW AND ICE CONTROL OPERATIONS

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16. ABSTRACT

Since 1988, the Washington State Department of Transportation (WSDOT) has been testing the use of weather information technologies in support of snow and ice control operations. In 1989, WSDOT contracted with a private meteorological service, had road thermography conducted on state roads in Area 5 of District 1, and installed sensor systems in four Area 5 locations. The thermography was also used as a basis for obtaining forecast temperature profiles for the State roads on which the thermographic analysis had been conducted. The pavement temperature forecasts, meteorological forecasts, and sensor data were all to be integrated into the snow and ice control decision process. The WSDOT contracted with The Matrix Management Group to evaluate the maintenance response to the new information, actual or potential cost savings with the information, and possible or real improvements in safety and service to the traveling public, and to suggest additional locations within the State which could benefit from improved weather information and/or operational changes in snow and ice control procedures which might result from the new information. This report presents a review of weather information system elements, provides an overview of the technologies in use by WSDOT, describes uses of weather information by managers, and notes some problems. A detailed benefit-cost analysis was not conducted; a parallel effort was done for a nation-wide project, and complete structured cost data were not generated by the WSDOT for this analysis. However, national results are discussed in terms of the scale of WSDOT operations. The participation and results associated with the pilot program were found to be mixed. A need for training of managers and operational decision makers in the full concept and expectations of a road weather information system, and in the particular technologies described herein, is perhaps the central focus of this report. Although the evaluation noted limited success, national and international studies point to a greater potential for reducing costs and improving service for snow and ice control. Because of that potential, additional locations for installing sensors are suggested.

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AN EVALUATION OF WEATHER INFORMATION TECHNOLOGIES FOR SNOW AND ICE CONTROL OPERATIONS

SUMMARY

Since 1988, the Washington State Department of Transportation (WSDOT) has been testing the use of weather information technologies in support of WSDOT snow and ice control operations. In 1988, the WSDOT contracted with The Matrix Management Group to investigate the use of weather information to reduce the costs of snow and ice control, and to improve snow and ice control operations. Based on the findings, the WSDOT decided to test through a pilot program the suitability and effectiveness of detailed, site-specific meteorological and pavement condition forecasts, road thermography, and meteorological and pavement condition sensors.

In 1989, WSDOT contracted with a private meteorological service for detailed pavement condition forecasts to supplement weather forecasts already being used. In a two-phased effort, the WSDOT contracted to have road thermography conducted on State roads in Area 5, District 1. Based on this thermographic analysis and discussion with the sensor manufacturer, sensor systems were subsequently installed in four locations in Area 5. The thermography was also used as a basis for obtaining forecast temperature profiles for the State roads on which the thermographic analysis had been conducted. The pavement temperature forecasts, meteorological forecasts, and sensor data were all to be integrated into the snow and ice control decision process. In theory, the information could provide for more timely decisions in calling out or releasing maintenance people. This could reduce the costs of snow and ice control and improve service on the roads.

In 1990, WSDOT contracted with The Matrix Management Group to evaluate the utility and benefit of these road weather information system (RWIS) components acquired to support Area 5, District 1 snow and ice control activities. To be evaluated were the maintenance response to the new information, actual or potential cost savings with the information, and possible or real improvements in safety and service to the traveling public. Additional locations within the State which could benefit from improved weather information, and operational changes in WSDOT snow and ice control procedures which might result from the new information were to also be suggested.

This report first presents a review of weather information system elements in order to place the WSDOT pilot program in context. Then an overview of the location of technologies

8. Better use of weather information in the snow and ice control decision processes would be enabled by having data routinely provided to the first-line supervisory level.

9. Beyond snow and ice control, WSDOT offices, such as bridge maintenance and plant management, have benefitted from the road weather information system.

10. Currently the funds for RWIS, including weather forecasts, come out of the local maintenance budget. Some managers are reluctant to spend maintenance funds for RWIS development.

The following **recommendations** are offered to correct deficiencies noted or to take advantage of technology not fully exploited. The WSDOT should:

1. Engage department personnel in developing a road weather information system era concept of operations that maximizes proactive use of the improved decision-making information.

2. WSDOT Managers need to determine how to optimally invest in RWIS and to establish a process to evaluate that performance with RWIS compared to expectations.

3. Consider moving existing District 1, Area 5 RWIS sensors as follows:

    - At sensor site, place pavement sensors in the lane with the least early morning traffic;

    - Add, at a minimum, sensor sites along I-90 near North Bend and SR 18 near Tiger Mountain summit;

    - Move the installation at the NE 195th/I-405 interchange into an open area, and add at least one pavement sensor on one of the elevated structures at the SR 522/I-405 interchange.

4. Add additional RWIS capabilities throughout the state, to include:

    - a CPU within each maintenance district;

    - a workstation at each maintenance area;

- portable terminals or computers for use by foremen for information acquisition;

- sensor installations in sufficient numbers to provide meteorological and operational information to decision makers and meteorologists. Four to six sites in each maintenance area should be considered, with six being optimal: one at a warm location, one at a cold spot, and four at "average" or representative locations. The sites should be selected to also cover trouble spots. A few examples include, at a minimum:

  — District 1 — along I-5 near Lake Samish, SR 2, and along I-5 near the Snohomish River;
  — District 2 — SR 97 to Swauk Pass;
  — District 3 — SR 104, 101 in Mason County and along I-5 in the Nisqually Basin area;
  — District 4 — SR 101 North of Raymond;
  — District 5 — Along I-82 near Manastash Ridge and in the Yakima Valley; and
  — District 6 — SR 195 South of Spokane, Nine Miles Falls.

5. Develop a statewide prioritized list of locations where RWIS sensors would assist snow and ice control decision makers, based on both operational and meteorological considerations and a participative approach with the districts. Criteria for rank ordering the proposed sites need to be developed.

6. Develop and conduct a training program to orient maintenance supervisors to the use of RWIS data and information to foster acceptance of the technology at all levels, and to facilitate the integration of this information into the snow and ice control resource allocation decision process.

7. Explore further RWIS procurement efforts with other agencies, especially cities and counties, using the District 6, Area 1 (Spokane) experience in multi-agency procurement as a model.

8. Establish procedures for preventive maintenance and calibration of installed RWIS hardware.

9. Institute a formal forecast feedback program for operational decision makers and managers to use in providing both positive and negative feedback to forecasting services, during a storm event itself, and as evaluation during and after the season for input to planning better tailored weather support.

10. Require in any future RWIS procurement that data from the RWIS are to be considered in the public domain to ensure the widest dissemination is possible.

11. Create a staff weather advisor position, either a part-time or partially funded meteorologist or consultant to:

    - assist in the expansion of the RWIS technology, to include recommendations for siting of RWIS instrumentation;
    - help develop an RWIS implementation training program;
    - establish a forecast evaluation program; and
    - work within the WSDOT across state agencies as an advisor for establishing and satisfying weather information needs.

INTRODUCTION

Since 1988, the Washington State Department of Transportation (WSDOT) has been testing the use of weather information technologies in support of WSDOT snow and ice control operations. The use of such technologies was first recommended in 1987 in a report prepared by a Snow and Ice Committee [WSDOT, 1987]. In 1988, the WSDOT contracted with The Matrix Management Group to investigate the use of weather information to help reduce costs of snow and ice control, and to improve the effectiveness of snow and ice control operations.

Based on the initial findings of that investigation, the WSDOT decided to test the use of meteorological and pavement condition sensors, road thermography, and detailed, site-specific meteorological forecasts. The suitability and effectiveness of these technologies to assist highway maintenance managers in allocating snow and ice control resources was to be determined. Sensor systems had been in use in the Snoqualmie Pass area to monitor the temperature and surface condition of the Denny Creek Bridge. These sensors had demonstrated their utility in providing decision information with regard to the need for chemical treatment of the bridge for snow or ice. The WSDOT wanted to test their use in an urban area.

In 1989, in a two-phased effort, the WSDOT first contracted with Thermal Mapping International, Ltd. (now Vaisala-TMI) to conduct road thermography on selected State roads in Area 5, District 1. Using this thermographic analysis Vaisala-TMI suggested sensor locations. Following a protest of a contract award to Vaisala-TMI for sensor installation, Surface Systems Incorporated (SSI), was awarded the sensor contract. SSI suggested the following sensor locations based on their experience, some input from the WSDOT, but no meteorological analysis:

- 130th Ave N.E. and I-5 in North Seattle;
- 195th Ave N.E. and I-405 north of the Woodinville interchange with SR 522;
- Along I-5 approximately 0.5 mi north of Southcenter; and
- Along I-90 at SR 18.

WSDOT also contracted with SSI to provide forecast pavement temperatures and conditions, and forecast temperature profiles for the State roads on which the thermographic analysis had been conducted. To complete the mix of weather information, WSDOT contracted with Northwest Weather Network for special weather forecast support. The pavement temperature forecasts, meteorological forecasts, and sensor data were intended to be integrated into the snow and ice control decision process to help make timely decisions in calling out or releasing maintenance people.

EVALUATION OBJECTIVES

Average annual costs for WSDOT snow and ice control operations exceed $15 million. Earlier investigation [Boselly, 1989] indicated that certain weather information technologies had the potential to reduce the cost of snow and ice control. In particular, the investigation indicated that the proactive use of weather information, i.e., making decisions based on forecasts rather than reacting to conditions observed, would provide for more efficient use of snow and ice control resources and thereby reduce costs. At the same time, the level of service to the road users could improve. Research conducted by the Strategic Highway Research Program [Boselly, 1992; Boselly, et al, 1993] further indicates that cost savings are possible for snow and ice control through the implementation of road weather information system (RWIS) technologies.

RWIS technologies include atmospheric sensors; pavement temperature and road condition sensors; road thermography which provides profiles of pavement temperatures; detailed weather forecasts of road and weather conditions; the transmitted and human communications associated with the acquisition, dissemination, and use of weather information; and ideally the advice from a management analyst-meteorologist working closely with the information users to facilitate the evaluation.

Due to the relatively high cost of thermography and sensors, the WSDOT decided to evaluate their utility and justification. In 1990, The Matrix Management Group began evaluation of the utility and benefit of the RWIS technologies in support of WSDOT snow and ice control activities. In addition, the WSDOT wanted recommendations for additional locations within the State which could benefit from such technologies.

The specific objectives of this evaluation include:

- determine the ability of the RWIS to improve maintenance response to snow and ice control requirements;

- determine cost savings through the use of weather information;

- analyze increased safety or service levels for the travelling public; and
- determine the applicability of an RWIS to other regions of the State;

An additional benefit from the investigation was expected to be the opportunity to determine any operational changes that would enhance the WSDOT snow and ice control program resulting from the use of RWIS information.

REVIEW OF WEATHER INFORMATION TECHNOLOGIES

During the course of the initial investigation, it became apparent that weather information technologies routinely in use in Europe, and being tested in some locations in the United States, had potential for helping the WSDOT. Meteorological and implanted road sensors were being used to help in the detection and prediction of road icing conditions. Road thermography, i.e., the use of infrared thermometry to develop profiles of road temperatures, was being used to help with the siting of road sensor systems and the prediction of pavement temperatures. In Europe, the implementation of the technology had advanced to the point that a Standing European Road Weather Commission (SERWEC, now SIRWEC — Standing International Road Weather Commission, with the addition of the United States and Japan) had been formed under the auspices of the Permanent International Association of Road Congresses (PIARC). Also the European Community had a Cooperation in Science and Technology (COST) project devoted to investigation of the use of weather information in support of snow and ice control activities. These technologies are now collectively known as road weather information systems (RWIS).

In a few areas within Washington, WSDOT personnel were already using weather information to assist in making decisions related to snow and ice control. Weather forecasts from a private meteorological service were being used, as were roadway sensors at Snoqualmie Pass. Sensors had been used as far back as the 1960s in the Interstate 5 Ship Canal Bridge, but these sensors were badly placed and unreliable. The sensors at Snoqualmie Pass had demonstrated reliability and utility for the snow and ice control managers at Hyak.

STANDARD WEATHER INFORMATION

Weather data and information come in three basic forms: observations, climatology, and forecasts. Observations are obtained from in-place (*in-situ*) sensors such as thermometers, hygrometers for relative humidity or dewpoint temperature, and anemometers for wind speed and direction. Depending on the needs of the users of meteorological data, additional data may be provided. Climatology refers to the compilation of observational statistics over a period of time, typically 30 years.

Most meteorological data gathering has been justified by the needs of aviation, and thus is geared to aviation needs. For aviation purposes, for example, cloud cover, weather conditions, surface visibility and restrictions to visibility (fog, smoke, haze, etc.), and barometric pressure are recorded by human observers using instruments, although automated observing systems are now being fielded. In order to support aviation, most formal weather observing facilities are located at airports. Aviators use observations and forecasts of weather conditions to make decisions on whether to fly or not, and how to go, whether locally or to some other location.

Other observations include winds, temperature and dewpoint, and atmospheric pressure at certain heights above the earth. Remote observations (not *in-situ*) also provide meteorological information. Weather radar data, for example, determine the intensities and locations of severe weather; meteorological satellite data provide identification and allow monitoring of larger-scale weather phenomena.

Remote data usually require interpretation by a trained meteorologist. However, meteorologists also use all of the other types of observations. Weather data are used to initialize computer models which produce forecasts, to monitor the behavior of the atmosphere, and to check forecasts. Observations are also critical to maintaining awareness of the need for weather advisories, watches, and warnings. In other words, meteorologists monitor observations, issue forecasts, and in general advise their clients on weather conditions which are critical to operations or safety of life and property. The clients then decide whether to take action or not based on thresholds for action they have established. Typical activities with weather impacts for which many people establish thresholds are construction (too cold, rain, wind), vegetation control (too windy, rain), golf (too cold, windy, wet, or thunderstorms), and even driving a vehicle (snow, ice, fog). Those individuals who wish to undertake these or other impacted activities can make decisions based on weather information if it is available to them in terms of the thresholds that matter.

National efforts to acquire better observations of the atmosphere are rapidly changing the quality and quantity of information. A nationwide weather radar system, called the Next Generation Weather Radar (NEXRAD), will provide improved severe weather, winter storm, and precipitation information. NEXRAD will provide nearly complete coverage of the contiguous 48 states using high-power, Doppler radar technology.

Automated observing equipment is being installed by both the Federal Aviation Administration (FAA) and NWS. The automated equipment will increase the frequency of data availability and the areal coverage of observations. The NWS is also installing and testing vertically pointing radars which acquire information nearly continuously on the state of the atmosphere.

The new observing capabilities will certainly improve understanding of the atmosphere and hence, forecasts. Some of the data, especially NEXRAD and automated surface observations, should directly assist decision makers who need weather information.

Without information, people can only guess as to what they should do. With weather observations in hand, people at least have knowledge of current conditions, but may find their activity impacted some time later. The best form of information is a tailored forecast of the conditions which would likely impact the activity during a specified timeframe. With such information, a more informed decision can be made about undertaking an activity.

Weather forecasts can be obtained from a number of sources. These include the National Weather Service (NWS); The Weather Channel™, which repeats the NWS forecast and provides general weather discussions along with views of satellite and radar imagery; and local media, which may reissue the NWS forecast or provide their own from staff meteorologists. Each of these sources provides forecasts which are general in nature and usually apply to a large area and pertain to people with a wide variety of interests. If forecasts are required to make decisions whether to perform certain maintenance activities at specific locations, or more detailed information about the types and timing of weather events to be expected is needed, then the forecasts must come from different sources.

Possible sources of detailed weather forecasts are private meteorological services or agency-owned or -funded meteorologists. (An example of the latter is the avalanche forecasting team partially funded by the WSDOT and collocated with the NWS forecast office.) A private meteorological service is hired under contract to provide specialized forecasts. These forecasts are usually tailored to the needs of the agency needing the forecasts. The fee for the forecast service is usually directly proportional to the specificity required in the forecast. The fee may also be tied to the frequency of communication required between the private meteorological service and the agency. For example, one telephone facsimile transmission per day of a prepared forecast would typically cost less than having the ability to conduct two-way telephone communication between the forecaster and the user to ensure such communication fosters mutual understanding of the user's needs and a forecast's meaning and applicability.

ROAD WEATHER INFORMATION SYSTEMS

Road weather information systems (RWIS) involve an extension of standard weather support discussed in the previous section.

Sensors

Meteorological sensors are used to obtain information on atmospheric parameters of interest for weather condition monitoring and forecasting. These parameters usually include temperature, relative humidity or dewpoint temperature, wind speed and direction, a determination of the occurrence of, and more recently, the amount, type and rate of precipitation, and visibility.

In addition to meteorological data, RWISs typically gather information about road conditions through the use of sensors placed in the road. As with meteorological sensors, these sensors provide information for road condition monitoring and forecasting. Roadway sensors provide important information for snow and ice control such as:

- the temperature of the pavement which is one of the key elements in the formation of ice, frost, or the bonding of snow to pavement. This information is especially useful in areas where the road surface temperature remains close to or frequently passes through 0°C (32°F).

- a measure of the conductivity of the road surface, which can be correlated to the amount of deicing chemicals residual on the pavement; and

- a measure of the road surface capacitance, which helps determine whether the surface is frozen, wet, or dry.

Additionally, a subsurface temperature, measured at about 45 cm (18 in) beneath the surface, is gathered to be used as an input for pavement temperature forecasting models, described briefly below.

Sensors in the road environment are connected to a Remote Processing Unit (RPU) which formats and transmits the data to a Central Processing Unit (CPU). The RPU is typically enclosed in a electrical box on-site, and data are relayed to the CPU via telephone lines or radio transmission. Data received at and stored in the CPU are accessible to maintenance personnel on a dial-up basis from either personal or portable computers. One CPU can serve many RPUs and dial-up customers.

Pavement and subsurface sensor data provide valuable information for developing forecasts of pavement temperatures. In the mid-1980s, models were developed to forecast pavement temperatures. It was recognized that for planning and resource-allocation purposes, knowing what the pavement temperature will be is crucial. The models developed are based on the energy budget at the surface of the pavement and can provide temperature forecasts up to 24 hours in advance. The models have demonstrated the ability to predict pavement temperatures within $\pm 1\,^{\circ}C$ 90% of the time [Thornes and Shao, 1991]. Pavement sensors allow a manager or forecaster to monitor the accuracy of a pavement temperature forecast.

A newer development in sensor technology is also providing the ability to simulate the pavement temperature at which moisture on the surface would predictably freeze. This is a sensor which cools a surface to the point where moisture freezes, as a surrogate for the actual pavement surrounding it. This provides a key piece of information needed for snow and ice control. The combination of a freezing-point sensor and forecasts of road temperature is expected to be the best information for the assessment of the potential for icing on roads.

In addition to their observing systems, RWISs usually include some form of forecast for weather and/or road conditions. Forecasts of weather events are important for snow and ice control managers. A forecast that snow is going to occur and that up to five or six inches are expected would certainly generate interest. However, what happens in the road environment may differ from what happens at a weather reporting station in a different location. Managers really need to know what is going to happen on their roads. With a forecast of road temperatures and durations above and below freezing, it is possible to determine if the snow will stick to the pavement, or whether ice or frost will form. Knowing whether a pavement will be wet in conjunction with blowing snow provides another indication regarding road icing.

Even with sensor systems in place, and forecasts of weather conditions and pavement temperatures available, maintenance managers still have a lot of information to try to interpret in order to make decisions for mobilizing snow and ice control forces. What managers really need is information which can be readily integrated into the decision process. Forecasts of this type are "tailored" to the needs of a manager.

Tailored Weather Forecasts

Snow and ice control managers make decisions to mobilize resources based on critical pieces of information, or thresholds. For instance, snow-plows are mounted if a certain amount of snow has or is expected to accumulate; spreaders are loaded if ice is observed or expected as a result of certain temperature expectations. Ideally, the mobilization decisions are based on forecasts of information rather than observations. Otherwise, the decision process is reactive rather than proactive.

In order to obtain the information ideally suited for proactive decision making, snow and ice managers need to get together with their supporting meteorologists to discuss needs and capabilities. Meteorologists must understand the snow and ice control decision process and ascertain, with the help of the managers, the critical thresholds of weather information used by these managers and when the information is needed. The meteorologists must also learn the road networks for which these managers have responsibility; the managers need to understand what the meteorological support capabilities are. Together, they need to establish what meteorological and road information will be provided, and how it will be provided. What must be certain is that the information provided is in the form needed for the decision process, rather than information which needs additional interpretation in order to make decisions. This is the essence of tailored forecasts. General forecasts, such as are available from the NWS or media, require further analysis and interpretation by managers in order to make resource allocation decisions affecting public safety.

Road Thermography

One troublesome aspect of using pavement sensors for detecting pavement temperature is that these sensors provide information on only an extremely small area of the pavement. In addition, because of cost, sensors are usually at least tens of kilometers apart. Where to locate the sensors also has been controversial. Sensors can be located to <u>detect</u> conditions at trouble spots. They can also be located in spots generally representative of a larger area and be used for <u>prediction</u> of conditions, or located to monitor "upstream" or imminent weather conditions.

In any event, the pavement temperature will only be known in a few locations. In the mid-1980s, a technology called thermal mapping was developed in the United Kingdom to fill in the gaps. Thermal mapping was eventually marketed by Thermal Mapping International, Ltd. (TMI), now known as Vaisala-TMI (VTMI). Because of the company name with thermal mapping in it, the more generic term of road thermography is being used in this report.

Road thermography involves driving a vehicle with a downward-pointing infrared thermometer over a road network, sampling the pavement temperature every few meters, and recording the temperatures. The record of temperatures is used to construct profiles of pavement temperatures under specific atmospheric conditions. The sampling is usually done during the dark and in the morning hours when the pavement temperature would tend to be the coolest. Sampling is done under clear-sky, cloudy, and rainy situations. In theory, these conditions will cover the general tendencies of road temperature, so that under similar conditions the profiles developed would be representative of the future conditions.

Having temperature profiles allows meteorologists and managers to see the range of temperatures over a particular road network. Such locations can be selected to provide maintenance people pavement temperature information important for known trouble spots and also specify the pavement temperature range expected (warmest and coldest spots). Other sites which can help specify more average conditions can also be identified. These locations assist in providing forecasters and maintenance personnel knowledge of the general conditions in the area.

It is also important to find locations that can provide representative meteorological information. These sites should be relatively open, i.e., provide the sensors an opportunity to measure unimpeded air flow. The thermal profiles can be used to identify locations which meet pavement temperature needs, as described above, <u>and</u> are meteorologically representative. The profiles can therefore reduce the need for sensors at many locations.

In addition to assisting with sensor siting, road thermography has been used in British Columbia and in the United Kingdom to help establish snow plowing routes. A manager may want to ensure that the coldest areas are attended to first to minimize snow bonding to the pavement; in some instances warmer areas may not require immediate attention. In a few instances, thermal profiles have shown that some bridges were warmer than surrounding roads, when the managers felt the opposite was true. For instance, in Vancouver, British Columbia, the City snow and ice control people learned from the thermography conducted there that a few bridges downtown were warmer than adjacent roads, and they now don't automatically treat them first when snow or ice is expected[1]. The same result appeared in thermal profiles of bridges over SR 522 at the Interstate 405 interchange near Woodinville.

In theory, thermal profiles can be superimposed on pavement temperature forecasts for individual sites in order to provide forecasts of pavement temperature between those sites. For instance, if a pavement temperature forecast is available for the Woodinville/I-405 location, then a forecast thermal profile of I-405 can be generated by using the site forecast as the starting point and using the shape of the profile as the extension of the site forecast. This technique has been used in the United Kingdom with demonstrated success, and was contracted for by the WSDOT for the area thermally mapped in WSDOT District 1, Area 5.

Effective Communications

In order for RWIS information to be useful, the supporting meteorologist and the manager need to establish communication protocols for information transfer. The communication needs to be two-way, at a minimum. A manager needs to be able to contact the supporting meteorologist in case additional clarification of information is required. This is one of the major differences between obtaining weather information from a forecaster dedicated to the snow and ice control program and getting it from the NWS or media. In fact, the ability for a manager and meteorologist to converse sets apart <u>tailored</u> forecast support from such private meteorological services where the manager may need to further interpret a product received via facsimile, teletype, or telephoned "menu" or "checklist" forecasts.

In addition, road managers need to provide evaluative information to the supporting meteorologist so that the forecast/decision process is continually refined. The evaluative information can be positive or negative feedback. The evaluation process can take place in real time during an event to assist forecasters to "fine tune" a forecast and to ensure maintenance personnel understand the forecast. The process is also important following an event to help identify ways, if any, to improve weather support over the long run.

The other aspect of RWIS communications involves being able to acquire RWIS information at the decision-maker level. Sensor data and some forecast information are provided through a central computer system to computer workstations. Unless decision makers can access the workstation, the decision makers have to rely on someone else to relay and perhaps interpret

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1 Based on personal conversation with the Assistant City Engineer in charge of snow and ice control.

the information. It is very easy for the information to be neglected, forgotten, or misinterpreted if it has to pass through multiple levels of human communications.

In order to make forecasts of road and weather conditions as accurate and timely as possible, the supporting forecaster should also have access to RWIS sensor data. It is difficult to issue accurate and reliable forecasts for specific locations when the initial conditions are not known. In Europe, in general, RWIS forecasts are issued by national weather services which have access to national RWIS data systems. In this country, the major vendor of RWIS hardware also provides forecasts of pavement temperature and weather and road conditions. The vendor, in order to protect that capability, considers the data from installed systems as proprietary. This precludes effective communication of RWIS data outside that vendor's system.

Staff Weather Advisor

One way of improving RWIS communications is to have a facilitator for implementing and disseminating weather information and technologies. This role can be filled by permanent agency staff, either full- or part-time; by a contract employee; or by a consultant on a professional services contract. The primary function of this role is to optimize the relationship, or communications effectiveness across the boundary between meteorologist and operational decision maker, and to advise each party on how to manage their activities to maximize the results of their work through their relationship with the other party. This role can be called a staff weather advisor (SWA). The purposes of a SWA would include:

- serve as a liaison between state agencies who use or have a need for weather information;
- help develop plans to satisfy agency RWIS requirements, including preparation of scopes of work, specifications, and guidelines for use in a solicitation for professional meteorological services and monitoring of their performance;
- facilitate effective communications between supporting meteorologists and snow and ice control managers;
- facilitate the development of proactive decision strategies using weather information;

- develop training materials integral to the implementation of RWIS technologies; and

- help identify suitable locations for RWIS installations.

Although the snow and ice control/road weather information system connection could be the impetus for implementing such a position, there are other programs, such as the Clean Air Act State Implementation Plan, and other agencies in Washington State which could also benefit from having access to a SWA. The SWA could be the linchpin for interagency involvement in establishing a weather information system to support weather-impacted governmental programs throughout the state. The RWIS would be an important part of such a system.

RWIS TECHNOLOGIES IN WASHINGTON STATE

The purpose of this investigation has been to evaluate the RWIS components acquired to support snow and ice control operations in District 1, Area 5. During the course of the investigation, the WSDOT had the opportunity to acquire additional RWIS capability in the Spokane area. As will be described below, the District 6 maintenance managers were able to "piggyback" on installations of weather monitoring equipment near Spokane International Airport. By assisting with the installations, providing access to right-of-way, and acquiring pavement sensors and computer hardware and data acquisition and display software, the WSDOT was able to create an RWIS for a nominal cost.

INVENTORY OF RWIS TECHNOLOGIES

Table 1 provides an overview of the RWIS technologies being used in the specified maintenance areas. This information is based on data and information acquired during the 1990-1991 winter, and updated for 1992. Maps in Appendix C show the detailed locations of the installations.

USES OF WEATHER INFORMATION

This section describes the uses being made by the snow and ice control managers of the RWIS technologies acquired by the WSDOT. Each of the technologies is described separately, although it should be remembered that each technology should be considered only a part of a system.

SENSOR SYSTEMS

The initial sensor installation was made in the Interstate 5 (I-5) Ship Canal Bridge. The purpose of this sensor was to provide warning to motorists, using a variable message sign, that the bridge deck was icy. The sensor was unreliable. In addition, it was placed in the shoulder. The readings from the shoulder are unrepresentative of the bridge deck due to contamination with debris and lack of traffic. The sensors were removed.

The next installations were near the Snoqualmie Pass summit. Surface systems, Inc (SSI) sensors were installed in the westbound lanes of the Denny Creek Bridge. The sensors have been used to monitor pavement temperature to assist in the applications of alternative deicing chemicals. WSDOT decided that no salt would be applied to the bridge deck in order to protect the structure from the problems associated with salt. These sensors were upgraded in 1990, and an additional system was installed near the summit. The data from these sensors are provided directly to the maintenance facility at Hyak, where decisions are made whether to apply alternative deicing chemicals.

Table 1. Road Weather Information Systems Technologies in Use[2]

	RWIS Technologies		
Maintenance District/Area	Sensors	Forecasts	Thermography
1/1		●	
1/2		●	
1/3		●	
1/4		●	
1/5	●	●	●
1/6			
3/1		●	
3/3		●	
5/1[3]	●	●	
6/1	●	●	
6/3		●	
other			

In 1989, sensors were installed at four locations in the District 1, Area 5 (see Figure 1, Appendix C). Each site contains the following complement of sensors:

- one pavement sensor for determining pavement temperature, surface condition (wet, snow, ice, etc.), and surface salinity (deicing chemical presence;
- one anemometer for wind speed and direction;

[2] Does not include wind sensors on bridges, e.g., the Lake Washington and Hood Canal floating bridges.

[3] All of District 5 gets forecasts issued, but areas 2 and 4 get alert forecasts only.

- one electronic thermometer and one hygrometer to determine air temperature and relative humidity; and

- one precipitation detector.

In addition, one site has a temperature probe about 0.5 in. below the pavement to help make forecasts of pavement temperature.

The purpose of these installations was to test the ability of the sensors, and forecasts based on the sensor data, to assist in the snow and ice control decision process. In theory, such information could be used to improve the timeliness and effectiveness of resource allocation decisions. Data from these sensors have been transmitted to the District 1, Area 5 maintenance headquarters; the computer central processing unit is being moved to the Traffic Management Center. Data are provided to field personnel via telephone.

The latest installation of sensors took place during the 1990-1991 winter, and subsequently for the 1992-1993 winter, in the Spokane area. Sensors were initially installed at the I-90, SR 2 interchange, and at the I-90, SR 902 interchange. These systems are unique in that they also have visibility sensors in the suite of instrumentation. Prior to the 1992-1993 winter, the additional sensor system was installed East of Spokane along I-90 at the Liberty Lake interchange.

FORECASTS

The use of weather forecasting support has been up to individual area maintenance superintendents. Nearly all contracts for weather forecasts have been with Northwest Weather Network, Inc., of Issaquah. These contracts are usually negotiated by the individual maintenance areas or districts. Table 1 shows those areas receiving forecasts. In those areas where SSI sensors systems are established, the maintenance area has also been able to subscribe to the SSI weather forecasting service.

For certain sites, RWIS vendors can provide pavement temperature forecasts. These forecasts require a subsurface temperature measuring device in order to assess the heat gain or loss from beneath the surface. Twenty-four hour forecasts of pavement temperature are issued for those sites. Pavement temperature is a critical ingredient in the decision process for snow and ice control. If the pavement temperature is expected to remain above freezing, and precipitation is expected, entirely different decisions are made than if the pavement temperature is expected to go below freezing. The same is true for condensation, which may result in either wet pavement, or frost or black ice on the pavement.

The recipients of these forecasts expressed nearly unanimous satisfaction with the service they received. Only one area superintendent interviewed expressed dissatisfaction with one service provider. But also almost unanimously, the satisfaction or dissatisfaction was based only on perceptions not analysis of objective data. The area superintendent interviewed who did maintain a record of forecast accuracy reported the forecasts received to be 83% accurate. Other research outside of WSDOT has indicated that pavement temperature forecasts can be accurate 90 percent of the time to within ± 1°C (1.8°F). [Thornes and Shao, 1991]

ROAD THERMOGRAPHY

In 1989, WSDOT contracted with TMI to have road thermography conducted on State roads in District 1, Area 5. Figure 1, Appendix C shows the roads on which thermal profiles were developed.

The thermography conducted in the Seattle area was used primarily to develop the ability to provide pavement temperature forecasts. WSDOT provided the thermography to SSI who built overlays of thermal profiles on computer-displayed road maps in order to color code forecasts of road temperatures. Theoretically, a manager would only have to pay attention to those road segments which have the specific colors for temperatures near or below freezing. The data were to also be used in helping to determine sensor sites. SSI identified locations, but indicated that in their opinion the thermal profiles were not essential to site selection.

Interviews with the forecast temperature "road map" users during the 1990-1991 winter season elicited praise and complete satisfaction with the products. Interviews with the same individuals in the 1991-1992 season indicated they didn't know whether the products were available or not. Following the 1990-1991 season, they felt the profiles weren't telling them anything they couldn't surmise on their own and therefore didn't try to access the profiles. SSI said they were providing the forecasts.

COMMUNICATIONS

RWIS sensor data can be obtained in a number of ways. In District 1, Area 5, data from the sensor sites are sent to the CPU via telephone lines and dedicated WSDOT communications. In District 6, Area 1, data are acquired by radio transmission West of Spokane, and by telephone line from the site at the Liberty Lake interchange on I-90. Sensors near Snoqualmie pass transmit data via telephone lines to the CPU at Hyak.

Weather forecasts are also obtained in various ways. Some Northwest Weather Network, Inc., 24-hour forecasts are received at vendor-supplied modem/printer terminals; others are received by telephone facsimile (fax) equipment. SSI forecasts include both 24-hour weather and pavement temperature forecasts.

Weather information passed to decision makers outside the location of the CPU/workstation is typically received by voice relay over telephone or radio. In some cases, data are retransmitted via fax, or the forecast is hand carried by someone who stops by the area maintenance headquarters.

Northwest Weather Network, Inc., does not have access to data from the roadside sensors. Data from SSI sensors are proprietary and are intended for use by WSDOT personnel only. SSI expresses concern over liability issues when forecasts are made using their data.

Ancillary weather information, such as weather maps and weather radar images can be subscribed to at the SSI-system workstation.

OTHER INITIATIVES

WSDOT maintenance managers at all levels have taken numerous steps to investigate technologies to improve snow and ice control. In addition to the technologies described, the WSDOT tested reflectors sensitive to air temperature. These reflectors, designed to change from reflecting white to reflecting blue as the air temperature changes from about 2°C (36°F) to 0° (32°F), are mounted on delineator posts. As the air temperature falls and the reflector colors change, motorists recognize the change and prepare for (the possibility of) ice on the roads. Unfortunately, the key parameter to measure is pavement temperature, not air temperature. Wisely, the WSDOT has decided not to implement the reflector technology.

In order to find another method for monitoring conditions, one area maintenance supervisor is testing the use of an infrared radiometer mounted outside the driver's side of a pickup truck cab. The radiometer points downward to the pavement and reports pavement temperature via a digital readout in the cab. The readout appears to be very responsive to pavement temperature changes. This data would be much more valuable than the digital air temperature readouts frequently installed in maintenance vehicles. Unfortunately, there is no current capability to record data. If this capability existed, it is likely road thermography could be conducted and temperature profiles constructed. Such an effort would require a validation of the measurements similar to that conducted in the SHRP H207 project.

FINDINGS

USES OF RWIS INFORMATION

Based on interviews, one of the early uses for weather information was intended to be dropping the practice of routine winter patrols. The purpose of patrols is to find trouble on the roads before the motorists do, and to take action as soon as problems arise. However, the practice of winter patrols is expensive. If maintenance decisions can be made based on forecasts, then patrolling for snow and ice control is, for the most part, unnecessary. Patrolling is a practice not easily done away with. Highway maintenance people in general, and snow and ice control people in particular, tend to be very risk adversive. Patrols have not been completely eliminated. They are implemented on a case-by-case basis.

The most frequent use of RWIS information has been to prepare to take appropriate action with impending adverse weather, typically snowfall which will require anti-skid treatment or plowing. In District 1, Area 5, for instance, crews were "armed and ready" when the first severe snowstorm hit the area in December, 1991. In District 3, Area 1, crews were actually not called out on New Years Eve of 1992, when the tailored forecast indicated the snowfall would begin later than other public forecasts indicated, which it did.

The Area Superintendent from District 6 Area also stated that the pavement temperature forecasts have been extremely valuable in deciding when to apply deicing chemicals, especially on the Sunset Hill section of Interstate 90 west of Spokane. He indicated they have had good success in only applying chemicals when needed, rather than applying chemicals rather routinely. District 1, Area 5, personnel have not had the opportunity to monitor successes because of the lack of occurrence of icing events in the region. Anti-icing, or pretreatment, involves putting down deicing chemicals just prior to a winter event to prevent ice or snow bonding. District 1, Area 5 maintenance personnel tested the process in the 1991-1992 and 1992-1993 winters. Some pretreatment is conducted at Snoqualmie Pass.

One significant problem associated with tailored forecasting support centers on the availability of RWIS data. Data acquired from SSI sensors are not available to forecasting services other than SSI. This means that Northwest Weathernet Inc. does not have access to either meteorological or pavement condition data at locations for which they must issue tailored forecasts. Similarly, the proprietary SSI data are not available to other highway agencies or state agencies, even though paid for with public funds.

Although the tests are not finalized, the Area 5 tests required information not available to the supervisor. The tests were conducted on SR 18 south of Interstate 90. No pavement sensors are in place along this highway. It was hoped to be able to use the pavement temperature from the sensor at the SR 18 - Interstate 90 interchange and thermal mapping profiles along SR 18. The profiles are too cumbersome to use in an operational setting. The decision makers resorted to using a hand-held radiometer to measure pavement temperature. The effort points to the need for good pavement temperature data and forecasts.

INTERAGENCY COOPERATION

The effort of the District 6 personnel to work cooperatively with other agencies in the Spokane area is especially noteworthy. For a small investment, the District 6, Area 1 maintenance personnel were able to gain access to RWIS data and forecasts. The small cost is due to the interagency involvement. This effort should serve as a model for the WSDOT to follow in expanding RWIS capabilities throughout the state.

Installations of other airport RWIS-type systems exist at Seattle-Tacoma International Airport, and Fairchild and McChord Air Force bases. One of the major costs in setting up an RWIS is the cost of the CPU. Each of these facilities, as is the case at Spokane International Airport, has a CPU which is capable of processing data from more RPUs than exist at the aerodrome. The potential exists for the WSDOT to use these CPUs to process data from WSDOT RPUs installed on nearby roadways.

In addition, other agencies in the local areas, for example King, Pierce and Thurston counties and municipalities within them could also participate. If more agencies than just the one with a CPU are interested, each agency could contribute to a CPU upgrade or purchasing another CPU. Similarly, Spokane County may be interested in helping expand the capabilities in the Spokane area. In each case, each agency would be responsible for the costs of RWIS sites for their specific use, their own communications costs, a *pro rata* share of the costs of shared sites, *pro rata* share of CPU upgrades or modifications, and *pro rata* sharing of system maintenance costs.

BENEFIT-COST ANALYSIS

A detailed benefit-cost analysis has been conducted in the SHRP research on the use of RWISs for snow and ice control [Boselly, 1991]. The analysis was based on a simulation model designed by Dr. Cy Ulberg of the Washington Transportation Center (TRAC). The net results of the analysis indicated that:

- RWIS technologies, working together, are cost-effective, i.e., sensors, forecasts, and road thermography. Benefit-cost ratios (B/C) exceed 5, when considering only the direct maintenance costs of labor, equipment, and material costs (i.e., benefits associated with lower budgets, not including benefits to the travelling public)

- Sensors and road thermography improve forecasting capability for both pavement temperatures and road conditions. Although their seemingly high cost lowers the B/C when compared to using forecasts alone, the level of service to the public is increased and the number of Type I errors (those decisions to not do something when one should have) is reduced.

Because of the detailed SHRP investigation and the lack of additional specific data, an additional investigation was not conducted in this project. However, it should be noted, that when compared to the costs of snow and ice control activities, RWIS technologies are relatively inexpensive.

In the following analyses, the cost of road thermography and RWIS hardware have been amortized over ten years based on a projected useful equipment life. Road thermography at $200 per mile becomes $30 per mile per annum over ten years when discounted at 8%. Using an example of four RWIS sites at $40,000 each in a 100-mile road network, their cost becomes $1,600 per mile, or $240 per mile per annum over ten years at 8% discount. If private meteorological services are contracted for at $3,000 per winter for the 100-mile network region, this annual cost is $30 per mile. If telephone lines are used for communication, another $1,500 per winter, or $15 per mile per year, is required. The total annual cost of a complete RWIS is about $315 per mile when discounted at 8%. If the initial RWIS capital costs are "straight-line" depreciated (amortized without discounting), the total annual RWIS cost can be considered to be only $225 per mile. The costs of snow and ice control in Washington are about $15 million per annum for the nearly 7,000 miles of state roads, or over $2,100 per mile per annum.

If RWIS sensors are placed about 30 km apart, over 250 locations would be required to set up a 30-km grid of RWIS sites over the entire state. However, given the climate of Washington, many such locations would be redundant. If even 50 sites were installed, road thermography were conducted on perhaps 3,000 miles of State highways, and tailored weather support were obtained from a private meteorological service, the total costs, using the same figures as above, would amount to about $600,000 for road thermography and $2,000,000 for hardware. This $2,600,000 could be "straight-line" amortized over 10 years for $260,000 per annum ($390,000 when discounted at 8%). Forecasts to cover the state could run as high as $100,000 per year, and annual communications costs are estimated at $20,000 for telephone. The total undiscounted annual cost, then, would be $380,000, which is less than three percent of the annual snow and ice control budget.

OPPORTUNITIES FOR RWIS EXPANSION

Given the potential for improving snow and ice control response, and thereby improving the service provided the traveling public through the use of RWIS, opportunities exist statewide for implementing RWIS technologies. These opportunities include using forecasts of weather and road conditions to develop proactive snow and ice control procedures, i.e., procedures that do not wait for the observation of a problem and then react to it. Reducing or eliminating patrolling is one example, but being able to get the right equipment to the right place at the right time is a key ingredient in using RWIS information successfully. There is no reason for any maintenance area to go without tailored forecast support. The cost of a tailored forecast service compared to the cost of snow and ice control is relatively insignificant, given that the potential payoff is great.

In addition to tailored forecasts, RWIS sensors and associated pavement temperature forecasts can be used in many locations, and likely with more opportunities for success than in the Seattle area. Every maintenance district, and perhaps every maintenance area, has one or more locations where RWIS sensors would provide useful prediction or detection information for snow and ice control. However, some locations may be more problematic for snow and ice control than others. Consultations with maintenance personnel, and meteorological guidance should be combined in developing a list of projected sites.

In order to assist in the determination of future sensor sites, road thermography should be considered for areas where more than one sensor site may be necessary, especially for urban locations in Western Washington and along major east-west or north-south corridors.

PROBLEMS NOTED

SENSORS

In reviewing data from sensors after their initial installation, we noted a significant problem with the pavement sensor located with the RPU at NE 130th and I-5 in North Seattle. The pavement temperature at the sensor location appears to be influenced significantly by traffic. At 5:30 A.M. on weekdays, the reported pavement temperature began to rise. One would not expect the temperature to rise until after sunrise and the sun is shining on the pavement. The sensor is located in the center of the lane, an area which is shown to be influenced by vehicle traffic, and also is located downstream from an unmetered on-ramp where the morning commuter traffic can be heavy. For pavement temperature forecasting purposes, it is recommended that pavement sensors be placed in lanes with the least traffic. Because minimum pavement temperatures are usually experienced in the early mornings, pavement sensors in areas with commuter traffic should be placed in the lowest traffic volume outbound morning traffic lane [Boselly, et al, 1993]. The existing sensor could still be used for monitoring road surface conditions during commuting hours, i.e., detecting actual conditions at that location.

Another sensor siting problem exists at the NE 195th and I-405 interchange near the Woodinville interchange. The site was apparently selected because of the availability of electrical power and/or telephone lines. The 10-meter tower with anemometer (wind sensor) on top is located alongside a line of evergreen trees. The trees block wind flow from the southwest, the prevailing wind direction during most inclement weather. In addition, only one pavement sensor was installed at the location. Road thermography showed very different conditions for the elevated structures at the Woodinville interchange than reported by this sensor. At least one pavement sensor should be installed in the elevated structure. Sensors can be located up to 760 m (2,500 ft) from an RPU, and up to four pavement sensors can be located with each RPU.

The incremental cost of adding a pavement sensor is only about 10% of the cost of an RPU. At each RPU location, at least two surface sensors should be installed, one for prediction (subsurface) and the other for detection (surface).

In the Seattle area, the sensor systems installed at the four RPU locations, when combined with road thermography, provide good coverage of the area for the most part. However, the weather to the east of the interchange of SR 18 and I-90 can be significantly different from weather to the west because of the influence of the Cascade Mountains.

Downslope, easterly winds can make the weather and the pavement conditions different enough that sensors should be installed in the North Bend area. Similarly, weather and road conditions to the south of the interchange on SR 18 can differ markedly from those at the interchange. Sensors should be installed along SR 18 near the Tiger Mountain summit.

Discussions with maintenance superintendents suggest many locations exist in each maintenance area where RWIS sensors could improve the efficiency and effectiveness of snow and ice control, and improve the service to the road users. Examples where sensors could assist, beyond those mentioned above, include (at a minimum):

- District 1 — along I-5 near Lake Samish, SR 2, and along I-5 near the Snohomish River;
- District 2 — SR 97 to Swauk Pass;
- District 3 — SR 104, 101 in Mason County and along I-5 in the Nisqually Basin area;
- District 4 — SR 101 North of Raymond;
- District 5 — Along I-82 near Manastash Ridge and in the Yakima Valley; and
- District 6 — SR 195 South of Spokane, Nine Miles Falls.

Detailed lists of both meteorologically and operationally significant lists could be developed working cooperatively with area maintenance personnel and meteorologists.

FORECASTS

Snow and ice control managers, in general, expressed satisfaction with the weather forecasts they had been receiving. In nearly all cases, the level of satisfaction was based on "gut feel;" only one manager conducted formal evaluations. This lack of formal evaluation can result in dissatisfaction when in fact the service is better than is perceived.

Another observed problem with the lack of evaluation is the likelihood little or no feedback was provided to the forecasting service; and they therefore were deprived of a basis to improve the quality of the service and its ability to meet the needs of the maintenance managers. The forecasters need positive and negative feedback to let them know they are on track or off base with the focus of their forecasts, both during a storm event and as a seasonal evaluation.

USE OF RWIS DATA

We noted a few problems with the use (or nonuse) of RWIS data. As already mentioned above, it was unknown by Area 1 managers during the 1990-1991 winter whether the WSDOT was receiving route-map pavement temperature forecasts, even though the WSDOT was paying for these forecasts and SSI said they were providing them. Additionally, no data were available from the RPU in North Seattle due to communications failure. Following the heavy rains of November, 1990, and the heavy snows in December, maintenance attention was then diverted to other activities than snow and ice control.

In general, for decision making purposes, pavement temperature and forecasts, and weather and road conditions and forecasts, are not readily available to the foremen who frequently are making the decisions. Each foreman responsible for an area in which RWIS data exist should have ready access to the data. Use of a portable computer would provide a capability to do this. The RWIS can be contacted from home or anywhere there is a phone to obtain the latest information. This process should become routine if snow or roadway icing is occurring or expected.

The maintenance people making the decisions for allocating snow and ice control resources don't know how to use the RWIS data. Consequently, the data are not used as effectively as they could be. Some of the symptoms of not knowing how to use the data are manifested in either backing away from the use of the system or speaking ill of the system or some of its components.

A lack of training on the purposes and expectations of RWIS, and especially how to use the data, is the primary reason for its lack of use. In order to properly use weather information, a decision maker must be able to select the appropriate weather information and use that information proactively. It is one thing to know how to push the right buttons on a computer to get weather information; it is another to be able to use the data. It frequently requires a behavioral change that is only likely with appropriate training. Most snow and ice control decision makers have been making conservative, reactive decisions for so long, they don't understand doing anything differently. They also don't know how to determine what is the appropriate information to use to make a proactive decision, or when to make it. As a consequence, some of the users resist using tailored weather information, feeling that it has no relationship to snow and ice control. Some also feel that the RWIS technology is not relevant to their needs, and that perhaps it is only something for people to play with.

Some of the reluctance to use RWIS data also comes from two standard management problems. First, there are indications that some perceive the RWIS to be an idea from headquarters that is being foisted on them. It was implied more than once that if the RWIS had not been paid for by headquarters, it probably wouldn't be in use. Second, a new person into a management position may perceive that the RWIS was the idea of the previous manager and therefore as unnecessary baggage left from a previous administration. In either case, there is a reluctance to use the RWIS; there is no buy-in into the system, and in fact, resentment. Adequate training is necessary to demonstrate the utility and advantages of having the RWIS, and that improved service to the public and reduced costs of snow and ice control are sufficient reasons for using the RWIS data and forecasts.

ROAD THERMOGRAPHY

The thermal profiles provided under contract to the WSDOT have basically languished in disuse since the thermography was conducted. The primary reason is that the data have little utility by themselves. They require detailed analysis and assimilation, perhaps through discussion with the technicians and a meteorologist to understand them. In addition, the meteorological content of the report accompanying the profiles did not provide engineers with sufficient confidence in being able to relate pavement temperature profiles to experience.

A prime example is the elevated structures in the Woodinville area showing up warmer than the surrounding roads. Experiences of maintenance personnel point to these structures icing up before the surrounding roads. There are at least three possible reasons for the apparent discrepancy.

- The structures are over the Sammamish Slough, a source of moisture for the structures to ice up first, even if the surface temperatures are warmer than surrounding roads. They may be warmer and still be below freezing.
- The structures may be warmer because the measurements were taken in late winter when the subsurface under the surrounding roads may have been close to its minimum and the flow of heat may have been away from the road surfaces.

- The meteorological conditions could have included downslope winds (easterly) which would tend to warm the exposed elevated structures.

- Maintenance personnel may be mistaken in their perception, having forced their observations to fit their expectations that bridges get cold first.

In any event, insufficient information was included for discussion purposes and the thermal profiles were looked at with some uncertainty, if not disbelief. More careful documentation of measuring conditions could help solve this. Also, the type of data acquired by another vendor, called "road climatology," actually includes measuring atmospheric temperatures at two heights along with the pavement temperature. Such data could also have helped to assuage fears that the pavement data were not correct.

COMMUNICATIONS

The RWIS installations in the Seattle area, geographically spread out more than in the other areas, rely on "land-line" communications — either WSDOT lines or telephone company lines. Telephone RWIS communications are generally the least reliable and the most costly. The WSDOT line used from North Seattle was the least reliable and least costly. The telephone communications from the SR 18/I-90 site were the second least reliable and the most costly. Long distance charges are incurred for communications with the RPU.

Having no data for one winter is costly in itself. Little or no data were available from North Seattle all of the 1990-1991 Winter; data gaps were frequently experienced from the SR 18 site, sometimes for days. Because of the unreliability of the telephone lines to the SR 18 site, it is impossible to identify the reasons for data gaps as bad telephone lines or the RWIS computers were experiencing problems.

In addition to the data gaps themselves, the missing data seemed to generate complacency and a general lack of caring and knowledge whether data existed or not. Some of this is because the data are not routinely accessible to the foremen who should be monitoring the data. Nonetheless, with the system's communications not working properly, there seemed to be little urgency in getting things fixed.

INTERAGENCY OPPORTUNITIES

In some geographical areas, the WSDOT maintenance personnel and other-agency personnel have very strong ties and working relationships regarding snow and ice control; in other areas, the agencies function autonomously. In many respects, the relationships are a function of the personalities of the managers within each agency.

In those areas where strong relationships exist, opportunities for sharing information, and perhaps for interagency cooperation in implementing RWIS are most probable. In addition, cost sharing can reduce the financial burden for one agency or another, and perhaps make possible an otherwise difficult purchase. Where agencies are autonomous, opportunities are lost because one agency is not aware of the goings on with another.

Snow and ice control in the Spokane area was a topic at monthly meetings of managers from three agencies: city, country and state. If is partly because of this relationship that the cooperative RWIS was possible in the area. The monthly meetings have been abandoned, and future cooperative opportunities may also have lessened.

OVERALL EVALUATION

The implementation of RWIS technologies in Washington State has been slow. As is the case with many fields of endeavor, people or organizations try something new because of the push from one or two individuals. It may also result from the successful marketing of one or more vendors. Tight fiscal constraints may generate interest in finding solutions to high expenses for snow and ice control; pressure from one or more sources to do a better job may pique interest. Or yet, it may result from "falling into" a situation where the cost is so minimal, it almost has to be tried.

Such is the case with RWIS in Washington State. In one way or another, all of the above reasons apply. Why it hasn't progressed farther may be for some of the same reasons. Certainly one or two advocates have retired or taken new positions. Some managers are reluctant to spend "maintenance money" on the technology, even though the potential exists to reduce maintenance costs. And perhaps the weather wasn't so bad that high snow and ice control costs stood out.

At least one of each RWIS technology has been type-tested by the WSDOT. The potential exists for RWIS information to become an important and powerful tool for the WSDOT to use for snow and ice control. In general,

- RWIS information can be cost effective, with respect to direct costs of labor, equipment and materials;

- Sensors appear costly, but can improve forecasts and hence the level of service;

- Road thermography is an important tool for helping to site sensor systems, but has limited operation use unless used in automated pavement temperature forecasts.

- Communications are critical to successful implementation.

Within WSDOT, discussions with managers provide a mixture of responses, ranging from it's great and I use it all the time, to I don't see the value of it. This applies to forecasts as well as sensor systems. Responses are even less enthusiastic for road thermography.

The biggest problem is that the systems have not been given a real chance to fail or succeed. Some of the managers really don't know how to change their practices associated with snow and ice control resource allocation decisions as a result of improved information. They still tend to be reactive, even when recognizing that becoming proactive could be a much better way of doing business. Also, the managers who have at least a peripheral interest in weather seem to use the system more than others. The lack of interest, or perhaps more properly, lack of training in the systems' use, has led to inattention in some instances. Based again on interviews, the managers that use the system regularly have more confidence and apparent need for the services and products than do the casual users.

It is especially difficult for managers to quantify the utility of RWIS. Whether the system reduces costs of labor, equipment, or materials, is frequently a subjective evaluation. The manager must try to imagine what decisions would have been made without the data, and compare the results with decisions made with the data.

By the time the system in Spokane was up and fully running the winter had disappeared, and there were few opportunities for evaluating the new RWIS. In the Seattle area, the frequency of occurrence of winter weather is not high, but December 1990 provided some unique insight. Managers felt that they were more than adequately prepared for the snow storms, were "armed and ready," and provided a better level of service than they would have without the data. The fact that many roads became impassible was due to roads being clogged by heavy traffic and eventually abandoned vehicles. Maintenance vehicles were provided the opportunity for one only pass in most cases, before they too, were caught in clogged traffic. But that pass provided improved conditions earlier than would have normally been the case.

Managers who have been using forecasts regularly for a few seasons are developing their own methodology for proactive decision making. With experience by both the providers and the users of the forecasts, the effective use of the information will improve. If the meteorologists can also get access to the RWIS sensor data, the forecast accuracy will also likely improve. And, it is the opinion of the author that with proper training, which should be designed to motivate and create a positive atmosphere for change, the importance of the RWIS data to effective decision making will be realized and the value of the RWIS will improve.

RECOMMENDATIONS

The following recommendations are offered to correct deficiencies noted or to take advantage of technology not fully exploited. The WSDOT should:

- Engage department personnel in developing a road weather information system era concept of operations that maximizes proactive use of the improved decision-making information.

- WSDOT Managers need to determine how to optimally invest in RWIS and to establish a process to evaluate that performance with RWIS compared to expectations.

- Consider moving existing District 1, Area 5 RWIS sensors as follows:

  - At sensor site, place pavement sensors in the lane with the least early morning traffic;

  - Add, at a minimum, sensor sites along I-90 near North Bend and SR 18 near Tiger Mountain summit;

  - Move the installation at the NE 195th/I-405 interchange into an open area, and add at least one pavement sensor on one of the elevated structures at the SR 522/I-405 interchange.

- Add additional RWIS capabilities throughout the state, to include:

  - a CPU within each maintenance district;

  - a workstation at each maintenance area;

  - portable terminals or computers for use by foremen for information acquisition;

  - sensor installations in sufficient numbers to provide meteorological and operational information to decision makers and meteorologists. Four to six sites in each maintenance area should be considered, with six being optimal: one at a warm location, one at a cold spot, and four at "average" or representative locations. The sites should be selected to also cover trouble spots. A few examples include, at a minimum:

- District 1 — along I-5 near Lake Samish, SR 2, and along I-5 near the Snohomish River;
- District 2 — SR 97 to Swauk Pass;
- District 3 — SR 104, 101 in Mason County and along I-5 in the Nisqually Basin area;
- District 4 — SR 101 North of Raymond;
- District 5 — Along I-82 near Manastash Ridge and in the Yakima Valley; and
- District 6 — SR 195 South of Spokane, Nine Miles Falls.

- Develop a statewide prioritized list of locations where RWIS sensors would assist snow and ice control decision makers, based on both operational and meteorological considerations and a participative approach with the districts. Criteria for rank ordering the proposed sites need to be developed.

- Develop and conduct a training program to orient maintenance supervisors to the use of RWIS data and information to foster acceptance of the technology at all levels, and to facilitate the integration of this information into the snow and ice control resource allocation decision process.

- Explore further RWIS procurement efforts with other agencies, especially cities and counties, using the District 6, Area 1 (Spokane) experience in multi-agency procurement as a model.

- Establish procedures for preventive maintenance and calibration of installed RWIS hardware.

- Institute a formal forecast feedback program for operational decision makers and managers to use in providing both positive and negative feedback to forecasting services, during a storm event itself, and as evaluation during and after the season for input to planning better tailored weather support.

- Require in any future RWIS procurement that data from the RWIS are to be considered in the public domain to ensure the widest dissemination is possible.

- Create a staff weather advisor position, either a part-time or partially funded meteorologist or consultant to:

    - assist in the expansion of the RWIS technology, to include recommendations for siting of RWIS instrumentation;

    - help develop an RWIS implementation training program;

    - establish a forecast evaluation program; and

    - work within the WSDOT across state agencies as an advisor for establishing and satisfying weather information needs.

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Thornes, J. E., and J. Shao. "A comparison of UK road ice prediction models," **Meteorology Magazine,** 120, 1991.

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Above publications are available in the WSDOT Library.

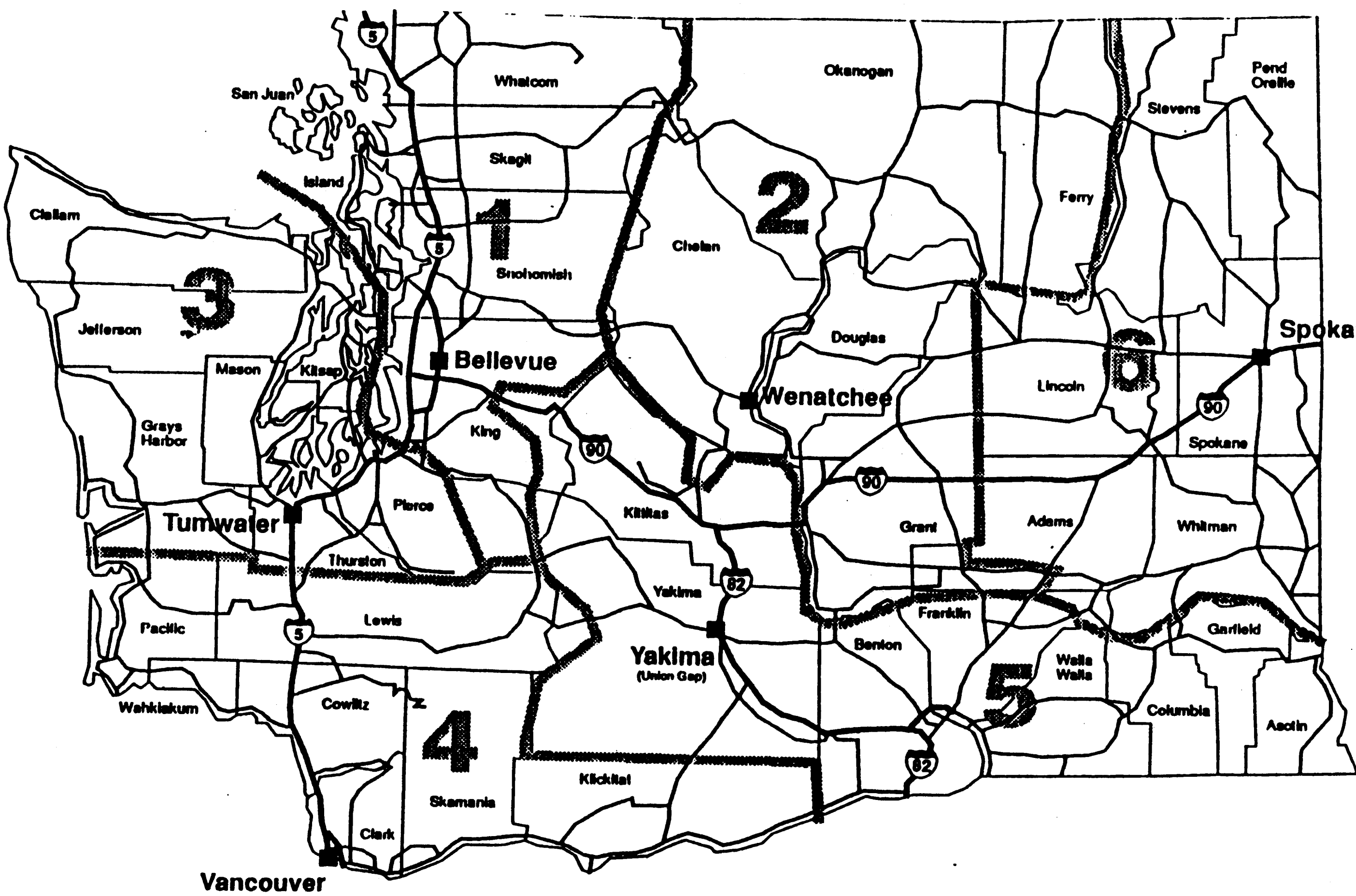
APPENDIX A

List of Acronyms

B/C	Benefit to Cost Ratio
COST	Cooperation in Science and Technology (European Community)
CPU	Central Processing Unit
Mn/DOT	Minnesota Department of Transportation
NWS	National Weather Service
PIARC	Permanent International Association of Road Congresses
RPU	Remote Processing Unit
RWIS	Road Weather Information System
SERWEC	Standing European Road Weather Commission
SHRP	Strategic Highway Research Program
SIRWEC	Standing International Road Weather Commission
SSI	Surface Systems Incorporated
SWA	Staff Weather Advisor
TMI	Thermal Mapping International, Ltd.
TRAC	Washington Transportation Center
VTMI	Vaisala-TMI, Inc.
WSDOT	Washington State Department of Transportation

APPENDIX B

WSDOT Districts



APPENDIX C

Detailed Locations of RWIS Sensor Installations

Locations of RWIS installations are shown as large black dots on each of the following two maps. There are three locations near Snoqualmie Pass, four in the Seattle area, two west of Spokane, and one east of Spokane.

APPENDIX C

Detailed Locations of RWIS Sensor Installations

Locations of RWIS installations are shown as large black dots on pages 48 and 49. There are three locations near Snoqualmie Pass, four in the Seattle area, two west of Spokane, and one east of Spokane. Page 48, Figure 1, also depicts the road network for which thermal profiles were developed in District 1, Area 5.

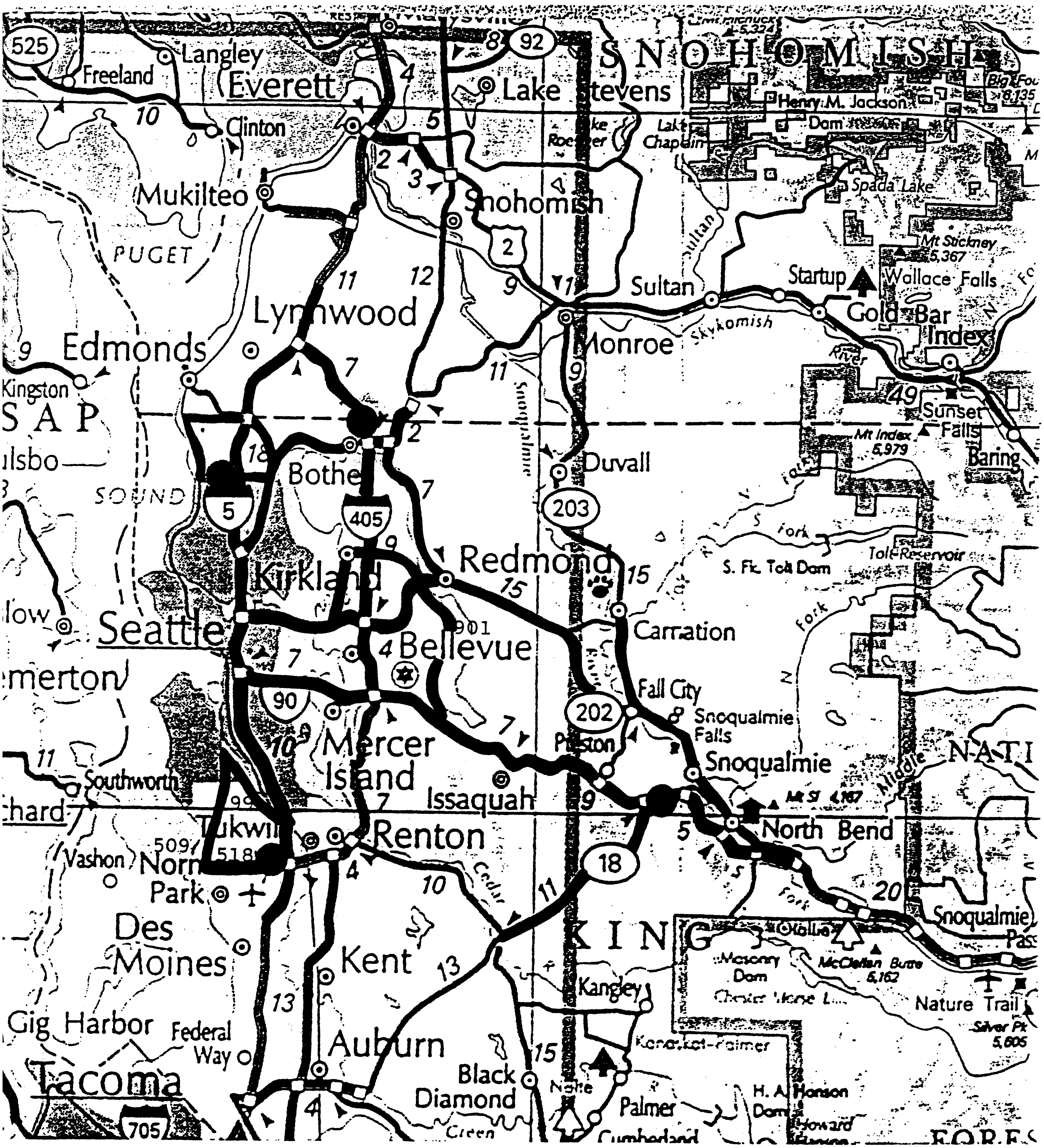


Figure 1. **Black dots show the locations of RWIS sensor sites in District 1, Area 5. Thick black lines show the road network where thermal profiles have been developed.**

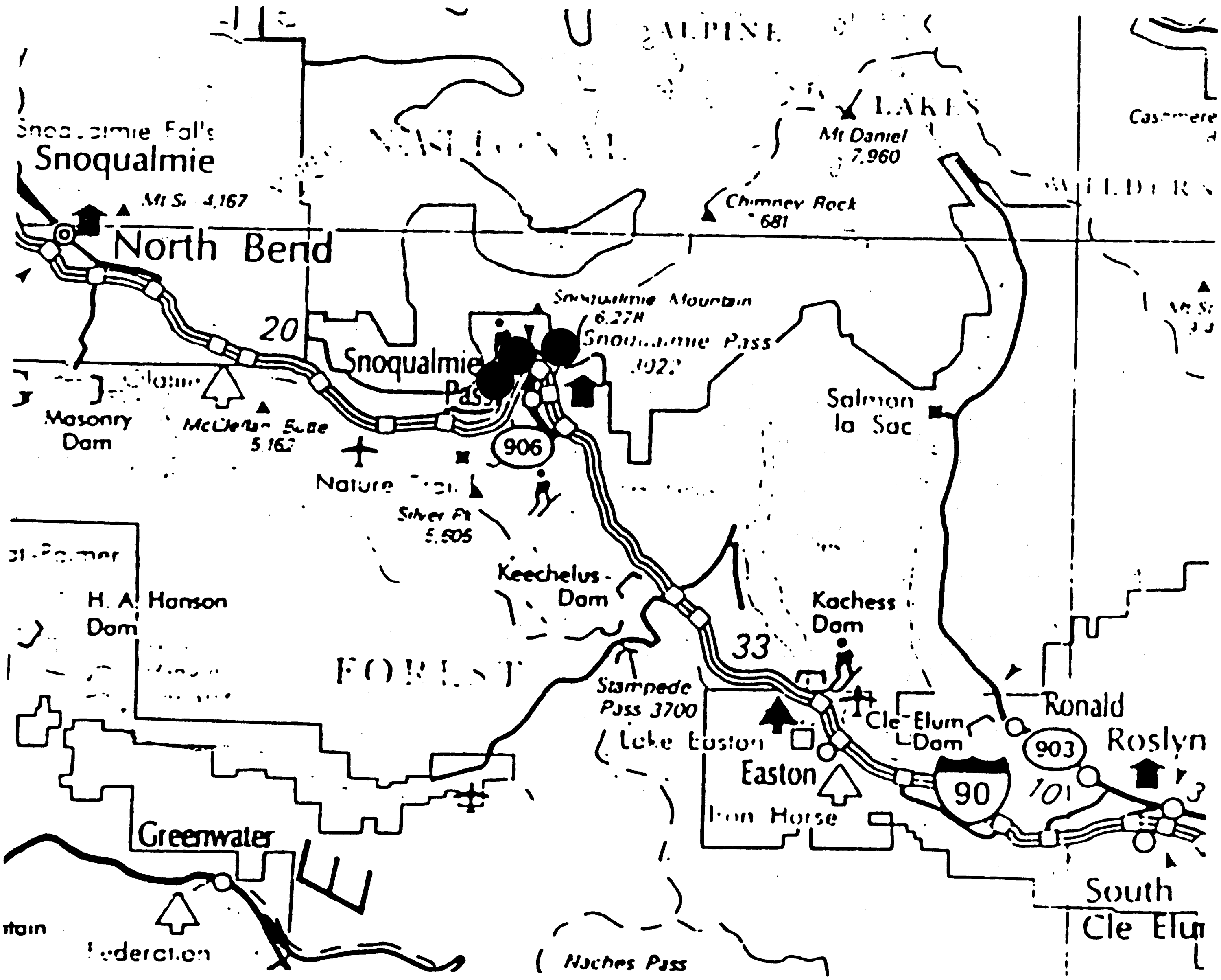


Figure 2. Black dots indicate approximate locations of RWIS sensor sites near Snoqualmie Pass.

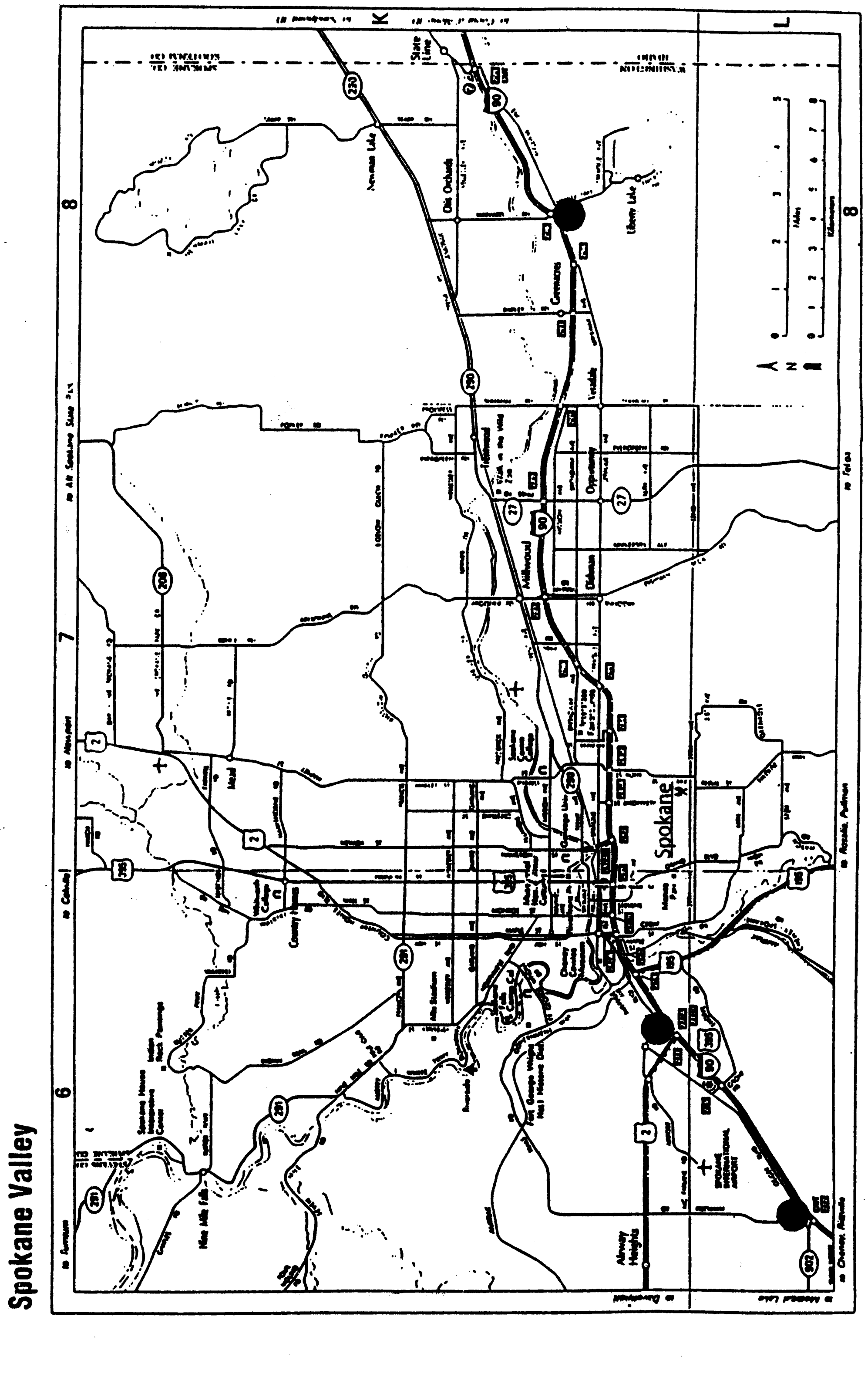


Figure 3. Black dots indicate locations of RWIS sensor sites near Spokane.