seemed to be reduced. A review of this effort might provide insight for future road design, construction, and reconstruction.

- *Resources Issues*

Equipment and staffing levels generally result in two to four hour cycle times, but in some cases, cycle times can reach six hours. These staffing levels may be adequate for spread-only operations, but are probably insufficient for clearing moderate to heavy snowfall. The staffing was developed to provide maintenance for one inch per hour snowstorms. Staffing and equipment issues, along with LOS goals, are addressed in Section V.

In addition, reducing cycle times in some areas will require the addition of satellite stockpiles and loaders to maximize the ability to apply materials.

The current staffing level also permits two operators per truck per 24 hours only if everyone shows. There may some opportunity to modify operator assignments once the LOS is specified for all areas. Currently there is also some redistribution of resources for the snow and ice control season. Extra personnel are available in the traffic maintenance Orgs. However, they are usually in the Central or District Headquarters areas. Flagstaff District has also borrowed personnel for the winter maintenance season from the Phoenix District.

2.4.3 Snow and Ice Control Resources

In order to evaluate the equipment resources available for snow and ice control, the project team gathered information from the District Snow Plans, contact with District personnel, and from ADOT records. Table 4 lists the equipment available for snow and ice control in the five districts, by Org (1997-1998).

The ADOT snow and ice control truck fleet was comprised of 238 units in the initial count. This included plow and spreader trucks, equipment for liquid applications, and loaders. This does not include equipment that can be leased from ADOT Equipment Services in Phoenix. About 20 percent of the fleet is two-axle trucks with five-yard material capacity. This limits the material spreading range to half that of the three-axle, ten-yard capacity trucks. Most newer trucks have wing plows. The equipment shown in the table does not include road graders and dozers.

Even with the advanced age of the fleet, up time is remarkably good. According to Equipment Services records, exclusive of preventive maintenance, the trucks are only down about 5 percent of the time. This means most of the equipment is typically available for snow and ice control. Interviews with operators, however, indicate that the operational availability of the equipment deteriorates with the length of a storm and the subsequent snow and ice cleanup. What begins with better than 90 percent of the equipment operational at the start of a storm, becomes about 75 percent after 24 hours. After 48 hours, mechanical problems become even more apparent due to the age of the equipment. The loss of equipment impacts the lane miles required of the remaining equipment and the work level of the operators on the road.

Table 5 lists the staffing for each of the Orgs. Orgs are typically staffed with two maintenance personnel for each snowplow truck, plus foremen and secretaries who should not plow. This results in Orgs in heavy snow areas being staffed with more FTEs than would

Table 4. Snow and Ice Control Equipment[1]

Org	2-Axle Trucks	3-Axle Trucks	Loaders	Other
HOLBROOK DISTRICT				
Holbrook	4	4	2	2 Water tanks[2], loaders
Winslow	3	5	2	
Kayenta	3	5	3	
Keams Canyon	3	2		Additional spreader[3]
Ganado	4	3	2	
Chambers	3	4	2	
KINGMAN DISTRICT				
Kingman	3	4	3	1 deicer truck
Seligman	4[4]	3	3	1 deicer truck
Needle Mountain	2	2	2	1 spreader, no plows
Wikieup	2	2	2	2 snowplows, 3 spreaders
PRESCOTT DISTRICT				
Prescott	2[5]	5	2	2500 gal deicer truck
Cordes Junction	2[4]	3	3	
Wickenburg	1	1	2	
Payson	3[4]	6	3	
GLOBE DISTRICT				
Globe	3[6]	2	2	1 water truck, anti-icing
Roosevelt		3	4	
Superior	1	2	2	1 13-yd dump truck
Indian Pine		6[7]	2	13yd dump +1 snowblast[7]
Show Low	3[6]	4	3	1 13-yd dump truck
St. Johns	2	2	3[8]	1 13-yd dump truck
Springerville	2[6]	5	3	1 Unimog
FLAGSTAFF DISTRICT				
Flagstaff	1	7	3	1 snowblast
Williams	2[4]	7	2	1 trk for liquid chemicals
Gray Mountain	1[9]	3	2	
Little Antelope	2[4]	5	4	
Page	3	2	2	
Fredonia	3[5]	2	3[10]	1 snowblast
District Pool	2		1	
Equipment Svcs		1		

[1] Equipment list comes from equipment billings, list of snow equip. from Equipment Svcs and from Superintendents
[2] Holbrook has two additional trucks 1500 gallon water tanks which can be used for applying snow and ice control chemicals; two additional loaders are in the District pool.
[3] Keams Canyon additional spreader is a v-box sand spreader for a small truck.
[4] Plus one Mack snowplow truck
[5] Plus one 1-ton truck and 1 Mack snowplow truck
[6] Plus one 1-ton with plow and spreader
[7] Plus one boot truck for anti-icing
[8] St. Johns shares a loader with Holbrook
[9] Plus two Mack snowplow trucks
[10] One loader is located in Littlefield

Table 5. Organizational Staffing[1]

Org	FTEs Allowed	FTEs Filled	Admin[2]
HOLBROOK DISTRICT			
Holbrook	15	11	0
Winslow	16	13	0
Kayenta	12	12	1
Keams Canyon	10	9[3]	0
Ganado	12	12	0
Chambers	12	11	0
Org. 8769	9[4]	8	3
KINGMAN DISTRICT			
Kingman	16	13	1
Seligman	14	14	1
Needle Mountain	12	10	1
Wikieup	11	11	1
PRESCOTT DISTRICT			
Prescott	16	16	1 sec'y[5]
Cordes Junction	14	12	1 sec'y
Wickenburg	10	9	1 sec'y
Payson	17	17	1 sec'y
GLOBE DISTRICT			
Globe	13	12	1
Roosevelt	11	11	1
Superior	11	11	1
Indian Pine	15[6]	12	1
Show Low	16[7]	14	1
St. Johns	12[8]	10	1
Springerville	15[8]	14	1
Org. 8369	4	3	0
FLAGSTAFF DISTRICT			
Flagstaff	17	17	1
Williams	17	18[8]	1
Gray Mountain	14	14	1
Little Antelope	17	15	1
Page	12	12	1
Fredonia	12	12	1
District Pool	5	5	0

[1] Staffing information was obtained from district administrative services or supervisory personnel.
[2] Administrative Support. Secretaries counted in FTEs.
[3] Two temporary employees.
[4] Includes two transport drivers with CDLs
[5] Secretaries not included in FTEs in the Prescott District
[6] Org with three seasonal employees
[7] Orgs with two seasonal employees
[8] Allowed 5% overfill

normally be needed to support the highway maintenance feature inventory and more personnel than needed to perform the summer work. Some Maintenance Engineers therefore hold off on filling vacant positions until late summer or early autumn. They then train the new hires for winter snow and ice control work. Depending on the winter storm burden on the Org, this may not afford enough time to fully train new people for the arduous winter tasks.

This staffing arrangement does not provide for illness or other loss of personnel during the winter and can lead to snow and ice control equipment not being utilized during winter storms. Additional workers are or can be made available. In some cases, additional personnel have been obtained from Phoenix Maintenance for the winter. Most districts have additional personnel with CDL's who could plow snow, e.g., transport drivers, and vegetation control and striping crews. These employees should be trained in snow removal and the operation of snowplows. In some cases, help can also be obtained in the Flagstaff, Holbrook, Prescott, and Globe Districts from sign and striping crews where there may be CDL-qualified workers.

The lane mile requirements for snow and ice control vary significantly depending on the climate of an area, the types of roads, the available equipment, and the location of stockpiles. Due to variations in snow plans between districts, it was not always readily apparent what equipment was assigned to a particular route. Conversations with supervisors ironed out most of the uncertainty.

From what could be gleaned from the snow plans for Orgs along I-40 and I-17, lane miles per truck route were distributed as shown in Table 6. The lane miles per truck route on I-40 ranged from an average of about 42 miles in Winslow to about 85 miles in Seligman. On I-17, the lane mile averages ranged from approximately 111 in Little Antelope to approximately 144 in Cordes Junction. Some of the Interstate routes included in the averages above also included some distance on state routes. Additionally, in reality some of the routes are longer because the operator had to travel to the route starting point. For example, if the distance to a route start were included in the calculations for Holbrook, the average would be about 56 lane miles. And, in reality, if there is snow or ice on the road, and a material application is required, the truck operator en route to a starting point will usually perform the required operation on the way to the assigned route.

Some of the lane-mile requirements for non-Interstate highways are confounded, unless analyzed carefully. For example three routes out of Payson on SR87 are 22-24 lane miles, but begin as much as 26 miles from Payson.

Some routes are just plain long. For example,

- The truck route on SR264 out of Keams Canyon is 171.6 lane miles long.
- The truck route north out of Ganado on US191 is 166.6 lane miles long.

These route assignments result in extremely long cycle times. At 40 mph driving speed, the cycle times are greater than 4 hours. These cycle times can increase further in snow and ice situations.

From the map in Figure 2, it is clear that the heavy snowfall areas are located along a swath of higher elevation stretching from north central Coconino County through Flagstaff, and then east-southeast along the Mogollon Rim to the White Mountains. Although the scale of the map

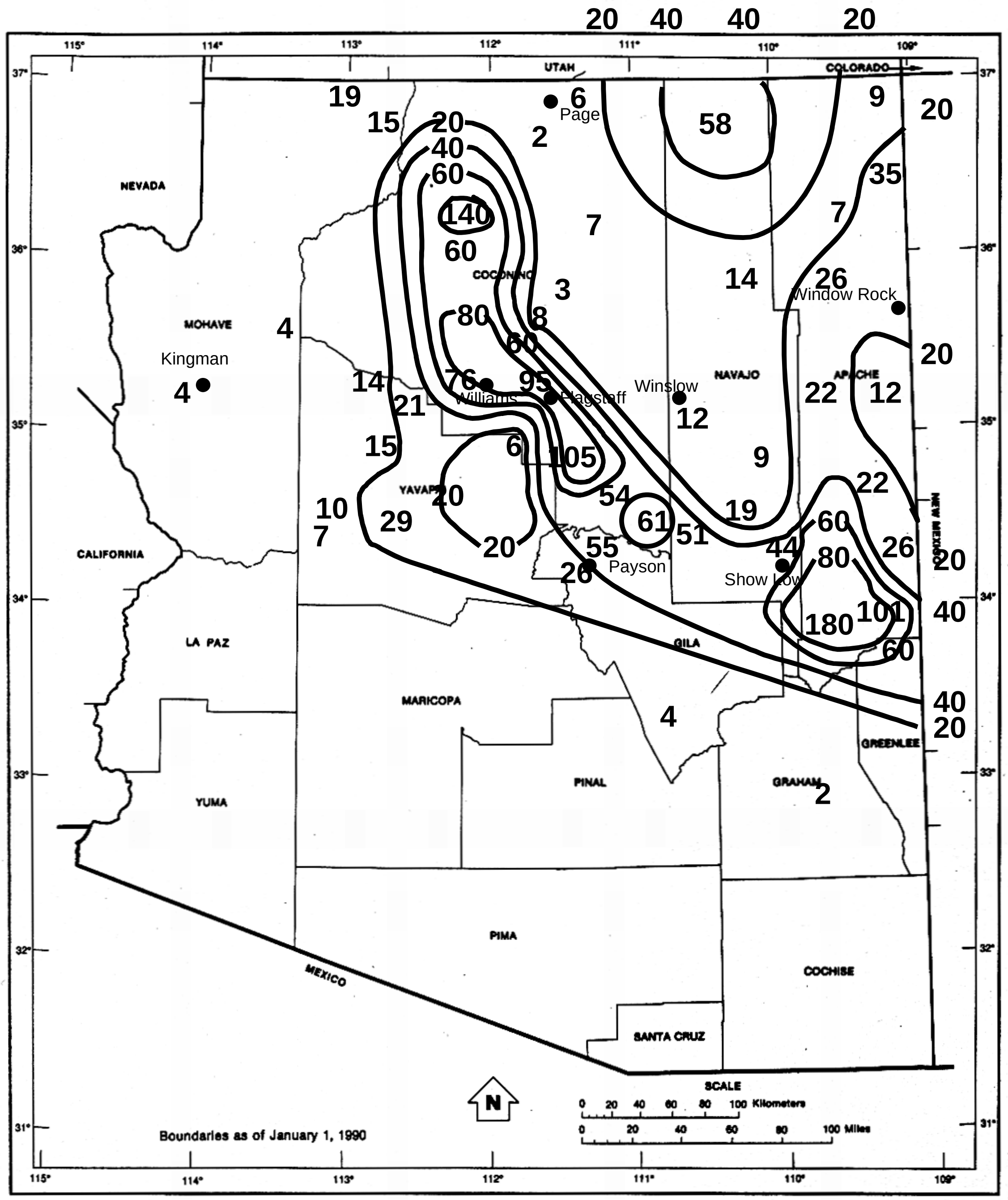

Figure 2. Average Annual Snowfall in Arizona

Note: The map was created using data obtained from the Office of the Arizona State Climatologist. The isolines are increments of 20 inches of annual snowfall, beginning with 20 inches. Detail is NOT provided in those locations where very large annual snowfall amounts are recorded, such as Jacob Lake and Hawley Lake.

doesn't permit analysis in detail, it is evident that the I-40 corridor begins receiving its heaviest snowfall from Ash Fork eastward to somewhere near Winona. There are also regions of heavier snowfall in northern Navajo County and northeastern Apache County.

In order to analyze resource allocations fully, one has to know the level(s) of service for highway segments. Until such time as a basic level of service is established by route, the staffing and equipment resources required to meet that level of service cannot be determined. An analysis of the snow plans resulted in a determination of the average lane miles per truck route on Interstate routes. These data are presented in Table 6 and discussed subsequently.

Table 6. Average Lane Miles per Truck Route on Interstate Routes[1]

Maintenance Org	Truck Route Lane Miles	Remarks
Chambers (I-40)	48	
Holbrook (I-40)	48	Includes Business 40
Winslow (I-40)	42.5	Assumes 4 3-axles on 40
Flagstaff (I-40)	47	Ranges from 36-58[2]
Williams (I-40)	66[3]	Ranges from 16 - 79
Seligman (I-40)	85.2[4]	Ranges from 70-103[5]
Kingman (I-40)	59.6	Ranges from 48-73
Little Antelope (I-17)	111	Ranges from 92-162
Cordes Junction (I-17)	144	Ranges from 104 to 184

1. Computed, where possible, from District Snow Plans
2. The Flagstaff Org has one 10-wheeler used as a "rover" on I-40 covering over 44 interstate miles, with significant winter weather usually occurring on about 25 or those miles. The truck can also take care of TIs as required.
3. Two routes of 79 and 78 lanes miles are covered by two trucks each for an effective 39.5 lane mile average.
4. Four the two dual-axle trucks on I-40.
5. Two routes out of Seligman require 37 – 44 miles of travel on I-40 prior to their truck routes of 96 and 36 lane miles, respectively, both with single-axle trucks.

The numbers show some snow and ice control routes that appear to be unusually short (lane miles) with probable short cycle times, while others have inordinately long routes with very long cycle times. Some of these long cycle times are increased by the locations of existing stockpiles. In some cases, the cycle time is further increased because smaller single axle trucks cover the routes with half the load capacity than the dual axle trucks.

When comparing the results in Table 6 with the average snowfall data, the resource allocations for the I-40 corridor appear reasonable if the only consideration is snowfall data. However, during wintry conditions, truck routes of 85 lane miles may result in over 3-hour cycle times. The routes on I-17, however, especially for Little Antelope, appear very long.

2.4.4 RWIS Maintenance Infrastructure

<u>Interviews with Signal Maintenance Personnel</u>

- No records are kept of RWIS maintenance and/or the status of the system.
- Overall system maintenance appears to be good at this point.

  - One pavement sensor has "popped out" and needs to be replaced;
  - A number of surface sensors needed to be "re-glued" and they've been taken care of by highway maintenance;
  - Two precipitation sensors needed to be replaced; that has been taken care of by the signal technicians.
  - One mountaintop radio repeater site was down for a while, but has been fixed.
- Historically, very little time is given to the RWIS maintenance. Attention is devoted to traffic signals and RWIS ends up on the bottom of the agenda.
- One signal technician recommended that one full-time technician devoted to the RWIS would be the proper level of maintenance to be provided by ADOT.
- Some problems go uncorrected for a long time. The Lupton site went down (due to lightning) "about 1.5 years ago", the parts are in to fix it, it is on the agenda to fix, but awaits converting to the same configuration as the Coastal Environmental sites to be installed in the Holbrook District.
- It was reported that vendor-provided maintenance prior to 1995 kept the system going, but at a significant cost to ADOT.
- The signal tech plans to do preventive maintenance and inspection work every six months, especially checking bearings on anemometers. This does not include sensor calibration.
- If compared with vendor-provided maintenance, the current site maintenance was originally described as "marginal at best." It now appears to be adequate with the repairs done in the last two-three months. The "in-house" maintenance can tend to be unresponsive due to concerns for the health of the traffic signals and the associated liability. It's a real dilemma with more and more signals going in and more and more liability issues.
- The office equipment, which includes the central processing unit, software, and remote terminals, is maintained by the Information Services person at Flagstaff and appears to be in good operating condition.
- No formal maintenance training has been provided to anyone maintaining the system. The signal technicians do have a full set of maintenance manuals to work from.

Interviews with Highway Maintenance Personnel

Interviews with highway maintenance personnel shed little light on the RWIS maintenance quality. There was consternation expressed in Holbrook with respect to the lightning strike that destroyed much of the electronics at the Lupton site. The impression left with the interviewers was that they believed the original vendor should fix the system because it must have been poorly protected from lightning. The interviewees also indicated that the site would be repaired by the signal technician(s) and a second RWIS vendor who won a contract to install three new RWIS sites in that District. (In an interview with a signal technician it was revealed that the new vendor was actually under contract to upgrade the site to their configuration).

It was disclosed in one other interview that one surface sensor at the Riordan site had been overlaid with asphalt concrete and was inoperable.

In order to use RWIS effectively, proper hands-on training in a scenario-based setting is generally accepted as the best mechanism. Such performance-based training has been used elsewhere effectively in developing anti-icing programs. The RWIS sites along I-40 were installed in 1993. Prior to the 1993-1994 winter the RWIS vendor provided initial operator training, i.e., the initial introduction to the system. This included instruction on what data are available from the system, and how to use the terminals and software to access data displays and forecasts. There was no real hands-on training and no training was provided on the system software or communications. Subsequently, the RWIS vendor provided some general weather training. Also, prior to the 1997-1998, ADOT contracted with Mr. Bob Blackburn to conduct some decision-based training based on the work he'd been doing with the Nevada DOT.

From evaluating the survey responses and the interviews of personnel, it is apparent there is a varied ability to fully utilize the RWIS data and products available. Most personnel recognize the utility of the pavement temperature and the pavement temperature forecast. Some don't use the system at all because of difficulty in accessing the system remotely. When away from an office/home environment, data are only available by talking to someone with access. Some of the individuals with the laptop computers didn't like to use them because of their monochrome display.

It is also apparent that the ADOT highway maintenance people who use the information don't put much faith in the forecasts they receive. There seems to be more acceptance of the NWS forecasts because the users can "call up the forecaster" in Bellemont. They find comfort in being able to talk to the forecaster. There has been no effort to do the same with VAMS forecasters even though the provider encourages such dialogue and provides an "800" number for that purpose.

Another problem with fully utilizing the RWIS lies in the relative lack of options available to the decision makers. Although anti-icing is being tried and tested, the capability is limited to a few locations where some liquid application capability exists. With manpower and equipment constraints, when anti-icing is being conducted, a standard plowing/spreading resource is unavailable.

Where anti-icing is not conducted, options are usually whether to apply abrasives or plow, or both, although some snow and ice control chemical capability does exist. Therefore, the major decisions center on when to call out people and when to implement plowing and spreading. These decisions usually are not based on RWIS information, although one Org indicates they plan to call out people with a 50 percent chance of snow forecast. From that point on, the practice is typically to keep at the work (plowing and spreading) until the roadways are near bare pavement. There are few efforts to use the information available to assist in attaining this informal level of service, such as monitoring forecasts of pavement temperature and clearing skies (during the day) for sufficient warming to assist in clearing the roads.

Information from the RWIS Vendor

In 1995, ADOT received a bid from the vendor to provide a service contract for the RWIS. The cost of that proposal was $22,000, and included annual inspections of each site, preventive maintenance (PM) at each site, and corrective maintenance as required. In 1995 that proposal also included repair of any damage caused by lightning. ADOT deemed the service contract to be too expensive and arranged for the in-house maintenance currently being conducted by the signal technicians in Flagstaff. There was never any training on system maintenance provided by the vendor, nor was any requested.

The cost to ADOT to maintain the system with the current policy is difficult to determine because very little maintenance has been conducted. ADOT did contract with the RWIS vendor to conduct an annual check and PM at each site prior to the 1997-1998 winter. The vendor conducted an annual preventive maintenance service at the seven RWIS sites along I-40 in November 1997. The cost for this maintenance was approximately $4,500.

The RWIS vendor identified the following RWIS problems:

- Two failed subsurface probes that the vendor would replace under warranty.
- The overall condition of the surface sensors as "poor. Immediate attention should be given to specific sensors …"
- One failed and one failing precipitation sensor; and
- One additional overlayed sensor at Lupton.

The responsibility for repair and service of the RWIS was not clearly defined initially. The damaged system consisted of roadside electronics, roadside and roadway hardware (including surface and subsurface sensors), communications, central computer equipment and software, and display terminal hardware and software. Numerous pavement sensors required re-epoxying, including re-epoxying of cables in Kerf cuts. The issue was resolved when ADOT highway maintenance agreed to fix the problems with the pavement sensors and signal maintenance was able to get some of the system up and running.

2.4.5 Level of Service (LOS)

Part of the information needed to address operational procedures resides in the LOS to be provided by highway maintenance personnel. Since this project focuses on procedures for winter maintenance operations, the LOS for snow and ice control from the Dye Management Group maintenance management system report was to be used.

Unfortunately, the information from that report was insufficient to conduct a meaningful analysis. The Dye process involved the use of photographs that showed five levels of service ranging from bare pavement (LOS 1) to closed roads (LOS 5) [1]. The surveys and interviews resulted in a desired LOS goal of 1.5 compared with a perceived current LOS of 2.1. In other words, people expected close to bare pavement. However, there was no indication of when this goal was expected to be achieved, e.g., how long after a storm? There was also no indication of a minimum acceptable LOS during a storm. Finally, there was no indication of what LOS is applicable to the various highway type classifications or descriptions. Certainly near bare pavement is not expected nor is it achievable everywhere.

Additional information was requested from each of the five Districts with snow and ice control responsibilities in northern Arizona. The project team developed an average winter storm scenario and presented that and other assumptions to the project's Technical Advisory Committee (TAC). As a result of that TAC meeting, each District was asked to complete a LOS form so that the team could assess resource needs with respect to the desired LOS for given road segments.

The team, with TAC approval, used an average storm scenario of one inch of snow per hour for six hours. The Districts were also presented a suggested set of end-of-storm goals based on roadway priority from the District Snow Plans. These goals and requests for other information were sent to the Districts for their response. The resulting data helped define LOS goals for snowplow routes in the five Northern Arizona Districts. The goals for the storm scenario are presented in Table 7.

Table 7. Level of Service Goals

Priority	Highway Description	Level of Service Goal
1	Interstate and other controlled access highways and freeways	Substantially free of loose snow, ice, and pack two hours after end of storm
2	Moderate volume U.S. numbered routes and state routes	Substantially free of loose snow, ice, and pack six hours after end of storm
3	Low volume state routes	Substantially free of loose snow, ice, and pack twelve hours after end of storm
4	Very low volume state routes	Plow and treat only after storm; patrol as required
5	Seasonal roads	Patrol as required

In order to meet the primary objective of this research, the research team had to look at the following areas:

- The use of weather information for snow and ice control
- Snow and ice control strategies and tactics;
- Decision making processes;
- Resources available for winter maintenance;
- RWIS siting and equipment maintenance; and
- LOS issues.

The team analyzed the various interactions between these areas and developed a set of recommendations that would provide ADOT with the capability to improve its snow and ice control procedures and processes in order to provide an improved level of service.

3. RWIS IN NORTHERN ARIZONA

3.1 RWIS HARDWARE

RWIS hardware consists of two major components: the roadside monitoring equipment, hereafter referred to as RWIS sites; and equipment, both hardware and software required to acquire other weather information, e.g., observations and forecasts of weather and pavement conditions, and ancillary weather products (radar and satellite imagery). The primary focus of this section will be the RWIS sites.

In 1993 ADOT installed seven RWIS sites along I-40. These sites are listed in Table 8 and are shown in Figure 3. In 1998, ADOT installed five additional RWIS sites, three in the Holbrook District in northern Arizona and two in the Safford District for monitoring blowing dust conditions. The Holbrook sites are listed in Table 9 and are shown in Figure 4.

The procurement specification for the new RWIS equipment required that the system be compliant with the Environmental Sensor Station (ESS) National Transportation Communications for ITS Protocol (NTCIP). The only vendor who indicated their equipment was NTCIP ESS compliant was Coastal Environmental.

One result of the second RWIS site procurement was the acquisition of equipment that was not compatible with the existing hardware and software. The older RWIS is a proprietary system based on a closed architecture. This system, originally designed for airport installations, had not yet evolved to an open system where multiple sources of information could be intermixed in a statewide highway environment.

Table 8. First Seven RWIS Sites Along I-40 in Northern Arizona

District	Name	Milepost
Kingman	Fort Rock	91.15
Kingman	Crookton	132.25
Flagstaff	Ash Fork Hill	154.2
Flagstaff	Pine Springs	158.99
Flagstaff	Riordan	190.76
Holbrook	Little Colorado River	256.89
Holbrook	Lupton	358.88

Table 9. RWIS Sites Added in 1998 in Northern Arizona

Name	Highway	Milepost
Clints Well	SR 87	291
Heber	SR 377	0
Painted Desert	I-40	312

Figure 3. Location of First Seven RWIS Sites along I-40 (Red Dots) per Table 8

Note: Locations are only approximate due to the base map and software used.

Figure 4. Location of First Seven RWIS Sites along I-40 (Red Dots) Plus Three New Sites Added in 1997-1998 (Blue Dots) per Table 9.

Note: Locations are only approximate due to the base map and software used.

Table 10. Road Weather Information System Sites (ITS Plan)

PRIORITY	DISTRICT	DESCRIPTION	STATUS
1	Flagstaff	I-17 @ MP 307	
2	Flagstaff	I-17 @ MP 314	
3	Flagstaff	I-40 @ MP 206	
4	Holbrook	I-40 @ MO 312	**Done**
5	Holbrook	SR87 @ MP 291	**Done**
6	Holbrook	SR 377 @ SR277	**Done**
7	Safford	I-10 @ MP 365	**Done**
8	Safford	I-10 @ MP 387	**Done**
9	Flagstaff	I 40 @ MP ___	
10	Holbrook	SR77 S. Holbrook	
11	Holbrook	SR264 @ Ganado	
12	Holbrook	SR264 @ Keams Canyon	
13	Holbrook	US160 @ Tuba City	
14	Holbrook	US64 @ Teec Nos Pos	
15	Flagstaff	SR89 N. Flagstaff	
16	Flagstaff	SR64 N. Williams	
17	Flagstaff	I-17 S. Flagstaff	
18	Flagstaff	I-17 @ Stoneman Lake	
19	Kingman	SR66 @ Peach Springs	
20	Globe	US60 @ Springerville	
21	Globe	SR77 @ Show Low	
22	Globe	US180 @ St. Johns	
23	Globe	SR77 S. of Holbrook	
24	Globe	SR260 @ Pinedale	
25	Globe	SR260 @ Heber	
26	Prescott	SR89 S. Ash Fork	
27	Prescott	SR89 N. Prescott	
28	Holbrook	I-40 @ Sanders	
29	Holbrook	I-40 @ New Mexico Line	
30	Holbrook	I-40 West of Sanders	
31	Holbrook	I-40 W. of Holbrook	
32	Holbrook	I-40 E. of Winslow	
33	Holbrook	I-40 W. of Winslow	
34	Holbrook	SR87 S. of Winslow	
35	Kingman	I-40 S SR89	
36	Kingman	I-40 E. of Kingman	
37	Kingman	US93 N. of Kingman	
38	Safford	I-10 West of Bowie	
39	Safford	I-10 @ New Mexico Line	
40	Tucson	I-10 N. of Tucson	
41	Safford	I-10 E. of Tucson	
42	Safford	I-10 @ I-19	
43	Safford	I-19 Btwn Nogales and Tucson	
44	Yuma	SR95 @ Parker	
45	Holbrook	SR77	

Table 10. Road Weather Information System Sites (ITS Plan) (continued)

46	Holbrook	SR264 @ Window Rock	
47	Holbrook	SR264 W. of Oraibi	
48	Holbrook	SR264 E. of Tuba City	
49	Holbrook	US160 E. of Kayenta	
50	Holbrook	US160 @ US191	
51	Safford	SR80 (20mi. Spacing)	
52	Safford	SR80 (20mi. Spacing)	
53	Safford	SR80 (20mi. Spacing)	
54	Safford	I-10 Btwn Wilcox & S. Simon	
55	Safford	SR181 Chir. Nat'l Mon.	
56	Safford	US191	
57	Safford	SR266 E. of Bonita	
58	Safford	US70 @ Duncan	
59	Safford	SR78 S. Morenci	
60	Safford	USFS Road	
61	Kingman	I-40 @ US93	
62	Kingman	I-40 @ MP 110	
63	Kingman	SR66 @ MP 117	
64	Kingman	SR68 @ MP 12	
65	Tucson	I-8 (40mi. Spacing)	
66	Tucson	I-8 (40mi. Spacing)	
67	Tucson	SR77 N. of Tucson	
68	Tucson	SR386 (Bottom)	
69	Tucson	SR386 (Top)	

As a result of the system incompatibility, two sets of central computers are required to access data from the sites. User software to access the data is also different. Therefore, the process for decision makers to acquire data is very cumbersome and in many cases, precludes the use of potentially valuable information.

Figure 5 shows the original 1997 ITS statewide plan for RWIS sites. As developed by ADOT's Transportation Technology Group, the site locations from the ITS plan are listed in Table 10. The following criteria were used in the identification of proposed RWIS sites:

- Elevations over 4000'
- Locations where predictive information would be beneficial
- Locations, that by history, districts deem advantageous;
- Key point where initial icing occurs
- Non I-40 locations, to track storms.

Inputs were requested from the five Districts regarding their need and recommendations for new RWIS sites. These sites are shown in Figure 6. Their locations are specified in Table 11. Changes have been made to the ITS Plan (Table 10) by some of the Districts. These changes are shown in boldface type. For example, there are two sites in the Holbrook District that have locations shown in the "New List" column with boldface type. These sites have been moved from the previous ITS locations. There are also six sites shown with "2008" in the same column. The specific locations were not identified since these locations are not programmed until FY 2008.

Sites that have been recommended by the Districts that are in addition to the ITS plan are shown in italics. Also, any additional information beyond that contained in the ITS Plan is also shown in italics.

Some sites from the original ITS plan have been dropped. Those ITS sites from Table 11 that are not included in the recommendations have "NO" shown in the column labeled "New List." These sites are also shown in Figure 7 with an X over the sites.

3.2 OTHER CONSIDERATIONS

Thermal mapping, the development of temperature profiles of roadways (road thermography) under various conditions, can be an important tool in the development of an RWIS plan. One of the best uses is to identify locations for RWIS sites. Thermal mapping can also be used to identify selected sites that are representative of other sites and therefore one or another site could be eliminated. Thermal mapping typically pays for itself in siting analysis alone, not including benefits accrued from more precise forecasting with thermal mapping information available to forecasters. The thermal mapping allows for forecasts of pavement temperature where there are no pavement sensors in place.

Adequate communications are necessary for the successful implementation of RWIS. If data cannot be acquired routinely, data may not be available when most needed. The current communication system for the existing RWIS is unreliable. Any upgrade of the existing RWIS and any addition to the current RWIS needs to consider developing reliable communications.

3.3 BENEFIT-COST OF RWIS

There are both direct and indirect costs associated with snow and ice control and RWIS usage. The direct costs for snow and ice control are the resources required (equipment), materials used (chemicals and abrasives), and labor. Indirect costs (or savings) for snow and ice control include increased mobility for travelers and throughput for commerce, reduced accident rates, decreased insurance premiums, reductions in costs to industry due to tardiness or inability to get to work, reductions in fuel consumption, and cleaner air with the reduced fuel consumption and increased mobility.

The costs of RWIS need to consider the costs for the hardware for the sites and associated data collection and processing capabilities, communication for acquiring and disseminating RWIS data and information, the purchase of site-specific tailored forecasts, and the maintenance of the system. If thermal mapping is included, that cost needs to also be considered.

Most studies in this country have been directed toward comparing direct costs of snow and ice control with the costs of RWIS. There have been varied results, but the SHRP RWIS project indicated benefit cost ratios of up to 5 to 1 for RWIS use [2]. This means for every dollar spent for RWIS, five dollars are saved in direct snow and ice control maintenance costs. Another study from Minnesota looked at implementing a statewide RWIS that would be comprised (originally) of over 200 sites. Looking at life cycle costs, which included communications, maintenance, training, and the additional personnel to monitor and conduct those functions, Minnesota calculated the entire system would be paid back in savings in six years.

Figure 5. Locations of Planned RWIS Sites Added from the 1997 ITS Plan (Green Dots)

Table 11. Road Weather Information System Consolidated Site Listing for Northern Arizona

ITS PRI.	ITS NO.	DISTRICT	ITS DESCRIPTION NEW LIST DESCRIPTION	NEW LIST
1	--	Flagstaff	I-17 @ MP 307 *(Barrier Wall)*	***MP 313***
2	--	Flagstaff	I-17 @ MP 314 *(Rocky Park)*	***MP 315.58***
3	--	Flagstaff	I-40 @ MP 206 *(Winona)*	***MP 212***
4	--	Holbrook	I-40 @ MO 312	**NO - Done**
5	--	Holbrook	SR87 @ MP 291	**NO - Done**
6	--	Holbrook	SR 377 @ SR277	**NO - Done**
9	--	Flagstaff	I 40 @ MP *Bellemont*	MP 185
--	--	Holbrook	*I-40 @ MP 270*	*MP 270*
10	29	Holbrook	SR77 S. Holbrook	MP 371
11	39	Holbrook	SR264 @ Ganado	MP 463?
12	40	Holbrook	SR264 @ Keams Canyon	MP 367
		Holbrook	US160 @ Jct SR564	*MP 374±*
13	43	Holbrook	US160 @ Tuba City	**NO**
14	46	Holbrook	US64 @ Teec Nos Pos	MP 450+/-
15	47	Flagstaff	SR89 N. Flagstaff *(Summit)*	MP 431.3
16	48	Flagstaff	SR64 N. Williams *(Tusayan)*	MP 233
17	49	Flagstaff	I-17 S. Flagstaff *(Kelly Canyon)*	MP 330.5
--	--	Flagstaff	US89 @ Rossman Hill	MP 536
--	--	Flagstaff	US89A @ Jacob Lake	MP 579.4
--	--	Flagstaff	*US160 @ Cow Springs*	*MP 354*
18	50	Flagstaff	I-17 @ Stoneman Lake	MP 306.3
19	52	Kingman	SR66 @ Peach Springs	MP 108
20	23	Globe	US60 @ Springerville	**NO**
--	--	Globe	SR273 @ Sunrise	*MP 377.6*
21	24	Globe	SR77 @ Show Low	**NO**
22	25	Globe	US180 @ St. Johns	**NO**
23	26	Globe	SR77 S. of Holbrook	**NO**
24	27	Globe	SR260 @ Pinedale	**NO**
25	28	Globe	SR260 @ Heber	MP304.2
--	--	Globe	SR191@Hannagan Meadow	MP 225.0
26	56	Prescott	SR89 S. Ash Fork	**NO**
27	57	Prescott	SR89 N. Prescott	**NO**
--	--	Prescott	SR87 @ Hefner Cut	*MP 281.9*
--	--	Prescott	*SR 260 @ Gordon Canyon*	*MP 286.9*
--	--	Prescott	*I-17 @ Copper Canyon*	*MP 280.6*
--	--	Prescott	*SR69 @ Bullwhacker Hill*	*MP 275.2*
--	--	Prescott	*SR80 @ Top of Pines*	*MP 306.5*
--	--	Prescott	*SR89A @ Mingus Mountain*	*MP 336.7*
28	30	Holbrook	I-40 @ Box Canyon	MP 345.25
29	31	Holbrook	I-40 @ New Mexico Line	US 191-345
30	32	Holbrook	I-40 West of Sanders	MP 331
31	33	Holbrook	I-40 W. of Holbrook	MP 294
32	34	Holbrook	I-40 E. of Winslow	US 191-448
33	35	Holbrook	I-40 W. of Winslow	MP 230
34	36	Holbrook	SR87 S. of Winslow	MP 330

Table 11. Road Weather Information System Consolidated Site Listing for Northern Arizona (continued)

--	--	Flagstaff	*SR64 @ Reservation Boundary*	*MP 278*
--	--	Flagstaff	*SR98 @ Kaibito*	*MP 331*
--	--	Flagstaff	*SR15 @ Virgin River Canyon*	*MP 14.0*
--	--	Flagstaff	*SR15 @ Black Rock*	*MP 27.0*
--	--	Flagstaff	*I-40 @ Monte Carlo*	*MP 149*
--	--	Flagstaff	*SR 89 @ Cedar Ridge*	*MP 505*
--	--	Flagstaff	*SR 89 @ Big Cut*	*MP 528*
--	--	Flagstaff	*SR 89A @ Midgley*	*MP 376.0*
--	--	Flagstaff	*SR 89A @ Rim Camp*	*MP 390.0*
--	--	Flagstaff	*SR 98 @ Summit*	*MP 344.0*
--	--	Flagstaff	*SR 180 @ Kendrick Park*	*MP 236*
35	51	Kingman	I-40 S SR89	MP 354
36	54	Kingman	I-40 E. of Kingman	MP 66
37	55	Kingman	US93 N. of Kingman	MP 48
45	37	Holbrook	SR77	2008
46	38	Holbrook	SR264 @ Window Rock	2008
47	41	Holbrook	SR264 W. of Oraibi	2008
48	42	Holbrook	SR264 E. of Tuba City	2008
49	44	Holbrook	US160 E. of Kayenta	2008
50	45	Holbrook	US160 @ US191	2008
61	53	Kingman	I-40 @ US93	**NO**
62	58	Kingman	I-40 @ MP 110	MP 110
63	59	Kingman	SR66 @ MP 117	MP 117
64	60	Kingman	SR68 @ MP 12	MP 12
--	--	Kingman	I-40 @ MP 82	*MP 82*

Figure 6. Locations of Planned RWIS Sites from the ITS Plan (Green Dots) with Added Input from the Five Northern Arizona Districts (Violet Dots).

Figure 7. Locations of Planned RWIS Sites from the ITS Plan (Green Dots) with Added Input from the Five Northern Arizona Districts (Violet Dots), Old ITS Sites Crossed Out.

In nearly all cases, the reduction in snow and ice control costs are related to labor (reduced overtime) and reductions in materials usage, particularly chemicals. The latter saving is typically related to anti-icing or pretreatment where the amount of chemicals can be reduced by as much as 50% compared to deicing. Amounts of abrasives can be reduced by 75%. These savings are related to the quality of the weather and pavement condition forecasts and the ability of the decision makers to make correct decisions based on the RWIS information. For a strategy such as plowing with friction enhancement (abrasives), the savings might be considerably less and the benefit-cost ratio lower.

Some states find even greater savings using RWIS for other maintenance decision needs, such as vegetation control, painting and striping, and pavement maintenance and repair. The information is also useful for construction decisions, too. The benefit-cost ratio could increase significantly if direct costs (savings) from these functions is considered.

Indirect costs need to be another consideration. A major study in Europe showed a benefit-cost ratio of 5 to 1 for indirect costs. These indirect costs were identified above. Studies in this country and in Canada have also showed significant reductions in accidents (costs) using deicing chemicals appropriately and through anti-icing.

If ADOT adopts a chemical priority policy in areas where appropriate and possible, the potential for lowering both indirect and direct costs for snow and ice control will likely be greater.

As indicated above, thermal mapping costs may also need to be included but results from thermal mapping projects have indicated that, by finding one redundant RWIS site that can be replaced the staff can typically pay for the cost of thermal mapping.

3.4 RECOMMENDED RWIS FOR NORTHERN ARIZONA

ADOT has developed a well-thought out RWIS site location plan that when fully implemented will provide adequate and appropriate information to its snow and ice control managers. ADOT should continue to pursue acquisition of RWIS hardware for those sites described in Table 12 and shown in Figure 7. The Table does not include sites with Xs in Figure 7. The key to successful implementation will require the involvement of the ADOT Snow and Ice Control Manager and the District RWIS Coordinators.

ADOT should develop an RWIS specification for equipment designed to meet the agency needs. This specification can then be included as a line item in maintenance or construction contracts, a specification for ADOT RWIS acquisition, or as a stand-alone RWIS acquisition tool for use by local contractors if ADOT chooses to acquire hardware using this method.

In addition to management oversight, successful implementation will require appropriate training of ADOT personnel, from first line decision-makers to Org and District supervisors and managers. Such training should not just include how to turn on equipment, acquire data, and describe what types of data are available; the training should be scenario-based performance based and preferably interactive using either computer-based or web-based training. The training program that is recommended by the research team is described in Chapter V.

Table 12. Recommended Road Weather Information System Sites for Northern Arizona

ITS PRI.	ITS NO.	DISTRICT	SITE DESCRIPTION	LOCATION
1	--	Flagstaff	I-17 @ MP 307 (Barrier Wall)	MP 313
2	--	Flagstaff	I-17 @ MP 314 (Rocky Park)	MP 315.58
3	--	Flagstaff	I-40 @ MP 206 (Winona)	MP 212
9	--	Flagstaff	I 40 @ Bellemont	MP 185
--	--	Holbrook	I-40 @ MP 270	MP 270
10	29	Holbrook	SR77 S. Holbrook	MP 371
11	39	Holbrook	SR264 @ Ganado	MP 463?
12	40	Holbrook	SR264 @ Keams Canyon	MP 367
		Holbrook	US160 @ Jct SR564	MP 374±
14	46	Holbrook	US64 @ Teec Nos Pos	MP 450+/-
15	47	Flagstaff	SR89 N. Flagstaff (Summit)	MP 431.3
16	48	Flagstaff	SR64 N. Williams (Tusayan)	MP 233
17	49	Flagstaff	I-17 S. Flagstaff (Kelly Canyon)	MP 330.5
--	--	Flagstaff	US89 @ Rossman Hill	MP 536
--	--	Flagstaff	US89A @ Jacob Lake	MP 579.4
--	--	Flagstaff	US160 @ Cow Springs	MP 354
18	50	Flagstaff	I-17 @ Stoneman Lake	MP 306.3
19	52	Kingman	SR66 @ Peach Springs	MP 108
--	--	Globe	SR273 @ Sunrise	MP 377.6
25	28	Globe	SR260 @ Heber	MP304.2
--	--	Globe	SR191@Hannagan Meadow	MP 225.0
--	--	Prescott	SR87 @ Hefner Cut	MP 281.9
--	--	Prescott	SR 260 @ Gordon Canyon	MP 286.9
--	--	Prescott	I-17 @ Copper Canyon	MP 280.6
--	--	Prescott	SR69 @ Bullwhacker Hill	MP 275.2
--	--	Prescott	SR89 @ Top of Pines	MP 306.5
--	--	Prescott	SR89A @ Mingus Mountain	MP 336.7
28	30	Holbrook	I-40 @ Box Canyon	MP 345.25
29	31	Holbrook	US 191 @ (Nr) Witch Wells	MP 345
30	32	Holbrook	I-40 West of Sanders	MP 331
31	33	Holbrook	I-40 W. of Holbrook	MP 294
32	34	Holbrook	US 191 @ (Nr) Many Farms	MP 448
33	35	Holbrook	I-40 W. of Winslow	MP 230
34	36	Holbrook	SR87 S. of Winslow	MP 330
--	--	Flagstaff	SR64 @ Reservation Boundary	MP 278
--	--	Flagstaff	SR98 @ Kaibito	MP 331
--	--	Flagstaff	SR15 @ Virgin River Canyon	MP 14.0
--	--	Flagstaff	SR15 @ Black Rock	MP 27.0
--	--	Flagstaff	I-40 @ Monte Carlo	MP 149
--	--	Flagstaff	SR 89 @ Cedar Ridge	MP 505
--	--	Flagstaff	SR 89 @ Big Cut	MP 528
--	--	Flagstaff	SR 89A @ Midgley	MP 376.0

Table 12. Recommended Road Weather Information System Sites for Northern Arizona (continued)

--	--	Flagstaff	SR 89A @ Rim Camp	MP 390.0
--	--	Flagstaff	SR 98 @ Summit	MP 344.0
--	--	Flagstaff	SR 180 @ Kendrick Park	MP 236
35	51	Kingman	I-40 S SR89	MP 354
36	54	Kingman	I-40 E. of Kingman	MP 66
37	55	Kingman	US93 N. of Kingman	MP 48
45	37	Holbrook	SR77	2008
46	38	Holbrook	SR264 @ Window Rock	2008
47	41	Holbrook	SR264 W. of Oraibi	2008
48	42	Holbrook	SR264 E. of Tuba City	2008
49	44	Holbrook	US160 E. of Kayenta	2008
50	45	Holbrook	US160 @ US191	2008
62	58	Kingman	I-40 @ MP 110	MP 110
63	59	Kingman	SR66 @ MP 117	MP 117
64	60	Kingman	SR68 @ MP 12	MP 12
--	--	Kingman	I-40 @ MP 82	MP 82

ADOT needs to upgrade its original seven RWIS sites along I-40 in order to make them state-of-the-art and compatible for the free-flow exchange of data. The new RWIS in northern Arizona also needs to be upgraded. Having two Central Processing Units (CPUs) at Flagstaff is not only cumbersome but limits access to important data. A single ADOT server should be the goal for current and future data acquisition from RWIS sites. Data should be accessible from the central server by managers and supervisors via Internet, the ADOT Intranet or dial-up telephone access. This upgrade specification should be identical to any specification developed by ADOT for new RWIS sites.

ADOT needs to consider alternate means of RWIS communications. Due to the extremely remote areas of Arizona, where radio or cellular telephone communications are currently limited, consideration needs to be given to using local telephone access to Internet Service Providers or to using Low Earth Orbiting Satellite (LEOS) communication in order to acquire data from remote RWIS sites. A communications analysis needs to be a part of formal site surveys that are conducted for each new site. A similar analysis should be conducted for existing sites with communication problems. Communication costs need to be considered an important aspect of the acquisition of new sites and should be included in life cycle cost analysis for each site.

Due to the nature of the technology, and after the problems experienced with in-house RWIS hardware maintenance, any RWIS acquisition should include service contracts beyond the warranty phase of a purchase. The service contract should include annual (at a minimum) preventive maintenance as well as provisions for on-site maintenance within an appropriate time period from notification of equipment problems.

In order to fully maximize the ADOT RWIS plan, a few additional RWIS sites are recommended.

Prescott District

1. Locate one or two additional sites on SR 260 at top and bottom of the hill east of Christopher Creek. This could be one site with pavement sensors near the top and the bottom of the hill. Consider moving the Gordon Canyon site west to this location.

2. Select one problematic bridge in the transition zone on each of SR 87, SR 89, and I-17. The installation should have pavement sensors on the bridge decks and approaches to the bridges as well as a suite of atmospheric sensors. Data from these sites would be used for frost prediction and treatment. Thermal mapping could indicate one or two locations that would suffice.

Globe District

Select one problematic bridge in the transition zone on US 60. Install, at a minimum, pavement sensors on the bridge deck and approach(es) to the bridge. Data from this site would be used for frost prediction and bridge deck snow and ice control treatments. The District should also review the sites identified on the original ITS Plan that are not included in Table 12 (see Figure 7) to determine if indeed one or more of these sites should be revived.

Flagstaff District

The District should consider moving the site identified at Bellemont to Parks (MP 178) or at the ADOT Rest Area (approximately MP 180) in order to provide better information for forecasters monitoring upslope meteorological conditions west of the divide. If there is a specific additional need near Bellemont, for instance monitoring wind and pavement conditions for blowing snow and icing, then perhaps an additional site near Bellemont needs to be considered. An additional consideration could be the installation of a lower-cost system at either location to monitor atmospheric conditions and a fully compatible RWIS with pavement sensors at the other.

The District shows two sites on I-17 (Barrier Wall and Rocky Park) that are to be located approximately 2.5 miles apart. A formal site survey should determine if these sites can be combined into one using remote-reporting pavement sensors for pavement conditions and if the meteorological information from one location is applicable to the other. Thermal mapping could also assist in this analysis.

The District should also add two sensor suites on SR 89 at Oak Creek Canyon north of Cave Spring. This could be one RPU site with pavement sensors near top and bottom of hill if the system installed can remotely monitor pavement sensors.

All Districts

In addition to the above additional site recommendations, and as recommended in earlier Working Papers, ADOT should conduct thermal mapping along:

- I-40 from Kingman to the NM state line;
- I-17 from Camp Verde to Flagstaff;
- SR 87 from Payson to Clints Well;

- SR 89 from Prescott to Ash Fork or SR89A on the Oak Creek Canyon Hill;
- SR 260 from Payson Ranch to Heber; and
- US 60 from Show Low to Springerville/Eagar to determine best locations for RWIS. It is likely there is redundancy in sites currently on the list, especially along I-40.

The possible redundancy arises from sites having similar meteorological and pavement temperature characteristics. The cost of any thermal mapping will be amortized quickly by not installing one or two sites. Thermal mapping will provide important information for pavement condition forecasters for frost or ice formation and snow accumulation. There can be operational benefit from thermal mapping for decision makers who can review thermal profiles to determine areas of concern or non-interest.

Prescott and Globe Districts each indicate a need for an RWIS along SR 260 near Heber: Prescott at MP 286.9 and Globe at MR 304.2. The Districts should analyze their needs, given that Holbrook has installed a site at Heber on SR 377, MP 0.2, to determine if the Heber site will satisfy their needs. Indications from vegetation at this location are that the moisture level is not representative of the area just to the West. Thermal mapping could assist in this analysis.

ADOT District maintenance and construction need to coordinate plans. Maintenance should overlay the RWIS plan onto construction plans. Where construction programs coincide with planned RWIS siting, the District should include a requirement in the plan for the installation of an RWIS. The Federal Highway Administration (FHWA) has indicated that RWIS is eligible for the same cost sharing that is used for FHWA-funded construction. For example, if the project is a "90-10" cost sharing project, then the RWIS installation is eligible for 90% funding by the FHWA. This provides additional rationale for ADOT to develop a standard RWIS specification. There should also be consideration for replacement of pavement sensors when resurfacing pavement.

Each ADOT District should coordinate its RWIS plan with the counties and municipalities in its area of responsibility. It is likely that one or more of the agencies would be interested in participating with ADOT through a partnering arrangement. Site locations can possibly be moved slightly to provide information for county roads or city streets. These agencies can also reap the benefits of better decision information. And through a partnering arrangement, costs can frequently be shared and the cost to ADOT could be reduced.

Partnering arrangements can usually prorate the costs in a particular area. For instance, an agency may participate in the installation of a site, e.g., paying 20% of the cost of that site, in order to access data from that site and perhaps obtain forecasts for that site. Then that agency could also pay 20% of the costs to maintain that site, 20% of the cost of the communications, and 20% of the cost of the forecasts (if the same forecast is used). These partnering arrangements typically work out to be win-win arrangements. ADOT personnel just need to find the right "hot buttons" to push. The ADOT LTAP program has provided many of these agencies with some insight into RWIS technology and its benefits.

ADOT maintenance should coordinate the RWIS plan with the ADOT Aeronautics Section. Frequently the aeronautics people have their own plan to install or upgrade weather equipment at state-owned, operated, or monitored airports. Many times these airport weather sites could be used by highway personnel and vice versa. There are plans for an Automated Surface Observing System (ASOS) IV. ASOS IV is similar to the current ASOS III but has pavement sensors added for runway (and could be for collocated highway) monitoring. An ASOS IV system has been tested. If fielded, there is opportunity for and additional justification for an integrated statewide system, one with costs shared by the aviation and surface transportation sectors.

In a similar vein, ADOT should coordinate the final plan with the National Weather Service (NWS) office in Bellemont. It is assumed that data from all planned RWIS sites would be accessible to the NWS. There is a possibility that some federal funds from the Department of Commerce through the NWS might be available to establish additional weather monitoring sites in the remote areas of Arizona. Additional data for the NWS are important for forecast preparation, forecast verification, and radar data ground truth. As in the case of other highway agencies, ADOT instrumentation from planned sites, or sites with some slight adjustments of planned ADOT siting, could satisfy NWS needs. There may also be some opportunity to have the NWS share in the communications costs from certain sites.

It is not without precedent for the private sector to partner with a government agency. One such arrangement had a (very) large corporation paying for forecasts provided to a state DOT. The corporation recognized the benefit to them and their employees to get a better level of service for snow and ice control. The trucking industry might be a willing partner.

There may also be partnering opportunities with other entities such as the Bureau of Indian Affairs, Native American nations, Bureau of Land Management, National Forest Service, National Park Service, ski areas, etc. All of these agencies have some need for weather information.

Other RWIS-related recommendations are described in Section V under Weather Information for Snow and Ice Control.

4. SNOW AND ICE CONTROL STRATEGIES AND TACTICS

4.1 SNOW AND ICE CONTROL STRATEGIES

The following describes a generic set of snow and ice control strategies and tactics that can be accomplished by any of the ADOT Districts. In some cases, additional resources are required in order to implement fully these procedures. These resources are identified in Section V.

There are four basic strategies used in snow and ice control:

- Anti-icing
- Deicing
- Mechanical removal of snow and ice together with friction enhancement
- Mechanical removal alone.

The anti-icing strategy is designed to prevent the bonding of snow or ice to a roadway surface by use of timely applications of snow and ice control chemicals. This strategy can keep pavement bare in cases where frost or black ice might otherwise form. It can also increase the efficiency of mechanical snow or ice removal because of lack of bonding to the pavement. It can also make passive snow and ice control (e.g., do nothing more) work where surface and air temperatures are expected to rise above freezing and accumulations of snow or ice will melt.

Deicing is the use of chemicals to assist in the removal of snow or ice that is already bonded to pavement. Because of the higher chemical demand (energy) required to break the bond of ice to pavement, deicing typically requires the use of four to five times more amounts of snow and ice control chemical than does anti-icing.

Mechanical removal of snow and ice together with friction enhancement requires that abrasives (cinders, sand, etc.) be applied to snow or ice already bonded to pavement. The snow or ice can already be partially removed by plowing or scraping. Abrasives alone cannot be effective for either anti-icing or deicing.

Mechanical removal alone refers to the physical removal of snow or ice accumulations by plowing, scraping, brooming, blowing, etc. It involves no chemical or abrasive applications.

4.1.1 Goals

The goal of anti-icing is to maintain a high level of service or attain a level of service more quickly through the applications of chemicals to prevent snow and ice bonding. As such, an anti-icing strategy is well suited for highway routes with a high snow and ice control priority, provided the appropriate resources are available for maintenance forces. Anti-icing can be used for frost or black ice prevention. It can also be used in advance of a weather event where snow or thin ice is expected and the application of the chemicals produces a wet surface where falling precipitation either melts or can be removed efficiently because it has not bonded to the surface. Anti-icing can involve the use of one or many applications of chemicals during a storm in amounts less than that required for deicing operations, depending on the pavement and weather conditions.

The goal of deicing is to assist in the removal of accumulations of snow or ice where there is bonding to the pavement. Deicing of a snow accumulation can produce a mealy substance that is relatively easily removed from the pavement. It can also facilitate ice removal when applications follow scraping. Deicing can involve one or many applications during and after a storm depending on the pavement and weather conditions.

The goal of mechanical removal of snow or ice with friction enhancement is to provide a level of mobility by removing accumulated snow and ice and improving the friction available for road users. This usually requires applications of abrasives following the physical removal passes and frequently requires multiple treatments depending on the nature of the event and pavement conditions.

The goal of a snow and ice control strategy that involves mechanical removal alone is to physically remove significant accumulations of snow and ice without the use of snow and ice control chemicals or abrasives.

4.1.2 Conditions for Implementing Strategies

Anti-icing utilizing pretreatment usually involves the application of a liquid chemical or prewetted solid chemical (limit prewetted solids to lower speed and volume highways) in anticipation of events that would cause snow or ice to bond to and accumulate on a surface. This strategy can be used for the occurrence of frost or black ice on bridge decks or roadways. It can also be used in advance of a weather event. Current state of the practice and recent research findings suggest that when using liquid chemicals to prevent frost or black ice, the chemicals should be applied sufficiently far in advance of the expected or probable occurrence that the liquid water evaporates and leaves a chemical residue on the surface. This means no later than midday for expected occurrences at night. For precipitation events, liquid chemicals may be applied within a couple of hours of when precipitation is expected to occur and should NOT be applied if the onset of the precipitation event is expected to be rain. Rain will dilute the application and make it ineffective. Prewetted solids or straight solids can be applied at the time of precipitation. In all cases, the existing and forecast pavement temperature should be in a range suitable for the chemical being used.

Solid and prewet solid chemicals may also be used to support anti-icing by pretreating and treating very early in a storm. This pretreating with solid or prewet solid chemicals should be limited to low-speed and low-volume highways.

Deicing typically involves the application of solid or prewet solid chemicals on accumulations of snow or ice that are generally bonded to the pavement in order to break the bond. Chemicals should be applied under conditions where the chemicals will work and when the post treatment temperatures are not expected to lower sufficiently to cause refreezing of melted snow or ice snow and diluted chemical solution. Once the bond of snow or ice is broken, the snow or ice may be removed mechanically or displaced by traffic.

Mechanical removal alone is used with warm pavement temperatures where snow or ice is not likely to bond to the pavement and in very cold temperatures where chemicals will cause snow or ice to adhere to the pavement. It may also be used to keep low priority roads passable and as part of safety restoration operations, e.g., shoulder plowing, sight distance improvement, and clearing around safety appurtenances.

4.2 TACTICS

The particular tactics used in support of the strategies for snow and ice control are related to the equipment and materials available and the conditions at a particular location.

The tactics used in anti-icing require the application of liquid, solid, and prewet solid snow and ice control chemicals. Liquids have been distributed using tanks in pickup trucks, saddle tanks on plow trucks, and a tanker truck (see FHWA Manual of Practice for Effective Anti-icing [3]). ADOT personnel anecdotally indicate success in improving the ability to remove snow and prevent the bonding of snow and ice with liquids. Solid and prewet solid chemicals are distributed with conventional materials spreaders. Some ADOT spreaders have prewetting capability.

Deicing tactics usually include the application of solid or a prewet solid chemical to snow or ice that is usually bonded to the pavement. Various kinds of spreaders are used to make applications. Solid chemicals can be prewetted to enhance the melting capability of the chemical and to help adhere the chemicals to snow or ice.

Mechanical removal of snow or ice followed by friction enhancement involves plowing of loose snow or ice followed by the application of abrasives on critical areas or general applications. These materials will not significantly melt or disbond snow or ice unless chemicals are mixed with the abrasives in either a high ratio mixture (50-50) or are applied in high quantities. Abrasives can also be prewetted with liquid chemicals in order to enhance their ability to stick to snow or ice.

Mechanical removal alone involves plowing or otherwise removing loose snow or ice from highway areas without being followed by the application of chemicals or abrasives. Tactics include the use of various kinds of front-mounted truck plows and wing plows.

Some mechanical removal of packed snow or ice is accomplished with motor graders and underbody plows that have down-pressure capability. Other attachments for motor graders fracture the snow pack or ice and make it easily removable with bladed equipment. The final layers of ice will have to be loosened chemically or by solar warming of the pavement.

In some areas with significant snow accumulations, snow blowers are used to remove the deep snow. In some cases, front-end loaders can also be used in areas where plows or motor graders cannot operate.

4.3 RECOMMENDED PROCEDURES FOR SNOW AND ICE CONTROL IN NORTHERN ARIZONA

Currently. ADOT snow and ice control typically involves the mechanical removal of snow and ice (plowing) and friction enhancement (cinders). This strategy frequently does not allow the restoration of road surfaces to an acceptable pavement condition within an acceptable period of time. It can also allow the pavement surface to deteriorate to unacceptable (Table 7) levels of service.

In order to attain an acceptable LOS, ADOT needs to adopt anti-icing and deicing snow and ice control strategies appropriate for conditions like those given in Table 7. In particular, a chemical priority policy, i.e., using chemicals when they are likely to produce the desired result, is needed to ensure that the LOS goals can be attained. It is recognized that the application of chemicals for snow and ice control can meet with resistance in certain areas and with certain customers or interested parties.

It is also recognized that weather and road conditions can vary greatly over northern Arizona and into the transition zone. The various strategies and tactics are resource dependent and the implementation of them needs to consider the level of service goals for the snow and ice control routes.

In all cases, the implementation of strategies and their associated tactics should be based on the considerations of site conditions, the local climate, and traffic. Table 13 describes various factors that need to be taken into consideration when selecting strategies and tactics. This table is based on research in the National Cooperative Highway Research Program (NCHRP) Project 6-13, Guidelines for Snow and Ice Control Materials and Methods. The results of that research will provide more definitive guidelines for certain strategies and tactics.

4.3.1 Recommended Strategies

Where level of service goals and site conditions allow, ADOT should implement anti-icing as a standard strategy, recognizing that the actual implementation is a case-by-case operation dependent upon the current and expected road and weather conditions.

Table 13. Factors to Consider for Snow and Ice Control Strategies and Tactics

Table 13A. Climate Considerations

Frequency of Snow and Ice Events • Low • Moderate • High
Severity of Winter Temperatures • Mild • Moderate • Servere
Urban Influence • Small • Medium • Large
Water Influence • Minor • River • Lake • Other (steam plants, cooling towers, hot springs, etc.)
Elevation/Large Scale Topography • Plain • Rolling • Sloped (e.g., Mogollon Rim) • Mountainous

Table 13B. Traffic Condition Factors

Traffic Volume • Low • Moderate • High
Commercial Vehicle Mix • Low • Moderate • High
Vehicle Speeds • Low • Moderate • High

Table 13C. Site Condition Factors

Area Type • Urban • Suburban • Rural
Highway Segment Features • Hills • Curves • Grades • Intersections • Bridges • Sags • Ramps • Cross Slopes • Weaving Areas • Narrowings • Pavement Surface Types • Tangents
Solar Influence • Slope and Solar Aspect (e.g., uphill N-S or E-W) • Forest/Vegetation • Structures • Cuts
Wind Influence • Forest/Vegetation • Cuts • Exposed Stretches • Wind Channels

In addition to anti-icing, in areas where level of service requirements suggest that because of current resource limitations the goals are unattainable, ADOT should implement a deicing strategy. Deicing can improve the efficiency and effectiveness of snow and ice removal in those areas and help to maintain or attain a higher level of service.

Table 14. Recommended Application Rates for Solid and Liquid Sodium Chloride (Road Salt)

Probable Pavement Temperature at Treatment and Before Next Treatment	Ice Control Chemical Dilution Potential	Ice-Pavement Bond Characteristics Before Treatment	Application Rate: Solid (Note 5) Pounds Per Lane Mile	Application Rate: Solid (Note 5) Kilograms Per Lane Kilometer	Application Rate: Liquid (Note 6) Gallons Per Lane Mile	Application Rate: Liquid (Note 6) Liters Per Lane Kilometer
Greater than 32°F (0°C)	Low	Bonded/Packed	50 - 100	41 - 28	NR	NR
		Unbonded	Note 7	Note 7	Note 7	Note 7
	Medium	Bonded/Packed	100 - 200	28 - 55	NR	NR
		Unbonded	Note 8	Note 8	Note 8	Note 8
	High	Bonded/Packed	200 - 300	55 - 83	NR	NR
		Unbonded	50 - 100	14 - 28	22-44	52-104
23°F to 32°F (-5°C to 0°C)	Low	Bonded/Packed	100 - 200	28 - 55	NR	NR
		Unbonded	50 150	14 - 42	22-66	52-155
	Medium	Bonded/Packed	200 - 300	55 - 83	NR	NR
		Unbonded	150 - 200	42 - 55	66-88	155-207
	High	Bonded/Packed	300 - 400	83 - 100	NR	NR
		Unbonded	200 - 300	55 - 83	88-134	207-319
12°F to 22°F (-11°C to -5.5°C)	Low	Bonded/Packed	250 - 400	70 - 110	NR	NR
		Unbonded	100 - 250	28 - 70	NR	NR
	Medium	Bonded/Packed	350 - 450	98 - 125	NR	NR
		Unbonded	250 - 400	70 - 110	NR	NR
	High	Bonded/Packed	400 - 500	110 - 140	NR	NR
		Unbonded	350 - 450	98 - 125	NR	NR
Below 12°F (-11°C)	A. If unbonded, try mechanical removal without chemical. B. If bonded, apply chemical @ 450 to 500 pounds per lane mile. Plow when slushy and retreat when necessary. C. Apply abrasives when necessary.				NR	NR

Notes:
1. These are starting points. Local experience should refine these recommendations.
2. Pre-wetting chemicals should allow application rates to be reduced.
3. Application rates for chemicals other than sodium chloride will have to be adjusted.
4. Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible.
5. Values include the equivalent dry chemical weight in the prewetting solutions.
6. Values are shown for 23% contentration solution
7. If unbonded, try mechanical removal without applying chemicals. If pretreating, use 25-75 lb/ln-mi of solid or prewet solid chemical or 11-33 gal/ln-mi of liquid chemical.
8. If unbonded, try mechanical removal without applying chemicals. If pretreating, use 38-88 lb/ln-mi of solid or prewet solid chemical or 17-39 gal/ln-mi of liquid chemical.
9. NR = NOT RECOMMENDED

The implementation of anti-icing and deicing strategies should be based on tactics using reasonable amounts of chemicals based on current and expected conditions. Table 14 provides suggested applications rates of liquid and solid road salt.

The concentration of chemicals applied can change over time, i.e., become diluted, with the interaction of the chemicals, precipitation and accumulated snow or ice. Table 15 provides relative potentials of dilution of chemicals under various weather conditions. Care should be taken in applications of chemicals when the dilution potential is medium or high. For instance, the application of liquid chemicals on bonded or packed snow or ice is not recommended. However, very thin pack ice (<1/16 in [1.6 mm]) may be treated with liquids if post-treatment dilution potential is low. When the dilution potential is medium or high, application should be made more frequently. If the cycle times don't allow for an increase in frequency, applications should be either at greater rates, or the strategy should change to mechanical removal if refreeze is expected.

Table 15. Ice Control Chemical Dilution Potential

Table 15A. Ice control Chemical Dilution Potential for Snow Events				
		Rate of Precipitation		
		Light	Moderate	Heavy
Moisture Content of Snow	Powder	Low	Low	Medium
	Ordinary	Low	Medium	High
	Wet/Heavy	Medium	High	High

Table 15B. Ice Control Chemical Dilution Potential for Various Precipitation Events			
Form of Precipitation	Rate of Precipitation		
	Light	Moderate	Heavy
Rain	Low	Medium	High
Freezing Rain	Low	Medium	High
Sleet	Low	Medium	High

Table 15C. Ice Control Chemical Dilution Potential for Ice Deposition Events			
Form of Precipitation	Rate of Precipitation		
	Light	Moderate	Heavy
Frost or Black Ice	Low	Medium*	High*

* These rates are not likely.

4.3.2 Snow and Ice Control in the Transition Zones of Arizona

Transition zones in Arizona are simply locations that generally experience fewer snow and ice events than higher elevations and more than experienced by lower elevations. The key factor is average air temperature that decreases with increasing elevation, all other factors being equal.

Most snow and ice conditions that occur in the higher elevations also occur within the transition zone. These include:

- Snow of all types, intensities and duration
- Freezing rain
- Preferential icing of bridges and pavement sections

The difficulty here is in predicting where and what type of event is likely to occur. The rain/snow line and pavement temperature gradients are very difficult to predict. Strategically placed RWIS and other sensing systems and customized weather forecast products can help improve prediction accuracy.

4.3.3 Treatment Options for the Transition Zone

The treatment options and the decision making required are the same as for all other snow and ice areas in the rest of the state. The only difference is in the frequency and distribution of the various types of snow and ice events.

Preferential icing or black ice is more likely to occur in the transition zone because it is more often associated with nighttime air temperatures in the range of 32°F (0°C). Other snow and ice areas have sustained periods of lower temperatures that do not generate preferential icing as readily. Preferential icing is particularly hazardous because it is unexpected and virtually undetectable to drivers – especially those that live in the lower and warmer areas of the state.

Localized icing conditions occur when the pavement (or bridge deck) temperature is at or below 32°F (0°C) AND below the dew point temperature. It is common for bridge deck surfaces to develop frost (preferential icing conditions) when the adjacent highway surfaces do not. This typically happens in the fall and spring when these temperature conditions are satisfied, the sky is free of cloud cover, and the wind speed is calm (0 to 3 mph). The early morning hours, just before sunrise, are ideal times for bridge deck icing/frosting to occur. The prediction of these icing conditions is particularly difficult, especially for rural areas with elevation changes and varied roadside vegetation coverage.

The recommended treatment strategy for this condition is pre-treating with a liquid ice control chemical 6 to 66 hours before the potential event. Liquid ice control chemicals are also effective in treating black ice that has already occurred if the pavement temperature is above 23°F (-5°C). The availability and type of assets will ultimately determine how black ice is treated.

Some highway agencies have resorted to pretreating bridge decks with a liquid chemical when conditions are favorable for localized icing conditions to occur. These treatments are made either on a routine basis, either once or twice a week, or when forecasts indicate conditions are favorable. Field experience shows that a 27% concentration solution of magnesium chloride applied at 25 gal/ln-mi or a 23% concentration solution of sodium chloride applied at 11-28 gal/ln-mi have been successful in preventing frosting conditions for up to one week on low-volume roads and 3-4 days on higher volume freeways. These liquids need to be applied in the early afternoon to enable the water in the solutions to evaporate before dark, leaving only the chemical residue on the pavement surface. Such pretreatment applications should not be made if precipitation is expected to occur. Reapplication of the liquid chemical should be made after precipitation occurs that would dilute or wash away the residual chemical.

There have been relatively rare situations where low concentrations of residual calcium chloride and magnesium chloride on pavement or bridge surfaces have become damp and then frozen to form ice or have just become slippery from mixing with other surface contaminants. Attention to spread pattern control and the timing of applications is advised when using these chemicals.

Table 16 contains recommended strategies and tactics for northern Arizona based on road priority. The actual implementation will of necessity be related to available resources. Funding for additional resources will be required in order to implement these strategies and tactics in all areas.

Table 16. Recommended Strategies and Tactics for Northern Arizona

Table 16A. Strategies and Tactics for Interstate and High Volume Urban Arterials		
STRATEGY	**WHERE APPROPRIATE**	**TACTICS**
Anti-icing (pretreatment)	All areas[1]	Liquids or Prewet solids[2,3,4]
Anti-icing (pretreatment for frost prevention)	Bridges with a history of frost formation problems[5]	Liquids[4]
Anti-icing operations during a winter weather event	All areas	Liquids, solids or prewet solids[3]; Plowing
Deicing	Entire system	Solids or prewet solids; Plowing
Mechanical Removal w/Friction Enhancement	Entire system when conditions are not favorable for anti-icing or deicing	Plowing, scraping; Cinders
Mechanical Removal Alone	Entire system for large accumulations and post storm operations	Plowing, scraping, blowing

Table 16B. Strategies and Tactics for Moderate Volume Urban US and State Routes		
Anti-icing (pretreatment)	All areas[6]	Liquids or prewet solids[7,8,9]
Anti-icing (pretreatment for frost prevention)	Bridges with a history of frost formation problems[10]	Liquids[3]
Anti-icing operations during a winter weather event	All areas	Liquids, solids or prewet solids[2]; Plowing
Deicing	Entire system	Solids or prewet solids; Plowings
Mechanical Removal w/Friction Enhancement	Entire system when conditions are not favorable for anti-icing or deicing operations	Plowing, scraping; cinders
Mechanical Removal Alone	Any roads or other features that require snow removal.	Plowing, scraping, loading

[1] If resources are limited, at a minimum hills, curves, ramps; bridges; and segments with history of problems should be pre-treated.
[2] Tactics used here are dependent on traffic conditions, pavement temperature and winter weather event type. See the FHWA Manual of Practice for Anti-icing. Prewet solids are not effective in high speed or high volume traffic conditions.
[3] Don't use liquids with moderate to high dilution potential and/or event water content.
[4] For best results, apply liquids midday to allow liquid water to evaporate.
[5] Liquids can be applied twice weekly during the frost season or when forecasts indicate frost is likely.
[6] If resources are limited, at a minimum hills, curves, intersections; bridges; and segments with history of problems should be pre-treated.
[7] Tactics used here are dependent on traffic conditions, pavement temperature and winter weather event type. See the FHWA Manual of Practice for Anti-icing. Prewet solids are not effective in high speed or high volume traffic conditions.
[8] Don't use liquids with moderate to high dilution potential and/or event water content.
[9] For best results, apply liquids midday to allow liquid water to evaporate.
[10] Liquids can be applied twice weekly during the frost season or when forecasts indicate frost is likely.

Table 16C. Strategies and Tactics for Low Volume Rural US and State Routes		
Anti-icing	Hills, curves, intersections, bridges with history of problems[1]	Liquids or prewet solids[2,3,4]
Anti-icing (pretreatment for frost prevention)	Bridges with a history of frost formation problems[5]	Liquids[2]
Anti-icing operations during a winter weather event	Hills, curves, intersections, bridges with history of problems[4]	Liquids, solids or prewet solids[5,1,2]; Plowing
Deicing	Segments of routes with history of problems[6]	Solids or prewet solids; Plowing
Mechanical Removal w/Friction Enhancement	Entire system when conditions require snow removal and surface friction	Plowing; Cinders
Mechanical Removal Alone	Any roads or other features that require snow removal	Plowing, Scraping, Blowing

[1] If resources permit, anti-icing should be used on as many other road segments as is possible.
[2] Tactics used here are dependent on traffic conditions, pavement temperature and winter weather event type. See the FHWA Manual of Practice for Anti-icing. Prewet solids are not effective in high speed or high volume traffic conditions.
[3] Don't use liquids with moderate to high dilution potential and/or event water content.
[4] For best results, apply liquids midday to allow liquid water to evaporate.
[5] Liquids can be applied twice weekly during the frost season or when forecasts indicate frost is likely.
[6] If resources permit, deicing should be used on as many road segments as is possible within the considerations for environmental management areas.

5. ADDITIONAL RECOMMENDATIONS AND CONCLUSIONS

5.1 WEATHER INFORMATION FOR SNOW AND ICE CONTROL

The access to and use of short-term weather information by ADOT highway maintenance personnel can be improved. Better access to weather information, combined with appropriate training for decision makers, can improve the effectiveness and efficiency of snow and ice control operations. In addition to better access, the acquisition and use of more accurate and user-specific forecasts should also assist in improving operations. Although currently RWIS sites are installed in northern Arizona along I-40 and at two other locations in the Holbrook District, forecasts can and should be acquired from a forecasting service for all locations involved in snow and ice control. This should be stated in a functional specification for forecasting services. NWS forecasts and those obtained from media sources are neither timely nor site-specific enough for effective decision making.

One project task required recommendations for new or expanded RWIS sites in northern Arizona, and any other weather information systems that may be required. Recommended RWIS siting was provided in Section III. Given the expansive definition of RWIS that includes forecasting, the recommendations that follow include additions and upgrades to the information systems and their use.

In order to improve the acquisition and use of weather information and forecasts, a number of procedures are recommended for ADOT. These recommendations are presented in the form of guidelines. Actual implementation decisions will in some cases require funding. In addition, implementation of many of the recommendations will require upper maintenance management support.

The procedures and guidelines are divided into three groups of recommendations: equipment needed to implement recommendations; operating procedures for ADOT personnel to use in acquiring, and disseminating forecasts; and data analysis procedures for using forecasts and documenting forecast performance.

5.1.1 Weather Information Recommendations

The following recommendations are related to equipment and software procurements or upgrades that will improve access and use of weather and road condition forecasts.

1. Procure from Integrated Financial Solutions remote access software for downloading weather information from the SBWIS to PCs or laptops. This will allow access to weather information away from the office. This can be a stand-alone package for one PC/laptop computer where there is a SBWIS. Also, data can be entered into the ADOT Intranet using a network package at one node, or more than one node for redundancy, and then using node packages at each PC or laptop. One-time costs are approximately $695 for the network copy; $200 for each node (user on the net); or $395 for stand-alone software for use with a PC to access data from an existing SBWIS unit. The latter would allow remote access to the SBWIS unit that now has to be in a fixed location. There is still a monthly access fee per node from the SBWIS but the cost will be about $53 per node compared with SBWIS monthly lease costs of about $76 per unit. Integrated Financial Solutions can be contacted at (800) 729-5037.

2. Participate with the University of Utah's Cooperative Institute for Regional Prediction in its development of a mesoscale weather information acquisition capability that would include access to RWIS and weather data in Arizona and surrounding areas. The University of Utah serves as a focal point with assistance and cooperation from agencies in surrounding states that "own" the weather infrastructure, and with the NWS. This weather information should be accessible on the ADOT Intranet via the Internet.

Figure 8 is a representation of a web site for the Utah Mesonet. The Utah web site is on the Internet at **http://www.met.utah.edu/jhorel/html/mesonet/**. Items shown Figure 8 in boldface type are "hotlinks" to other web pages where mesonet data are available in different formats. The Utah DOT (UDOT) link is password protected because Utah has decided not to release to the publicly RWIS data. ADOT will need to decide what, if any, road measurements could be included in its release of data to the Utah Mesonet.

The web site was developed in conjunction with the Utah DOT and, the National Oceanic and Atmospheric Administration including the National Weather Service.

The following description of the Utah Mesonet is extracted from the web site in order to describe its purpose and capabilities. Some Arizona weather data are already displayed and are accessible via the Mesonet.

> **"Overview**
>
> "The Utah Mesonet is a cooperative project between researchers at the University of Utah and forecasters at the Salt Lake City National Weather Service Office. The goal of this project is to provide access to current weather observations in Utah and nearby states. Support for this project is being provided by the National Weather Service.
>
> "The Utah Mesonet relies upon weather observing networks that are managed by federal, state, and local agencies and private firms. Additional stations have been installed at key locations such as near the Great Salt Lake and at venue sites for the 2002 Winter Olympics in the Wasatch Mountains. Weather observations of temperature, relative humidity, wind speed and direction, precipitation, and other weather parameters are available at several hundred locations.
>
> "The Utah Mesonet is used operationally by the National Weather Service to monitor weather conditions around the region in order to protect lives and property. The Mesonet is also used extensively by researchers to understand severe weather events such as winter snow storms and damaging winds. The Utah Mesonet is available to the educational community for use in the classroom. Students in grades K-12 can observe weather conditions near their school or around the region.
>
> **"Access to Weather and Climate Information**
>
> "We've developed several different ways to access weather information in the Intermountain West. Weather information can be visualized in many different ways and different users have different needs. Here's a brief overview of the purpose for each of the available interfaces:

UTAH MESONET

Public Interface Current Weather Conditions Around the Intermountain West	**Research Interface** Detailed Weather and Climate Information around the Region
NWS Interface Developed by the National Weather Service	**UDOT Interface** Weather Information for Road Managers
2002 Olympics Interface Weather Conditions at Olympic Venues our	**Information and Links** Mesonet Overview and Links to Data Providers
Outreach Educational Activities and Lesson Plans	**Mesonet Operations** Status Information and Quality Control

Figure 8. Recreation of the Utah Mesonet Web Site for Weather Information Access

- Public Interface. Designed for quick and flexible access to current weather conditions. Stations are grouped by counties to direct users to weather information. Users are able to view weather conditions locally or on a large scale via the Weather Map option.
- Research Interface. Complete access to all of the weather and climate products developed as part of the Utah Mesonet, including: graphical overlays of surface temperature and wind on detailed terrain maps; spatial maps of surface temperature, dew point temperature, and sea level pressure; 3-dimensional analyses of the current weather; daily summaries of weather conditions around the region; and access to past weather information.
- National Weather Service (NWS) Interface. This Interface is maintained by the forecasters at the Salt Lake City National Weather Service Office. It is intended to provide fast access to the spatial distribution of weather conditions based on graphical overlays of surface temperature and wind on detailed terrain maps. In addition, changes in weather conditions are monitored in text format at stations selected by the user.
- Utah Department of Transportation (UDOT) Interface. Developed for local road managers who need to have flexible access to weather and road conditions.

It is password protected as a result of limitations on the redistribution of radar imagery and pavement conditions.

- 2002 Olympics Interface. Developed in cooperation with the Salt Lake City Organizing Committee in order to plan weather support for the 2002 Winter Games. Weather and climate information near venues is accessible.

“Usage Restrictions

“Data contained in the Utah Mesonet arise from cooperative arrangements with many different agencies and commercial firms. The data are intended to be used by personnel in governmental agencies to protect lives and property and by the public for general information. The data may also be used for research and educational purposes. Any other uses of the data from one or more stations must receive written approval from the agencies that installed the weather sensors. Contact the NOAA Cooperative Institute for Regional Prediction to receive information on how to obtain written approval.

“Due to the nature of data transmission across the Internet and other communication factors, the information found in the Utah Mesonet may not always be current. No warranties are expressed or implied regarding the accuracy, completeness, or reliability of the information contained in the Utah Mesonet. Data users are cautioned to consider the provisional nature of the data before using it for decision making.”

3. In coordination with the National Weather Service in Bellemont, AZ, procure additional weather stations to fill in meteorological gaps. This could improve NWS forecasts and provide both the NWS and ADOT with valuable weather information where there currently is none. Whenever possible, coordinate this same effort with the RWIS Plan that was presented in Section III.

4. Procure up-to-date portable computers for Org decision makers in order for them to access weather and other information resources. Portable computers purchased to acquire data from the original RWIS procurement and currently used by foremen along the I-40 corridor are old and lack graphics capabilities. They should be replaced.

5. Provide all snow and ice control decision makers with access to the Internet for acquiring weather information and forecasts.

6. Provide Org decision makers who have laptop computers with portable telephones that have appropriate jacks for using laptop computers in vehicles or away from the office to access the ADOT Intranet, SBWIS, the ADOT RWIS and forecast products, and Internet weather. Figure 9 shows ATT Wireless Coverage in the western US, including Arizona. Most of northeast Arizona and the I-40 and I-17 corridors are covered. Gaps exist on I-40 east of Kingman and on I-17 well south of Flagstaff.

7. Provide all personnel who have or will have Internet access Internet browser software that is Java-compatible. This will permit users to see and use the latest advances in visualizing weather information, such as regional radar loops.

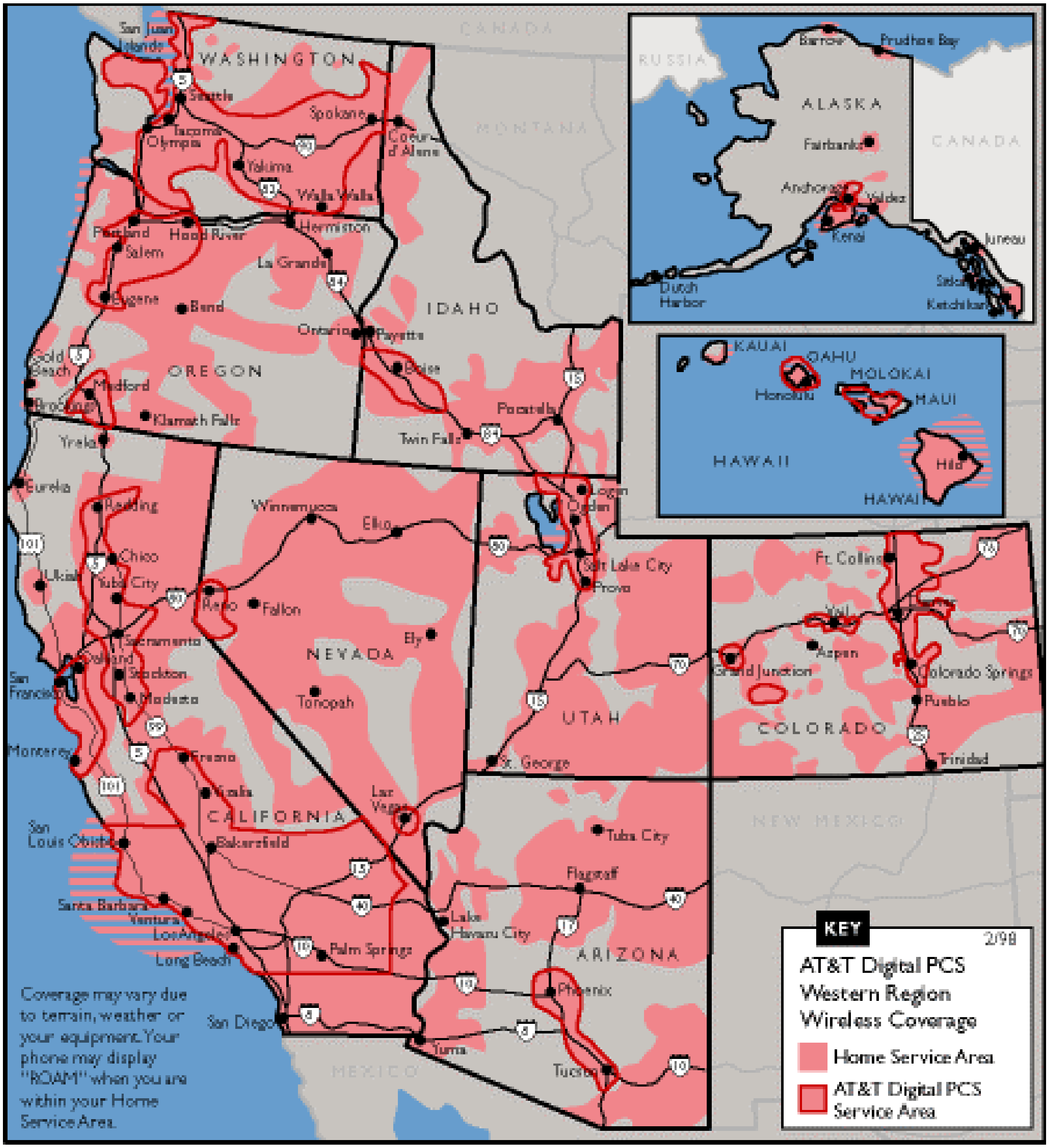

Figure 9. ATT Wireless Coverage in the Western US.

8. Contract with the University of Arizona, for the development of mesoscale forecast products that will enhance the forecasting of winter weather along the transition zone, the Mogollon Rim, and the high country in Arizona. Products developed by the University should be made available on the Internet for use by whoever provides the forecasting support to ADOT. A minimum set of useful products should include high resolution forecasts of surface temperatures, dew point temperatures, snow level, precipitation amounts, and a cross section of these parameters from west to east through the transition zone and the Mogollon Rim.

9. Conduct thermal mapping on state roads to help provide better information for pavement temperature forecasting, especially in areas where no RWIS data exist. Thermal mapping data can help improve pavement temperature forecasting for snow accumulation, freezing rain events, and frost. A minimum set of roadways for thermal mapping should include, but not necessarily be limited to:

- I-17 from Camp Verde to Flagstaff;
- I-40 from Kingman to the New Mexico border (Ash Fork to Winslow at a minimum);
- Either SR89 from Prescott to Ash Fork or SR89A to the top of the hill at Oak Creek Canyon;
- SR 87 from the Payson area to Clints Well;
- SR 260 from Payson to Heber; and
- US 60 from Show Low to Springerville/Eagar.

10. Begin a library of weather- and snow-and-ice-control-related materials at each Org. Include books at the introductory level. A minimum set of books should include:

- *SKYWATCH – The Western Weather Guide*, authored by Richard A. Keen, and published in 1987 by Fulcrum Inc. of Golden, CO. Each Org in the Flagstaff District at one time had a copy.
- *The Snow Fighters Handbook* from the Salt Institute.
- The AASHTO *Guide for Snow and Ice Control*.
- The FHWA *Manual of Practice for Anti-Icing*.
- *Basics of Snow and Ice Control* from the American Public Works Association.
- District Snow Plan.
- *Handbook on the Use of Chemicals in Arizona* from ADOT.

11. Develop a guide to the availability of weather information in Arizona.

12. If the in-place RWIS sites are not working properly, the capability to provide good forecasts is diminished. Add sufficient personnel to the signal technician section in Flagstaff to be able to respond to RWIS outages or problems within 24 hours. If adding personnel is not an option, then issue a Request for Proposals (RFP) to obtain contract maintenance for its RWIS equipment. The RFP should include minimum standards for maintaining system performance and penalty clauses for not doing so.

13. If the AASHTO winter Maintenance Policy Coordinating Committee votes to develop a computer-based training program for snow and ice control, contribute to the pooled fund study.

In addition to the above recommendations for weather information, the research team developed a set of procedures for ADOT to implement in order to utilize weather information more effectively in their snow and ice control operations. The procedures are shown in Appendix B.

5.2 RESOURCES FOR SNOW AND ICE CONTOL

The level of service capability is primarily the result of the cycle time (plowing and materials spreading) that can consistently be maintained. Mainly this is a function of fleet size and associated personnel resources. Other important factors include: the capability of the plowing and materials spreading equipment (plowing width, spreader capacity and spreader type), available treatment options, facility/loading point locations and the nature of the snow and ice events. The current ADOT snow and ice fleet size, character, and associated support resource are simply ***not adequate*** to provide the level of service desired.

5.2.1 ADOT Snow and Ice Control Truck Fleet Size

An analysis of existing truck fleet capability in terms of cycle time was performed. This was based on the responses of ADOT personnel to the ADOT LOS data base form in Figure 1 and information found in the District snow and ice control plans. The responses to the LOS form provided data on route location, route boundaries, length, route priority level as defined in the State Plan, current cycle time for the route, and current and desired times to reach a desired road condition of 2.0 (“Occasional areas of snow accumulation with small patches of ice or slush, no traction aids required; generally safe”) after the end of a typical storm. Cycle time, as used in this report, is the time it takes to complete a snow and ice treatment – including time for deadheading, reloading and attending to necessary human body requirements.

Tables 17A – 17E contain priority and cycle time data taken directly from the LOS Data Base Forms (Figure 1) returned from the five districts. Lane miles were calculated by subtracting LOS questionnaire milepost limits, multiplying by the number of highway lanes and adding five percent for intersections, turning lanes, widening, etc. The number of trucks for each route was determined from the questionnaire and the District snow and ice control plans. The average cycle time, the average lane-miles per truck, and the average production rate per truck are given by route priority level for each District in Tables 17A–17E. The weighted average production rate per truck is also given for each District. Here, production rate is defined as the number of lane-miles that a snow and ice control truck treats during a cycle, divided by cycle time.

Table 17A. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Flagstaff District

Priority 1

	A Org	B Cycle Time, Hours	C Lane Miles	D No. of Trucks	E B x D
	50	1.5	52	1	1.5
	50	1.1	36	1	1.1
	50	2.0	180	4	8.0
	51	6.0	156	3	18.0
	52	8.0	154	2	16.0
	53	4.7	164	3	14.1
	53	1.5	32	1	1.5
	54	5.0	124	2	10.0
	54	1.5	6	1	1.5
	55	5.0	78	2	10.0
	55	3.0	66	2	6.0
Sum		39.3	1048	22	87.7
Avg.		3.6			
	Average Lane Miles/ Truck				**48**
Average Production Rate	Sum C/Sum E =	11.9	ln-mi/hr/truck		

Priority 2

	A Org	B Cycle Time, Hours	C Lane Miles	D No. of Trucks	E B x D
	50	2.8	70	1	2.8
	51	6.5	104	2	13.0
	52	4.8	94	2	9.6
	52	3.7	36	1	3.7
	53	2.3	56	2	4.6
	54	6.0	112	1	6.0
Sum		26.1	472	9	39.7
Avg.		4.4			
	Average Lane Miles/ Truck				**52**
Average Production Rate	Sum C/Sum E =	11.9	ln-mi/hr/truck		

Priority 3

	A Org	B Cycle Time, Hours	C Lane Miles	D No. of Trucks	E B x D
	50	12.0	36	1	12.0
	51	5.3	30	1	5.3
	51	6.0	78	1	6.0
	52	3.3	58	1	3.3
	54	6.0	104	1	6.0
	55	2.0	26	1	2.0
Sum		34.6	332	6	34.6
Avg.		5.8			
	Average Lane Miles/ Truck				**55**
Average Production Rate	Sum C/Sum E =	9.6	ln-mi/hr/truck		

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 11.6 \text{ ln-mi/hr/truck}$$

Table 17B. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Prescott District

	Priority 1				
	A	B	C	D	E
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	51	4.6	184	1	4.6
	51	2.1	84	1	2.1
	51	1.1	22	1	1.1
	51	0.7	14	1	0.7
	53	3.4	80	1	3.4
	53	2.5	50	1	2.5
	53	1.0	20	1	1.0
	53	1.6	32	1	1.6
	50	1.5	30	1	1.5
Sum		18.5	516	9	18.5
Avg.		2.1			
	Average Lane Miles/ Truck				**57**
Average Production Rate	Sum C/Sum E =		27.9	ln-mi/hr/truck	

	Priority 2				
	A	B	C	D	E
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	51	1.5	30	1	1.5
	51	2.1	41	1	2.1
	53	1.5	30	1	1.5
	53	1.3	22	1	1.3
	53	1.3	25	1	1.3
	53	1.2	24	1	1.2
	50	1.5	30	1	1.5
	50	1.2	23	1	1.2
	50	2.8	56	1	2.8
	52	2.5	51	1	2.5
Sum		16.9	332	10	16.9
Avg.		1.7			
	Average Lane Miles/ Truck				**33**
Average Production Rate	Sum C/Sum E =		19.6	ln-mi/hr/truck	

	Priority 3				
	A	B	C	D	E
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	51	1.6	31	1	1.6
	53	1.0	19	1	1.0
	50	1.4	28	1	1.4
Sum		4.0	78	3	4.0
Avg.		1.3			
	Average Lane Miles/ Truck				**26**
Average Production Rate	Sum C/Sum E =		19.5	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 23.0 \text{ ln-mi/hr/truck}$$

Table 17C. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Globe District

	Priority 1					Priority 2					Priority 3				
	A Org	**B** Cycle Time, Hours	**C** Lane Miles	**D** No. of Trucks	**E** B x D	**A** Org	**B** Cycle Time, Hours	**C** Lane Miles	**D** No. of Trucks	**E** B x D	**A** Org	**B** Cycle Time, Hours	**C** Lane Miles	**D** No. of Trucks	**E** B x D
	50	1.5	12	1	1.5	50	1.0	18	1	1.0	52	8.0	108	1	8.0
	52	4.0	45	1	4.0	50	2.0	43	2	4.0	55	5.0	67	1	5.0
	53	0.5	20	1	0.5	50	1.0	14	1	1.0	55	5.0	45	1	5.0
	53	0.5	22	1	0.5	53	2.0	20	1	2.0					
	54	4.0	75	1	4.0	54	3.0	127	3	9.0					
	54	4.0	39	1	4.0	56	2.0	67	1	2.0					
	56	3.0	98	2	6.0	56	2.0	40	1	2.0					
	57	2.5	53	1	2.5	56	0.5	9	1	0.5					
	57	1.0	32	1	1.0	55	2.5	61	1	2.5					
	57	1.5	51	1	1.5	55	2.5	58	1	2.5					
	57	2.5	43	1	2.5	55	1.5	14	1	1.5					
Sum		25.0	490	12	28.0		20	471	14	28.0		18.0	220	3	18.0
Avg.		2.3					1.8					6.0			
	Average Lane Miles/ Truck				**41**	**Average Lane Miles/ Truck**				**34**	**Average Lane Miles/ Truck**				**73**
Average Production Rate	Sum C/Sum E =		17.5	ln-mi/hr/truck		Sum C/Sum E =		16.8	ln-mi/hr/truck		Sum C/Sum E =		12.2	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 16.6 \text{ ln-mi/hr/truck}$$

Table 17D. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Holbrook District

	Priority 1				
	A	B	C	D	E
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	4.5	166	3	13.5
	50	5.0	110	2	10.0
	50	2.5	28	1	2.5
	51	3.0	160	3	9.0
	51	1.7	21	1	1.7
	52	6.5	56	1	6.5
	54	3.0	62	1	3.0
	54	2.5	70	2	5.0
	55	8.0	188	4	32.0
Sum		36.7	861	18	83.2
Avg.		4.1			
	Average Lane Miles/ Truck				**48**
Average Production Rate	Sum C/Sum E =		10.3	ln-mi/hr/truck	

	Priority 2				
	A	B	C	D	E
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	4.0	27	1	4.0
	52	9.0	241	4	36.0
	53	4.0	118	2	8.0
	54	3.0	44	1	3.0
	54	1.5	26	1	1.5
	54	1.5	30	1	1.5
	55	4.0	28	1	4.0
Sum		27	514	11	58.0
Avg.		3.9			
	Average Lane Miles/ Truck				**47**
Average Production Rate	Sum C/Sum E =		8.9	ln-mi/hr/truck	

	Priority 3				
	A	B	C	D	E
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	4.0	68	1	4.0
Sum		4.0	68	1	4.0
Avg.		4.0			
	Average Lane Miles/ Truck				**68**
Average Production Rate	Sum C/Sum E =		17.0	ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 10.0 \text{ ln-mi/hr/truck}$$

Table 17E. Operational Cycle Time, Lane Miles per Truck, and Production Rate, Kingman District

	Priority 1					Priority 2					Priority 3				
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D	Org	Cycle Time, Hours	Lane Miles	No. of Trucks	B x D
	50	3.0	113	2	6.0	50	6.0	133	1	6.0					
	50	3.0	16	1	3.0	53	2.0	44	1	2.0					
	50	3.0	58	1	3.0										
	50	3.0	38	1	3.0										
	51	3.0	296	4	12.0										
	51	4.0	36	1	4.0										
	53	2.0	64	1	2.0										
	53	2.0	36	1	2.0										
Sum		23.0	657	12	35.0		8	177	2	8.0					
Avg.		2.9					4.0								
	Average Lane Miles/ Truck				**55**	**Average Lane Miles/ Truck**				**89**	**Average Lane Miles/ Truck**				
Average Production Rate	Sum C/Sum E =		18.8	ln-mi/hr/truck		Sum C/Sum E =		22.1	ln-mi/hr/truck		Sum C/Sum E =			ln-mi/hr/truck	

District Weighted Average Production Rate

$$\frac{\text{Sum (Production Rates x No. of Trucks)}}{\text{Total Number of Trucks}} = 19.3 \text{ ln-mi/hr/truck}$$