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Effect of Video Camera-Based Remote Roadway Condition Monitoring on Snow Removal-Related Maintenance Operations

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Master of Science

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ABSTRACT

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Remote monitoring through the use of cameras is widely utilized for traffic operation, but has not been utilized widely for roadway maintenance operations. The Utah Department of Transportation (UDOT) has implemented a new remote monitoring system, referred to as a Cloud-enabled Remote Video Streaming (CRVS) camera system for snow removal-related maintenance operations in the winter. The purpose of this study was to evaluate the effectiveness of the use of the CRVS camera system in snow removal-related maintenance operations. This study was conducted in two parts: opinion surveys of maintenance station supervisors and an analysis on snow removal-related maintenance costs. The opinion surveys were performed in two methods: direct interviews and an online questionnaire. The responses to the opinion surveys mostly displayed positive reviews of the use of the CRVS cameras. On a scale of 1 (least effective) to 5 (most effective), the average overall effectiveness given by the station supervisors was 4.3 for both direct interviews and online questionnaire. On the online questionnaire, supervisors were asked to give an estimate of the reduction in expedition trips after having the CRVS camera installed. An expedition trip for this study was defined as a trip that was made to just check the roadways if snow-removal was necessary. The average of the responses received was calculated to be a 33 percent reduction in expedition trips. For the second part of this study, an analysis was performed on the snow removal-related maintenance cost data provided by UDOT to see if the installation of a CRVS camera had an effect in reducing expedition trips. Weather data of precipitation was also collected and analyzed; the analysis showed a close relation between precipitation patterns and patterns of snow removal-related maintenance costs of pairs of adjacent maintenance stations selected for analysis. This close relation in precipitation pattern and snow removal-related costs allowed a comparison of expedition cost of a maintenance station with a CRVS camera and a station without one. This expedition cost comparison was performed for 10 sets of maintenance stations within Utah. It was difficult to make any definitive inferences from the comparison of expedition costs over the years for which precipitation and expedition cost data were available; hence a statistical analysis was performed using the Mixed Model ANOVA. This analysis resulted in an average of 14 percent higher ratio of expedition costs at maintenance stations with a CRVS camera before the installation of the camera compared to the ratio of expedition costs after the installation of the camera. This difference was not proven to be statistically significant at the 95 percent confident level, but indicated that the installation of CRVS cameras was on the average helpful in reducing expedition costs and may be considered practically significant. It is recommended that more detailed and consistent maintenance cost records be prepared for accurate analysis of cost records for this type of study in the future.

Keywords: remote monitoring, snow removal-related roadway maintenance

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1 INTRODUCTION

For a State Department of Transportation (DOT) in a cold region, snow removal-related roadway maintenance is a major and important part of the tasks maintenance crews are responsible for. DOTs are responsible to provide safety in travel for the public by clearing roadways of snow and ice. With limited resources, it is difficult to maintain all roadways within the state during winter conditions.

State DOTs are constantly trying to allocate the limited resources to serve the public efficiently and effectively. However, this becomes a challenge when there are numerous miles of roadways to maintain. It requires many hours and physical labor to maintain all roadways. Remote monitoring is a method used to help DOT maintenance crews efficiently maintain certain roadways that require attention in a timely manner.

Remote monitoring through the use of cameras is already widely utilized for traffic operation, control, and management. It provides an effective method to monitor traffic over a large number of roads throughout the state from few traffic operation centers. However, the use of video-based highway monitoring for maintenance operations has not been utilized widely by maintenance shed employees.

This report presents the findings of a study on the effect of the use of video camera-based remote roadway condition monitoring on snow removal-related maintenance operations. This chapter consists of the following sections: 1) background of the study, 2) purpose of the study, and 3) the organization of this report.

1.1 Background

The Utah DOT (UDOT) has implemented the use of video camera-based highway monitoring for maintenance operations, mainly for snow removal-related maintenance operations in the winter. The remote monitoring system implemented by UDOT does not use conventional Closed Circuit Television (CCTV) cameras, but rather a new system provided by Live View Technologies. This new video camera-based remote monitoring system evaluated in this study is referred to as a Cloud-enabled Remote Video Streaming (CRVS) camera system in this report. The CRVS cameras are different from CCTV cameras because they are accessible from various devices via the internet and the maintenance station supervisors and workers can zoom, pan, and tilt the cameras from various devices. The devices include computers, smartphones, and tablets. This system is described visually in Figure 1-1. A screenshot of one of the CRVS cameras being viewed by a desktop computer is presented in Figure 1-2.

The CRVS cameras are independent from the CCTV camera grid owned by UDOT. They run on power independent from UDOT's CCTV cameras, and are backed up by a solar-powered battery, as shown in Figure 1-3. The following list presents some of the additional features of the CRVS cameras as provided by Live View Technologies.

- The cameras run on low power consumption and the solar panel battery provides backup for 10 days without charge.
- The cameras provide high resolution video with full pan, tilt, and optical zoom functionality.
- The cameras provide night vision with targeted infrared lighting.

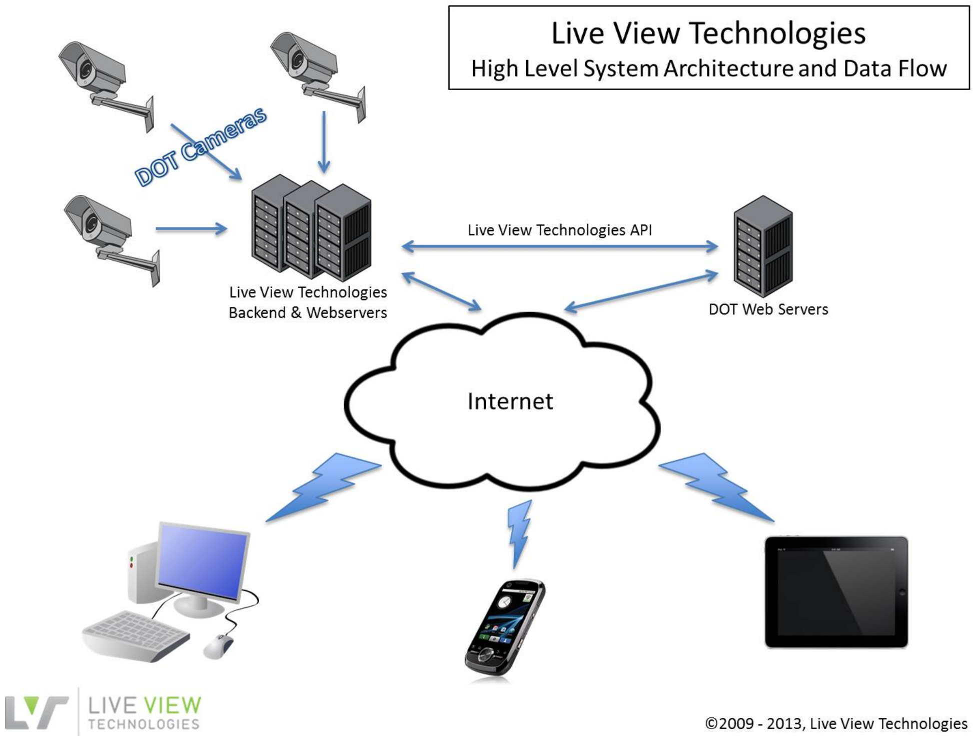

Figure 1-1: CRVS Camera System Overview (Provided by Live View Technologies)

Figure 1-2: Screenshot of CRVS Camera View

Figure 1-3: CRVS Camera

1.2 Purpose

The purpose of this research is to evaluate the effectiveness of the use of the CRVS camera system in remote roadway condition monitoring for snow removal-related maintenance operations at UDOT's roadway maintenance stations by conducting both qualitative and quantitative analyses.

1.3 Report Organization

This report consists of six chapters. Chapter 1 provides an introduction, background, and purpose of the study. Chapter 2 presents a literature review of the available sources of research relating to the topic of remote roadway condition monitoring. The literature review introduces examples of the use of remote roadway condition monitoring in four locations and summarizes the overall effectiveness of the use of cameras in remote monitoring. Chapter 3 introduces the study methods of the research. Chapter 4 presents the results of the first part of the study, which was to collect opinions of maintenance station supervisors on the use of the CRVS camera system. Chapter 5 presents the results of the second part of the study, which was a quantitative analysis of maintenance costs on snow removal-related maintenance operations. Chapter 6 provides conclusions of the study and recommendations for further studies.

2 LITERATURE REVIEW

A literature review was conducted to identify the existing operational effect and cost effectiveness of remote roadway condition monitoring. The literature review presents the findings from available research. As the CRVS system is fairly new, there was no available research on the use of the system. Rather, a literature review was conducted to identify the effect of conventional CCTV cameras in remote roadway condition monitoring. This chapter consists of the following sections: 1) necessity for roadway condition monitoring, 2) use of CCTV cameras in roadway condition monitoring, 3) effectiveness of CCTV cameras in roadway condition monitoring, and 4) chapter summary.

2.1 Necessity for Roadway Condition Monitoring

There is a massive network of roads and highways in the U.S. As of 2008, there are about 2.7 million miles of paved public roads in the U.S. (RITA 2012). With this many roads to keep in good condition, it becomes a great challenge for public agencies to monitor the conditions of each road. Conditions of the road affect driver behaviors and performances. Poor roadway conditions could lead to injuries and fatalities, traffic delay and congestion, and high operational and maintenance costs.

2.1.1 Injuries and Fatalities Due to Poor Road Conditions

Weather conditions have a significant effect on poor road conditions. This presents a challenge to public agencies in that they cannot control the natural occurrence of severe weather. Many areas in the U.S. experience challenging weather conditions, especially in the winter, such as snow and ice on the roads. Over 10 percent of all passenger vehicle crashes occur in rain, snow, or sleet each year. 18 percent of fatal passenger vehicle crashes (over 6,600) and 22 percent of injury crashes (over 470,000) occur under poor weather or pavement conditions each year (Pisano and Goodwin 2002). To prevent such disasters from happening, timely recognition of such road conditions is necessary. In winter roadway maintenance work, early detection of the commencement of freezing of a road surface and the application of freezing inhibitors is extremely important. However, early detection of problems requires constant monitoring, which can be costly and entails significant workload (Yamamoto et al. 2005). Therefore there is a necessity for effective remote road condition monitoring to carry out efficient and effective maintenance work.

2.1.2 Traffic Delay and Congestion Due to Poor Road Conditions

Not only does the failure to act and deice and remove snow from the roads create general threats to the health and safety to the public, it also has immediate consequences on traffic delay, traffic volumes, traffic congestion, and the public's image of public agencies (Hanbali 1994). When poor weather causes hindrances to the road, drivers naturally tend to be more cautious by slowing down, causing delay and congestion. Pisano and Goodwin (2002) report that "if weather reduces freeway capacity by 10 percent, traffic congestion can result" and "under congested conditions, small changes in effective capacity or traffic volume can have significant delay effects." The Oak Ridge National Laboratory has estimated that in 1999, capacity of U.S.

freeways and principle arterials was reduced by more than 11 percent due to fog, snow, and ice. Also, the Lab projected that nearly 544 million vehicle-hours of delay or 23 percent of total delay was caused by weather conditions, with snow accounting for 90 percent of delay (Pisano and Goodwin 2002).

2.1.3 **Direct Costs of Road Maintenance**

Other than the externality costs introduced such as injuries and fatalities from crashes, traffic delay, and traffic congestion, there are direct costs of road maintenance. Winter road maintenance accounts for 24 percent of road operating costs. Each year, over 2 billion dollars are spent on snow and ice control operations and over 5 billion dollars are spent for repairing roadway infrastructure damaged by snow and ice by state and local agencies. In 1999, state DOTs spent an average of $2,800 per route mile on winter road maintenance (Pisano and Goodwin 2002).

Safety in winter driving conditions must be provided to the public at minimum expenditures, since winter road maintenance operations do not provide permanent improvements to the highway system. Managing winter roads is a continuous process, and labor represents the largest class of expenditure in highway maintenance activities (Hanbali 1994). In many cases, road conditions are currently inspected by patrolling employees. There exists a challenge in this current situation in which the constantly changing winter road surface conditions are examined only by a few patrol employees dispatched a day (Kido et al. 2002). This presents a need for remote road condition monitoring utilizing CCTV cameras.

2.2 Use of CCTV Cameras in Roadway Condition Monitoring

Public agencies utilize different methods and devices to fulfill the responsibility of providing a high level of service by proper maintenance of roadways. Among these methods and devices is the use of CCTV cameras in remote road condition monitoring. CCTV cameras are becoming more affordable and accessible. Also, in many areas, CCTV cameras are already installed for other purposes, such as traffic monitoring (Yamamoto et al. 2005). Therefore there is potential to make the decision to utilize CCTV cameras for road condition monitoring purposes with low installation costs. There are several examples of CCTV cameras being used for road maintenance purposes. This section will examine the use of CCTV cameras for road monitoring purposes as demonstrated by the systems used in Washington State, New York, Idaho, and Japan.

2.2.1 Washington State

Many public agencies, such as the Washington State DOT, have invested in advanced technologies designed to monitor, report and forecast road related weather conditions, referred to as Road Weather Information Systems (RWIS). The Federal Highway Administration (FHWA) has invested in research and development for more sophisticated use of RWIS capabilities, referred to as Winter Maintenance Decision Support Systems (MDSS). The objective of the MDSS is to take advantage of recent advances in weather forecasting and understanding of pavement information designed to support proactive decision-making by winter road maintenance managers (Boon and Cluett 2002).

In Washington State, there are more than 50 RWIS stations located along roadway right-of-way at locations that typically experience the most severe weather-related road conditions. All of the RWIS stations provide air temperature, wind speed and direction detection; many provide road surface and subsurface temperatures. Many also have cameras providing a visual image of the conditions (Boon and Cluett 2002). An example of a RWIS station is shown in Figure 2-1.

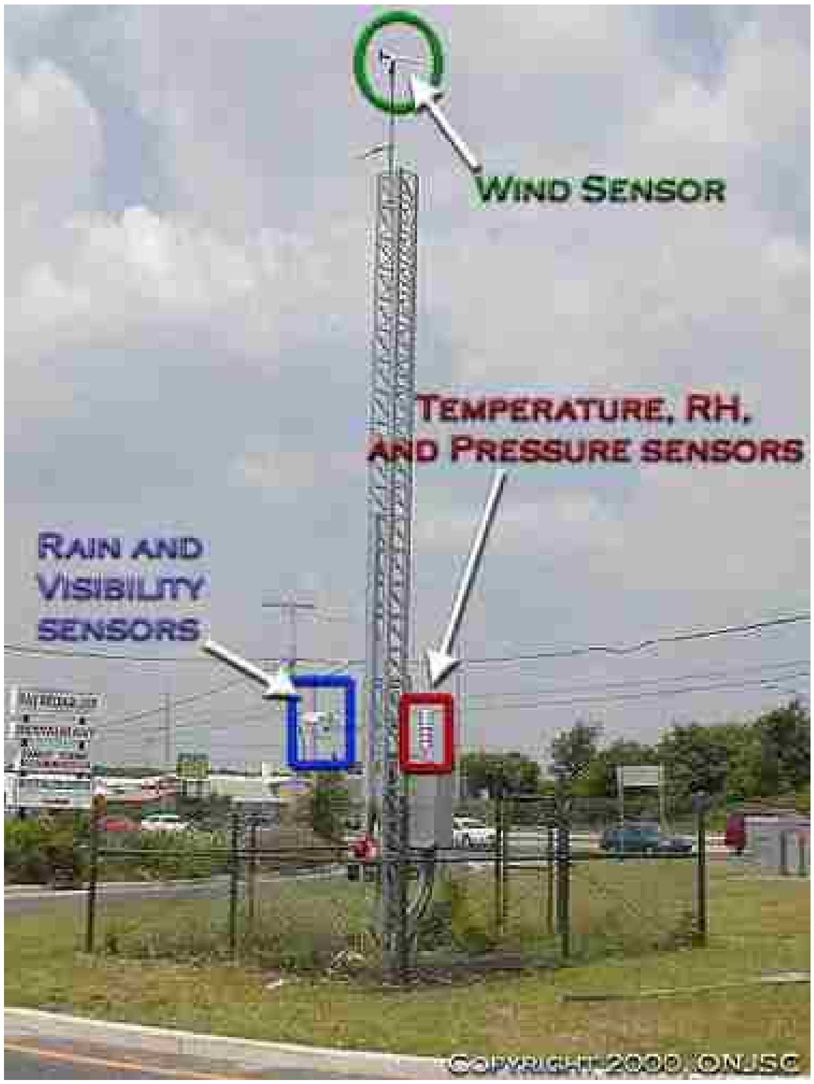

Figure 2-1: Example of a RWIS Sensor Station (Boon and Cluett 2002)

2.2.2 New York

In New York, the New York State DOT has developed a fixed anti-icing system prototype for a portion of the Brooklyn Bridge. In this system, operators review weather forecasts and view CCTV video images to monitor pavement conditions. Maintenance crews are mobilized to supplement anti-icing operations with plowing to remove snow and ice if there is a 60 percent or greater chance of precipitation and when pavement temperatures are predicted to be lower than air temperature. The New York State DOT is hoping to expand the anti-icing system by integrating a RWIS with the control system, CCTV camera, and a Dynamic Message Sign (DMS), which warns motorists during spray operations, to improve treatment decision-making (Goodwin 2003).

2.2.3 **Idaho**

The Idaho DOT utilized visibility sensors with forward-scatter detection technology in monitoring road conditions. Figure 2-2 shows a visibility sensor utilized by the Idaho DOT. A CCTV surveillance system was then used to evaluate visibility sensors. A CCTV camera was pointed at roadside target signs equipped with flashing lights, confirming actual roadway conditions (Goodwin 2003).

Figure 2-2: Visibility Sensor Utilized by the Idaho DOT (Goodwin 2003)

2.2.4 **Japan**

In Japan, CCTV cameras are used widely in various applications. Japanese public agencies have not missed seizing the opportunity to utilize CCTV cameras for road monitoring purposes. Sapporo is a city with nearly 2 million people in northern Japan. Having snowy winter weather, studies of roadway maintenance in winter conditions have been performed in Sapporo. In Sapporo, CCTV cameras are already widely installed, so road visibility data can be gathered over wide areas at low cost. Road administrators in Sapporo use CCTV cameras and visibility meters to obtain visibility information. A road visibility information system (RVIS) was developed for calculating the road visibility index (RVI), which categorizes visibility information in four ranks based on a visibility scale, in real time from daytime images obtained from the CCTV cameras along roads. The RVIS can change these still images into quantitative data (Nagata et al. 2008).

2.3 **Effectiveness of CCTV Cameras in Roadway Condition Monitoring**

From the examples of public agencies in various areas introduced in the previous section, it can be seen that several agencies are investing in utilizing CCTV cameras for road condition monitoring purposes. Agencies assess the advantages and disadvantages of CCTV cameras and estimate their effectiveness. This section will assess the advantages and disadvantages of CCTV cameras in road condition monitoring to analyze the effectiveness of investing in such technology.

2.3.1 **Advantages of CCTV Cameras in Roadway Monitoring**

When implementing technology into any task planning scheme, the benefit-cost ratio is an important indicator to whether the technology is worth investing in or not. “All current studies indicate that the benefits of RWIS far outweigh its costs, with an estimated benefit-cost ratio of between 2:1 and 10:1" (Rall 2010). RWIS equipment has evolved from simple air and road temperature measurements to complete roadside weather stations with cameras. Maintenance authorities can recover the cost of implementing RWIS by using more efficient and timely salting procedures for instance, reducing the cost of road maintenance (Crevier and Delage 2001). CCTV cameras have become inexpensive, and as discussed before, there are large numbers of cameras that have already been set up on roads for use in road management (Yamamoto et al. 2005). Therefore, there is potential to install new cameras or utilize existing cameras at low costs. This will be a factor in a better benefit-cost ratio.

The most significant advantage of utilizing CCTV cameras in road condition monitoring is the reduced cost in labor. The RVIS that is utilized in Sapporo has the capability to judge visibility from road images and functions in place of the road administrator's eyes (Nagata et al. 2008). This could lead to reductions in labor costs by replacing unnecessary maintenance crews with remote monitors provided by CCTV cameras. The use of CCTV cameras in accurate and timely weather observations from RWIS sensor stations can also reduce routine patrols, as the cameras become the eyes and ears of supervisors. Maintenance managers can mobilize just the right amount of personnel and equipment at just the right time in just the right place where attention is needed. The result is lower equipment use costs and improved labor productivity, particularly in large geographic areas (Boon and Cluett 2002). In the state of Washington, the implementation of RWIS has allowed the DOT to eliminate weekend and night shift work because of forecasts that make it possible to staff night and weekend shifts only when necessary. This has also resulted in increased employee job satisfaction (Boon and Cluett 2002). In Utah, using RWIS-supported forecasts has saved the DOT \$2.2 million per year in labor and material costs for snow and ice control activities, which accounts for 18 percent of the annual winter maintenance budget (Rall 2010).

Another advantage that CCTV cameras can provide is awareness to the public, particularly the motorists that will use the road facilities. Boon and Cluett state that "investments in RWIS can provide travelers with better information for safe and efficient travel" (Boon and Cluett 2002). The information obtained from each station can be sent to DMSs, warning motorists of poor road conditions or of maintenance actions that are currently being performed. An example of a DMS is shown in Figure 2-3.

Figure 2-3: Example of a Dynamic Message Sign (Rall 2010)

In many cases, images from CCTV cameras are open to the public through the internet so motorists can plan ahead in making trips. The assumption is that more informed travelers will make better decisions about where, when, and how to travel, resulting in a safer driving environment during severe weather conditions (Boon and Cluett 2002). The Environmental Sensor Station (ESS) is the primary field component of the RWIS that collects and sends information to maintenance managers, DMSs, and the public, as shown in Figure 2-4. A CCTV camera could be installed to the ESS.

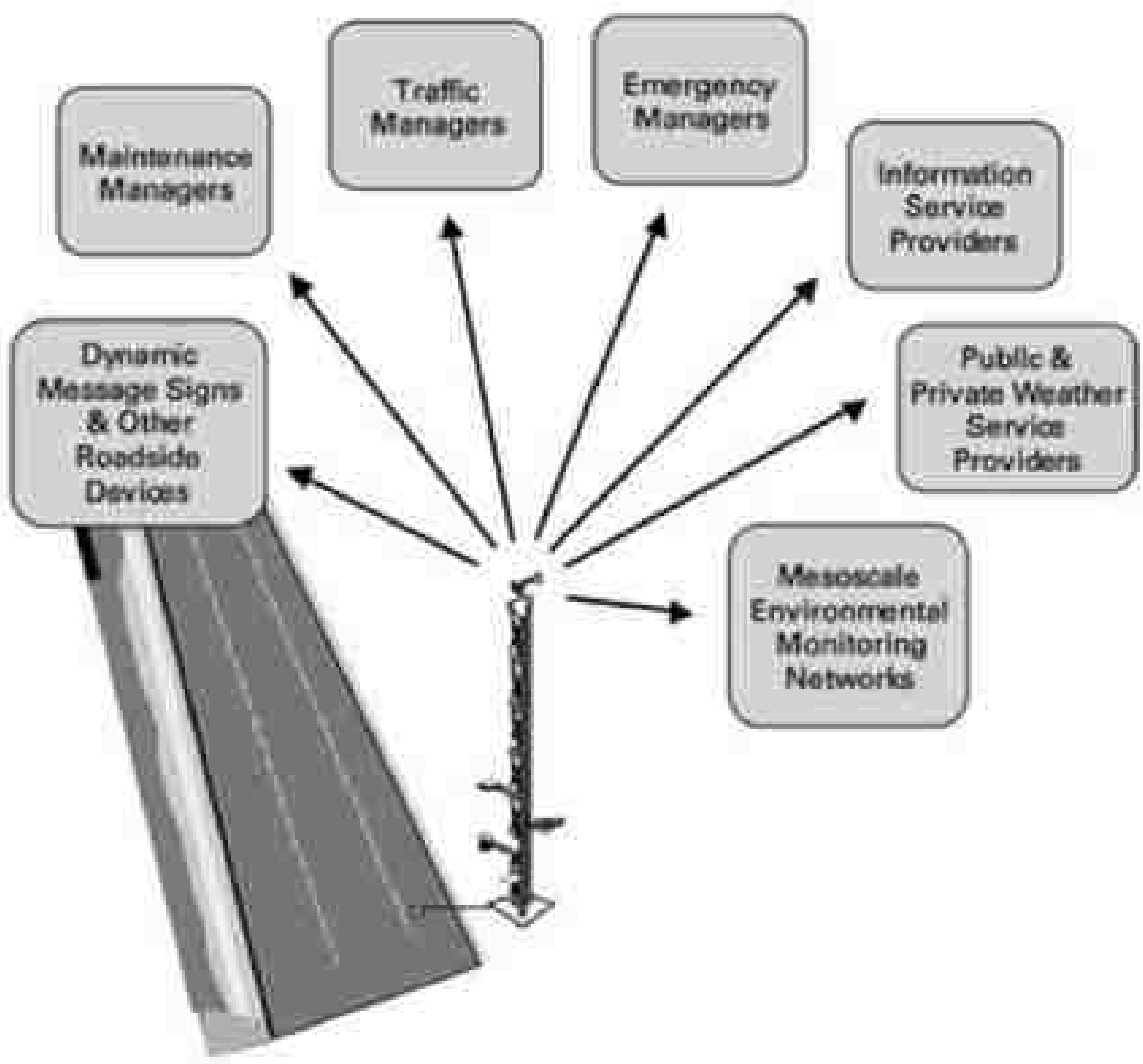

Figure 2-4: Operational Applications of Environmental Sensor Station (Rall 2010)

2.3.2 **Disadvantages of CCTV Cameras in Roadway Monitoring**

While CCTV cameras are becoming affordable, the cost of installing many of these cameras could be substantial, especially when installing new cameras at locations that do not have existing cameras. In Washington, the North Central Region Winter Maintenance Plan called for installation of up to 20 additional RWIS sensor stations at a total cost of $1.4 million (Boon and Cluett 2002). Also, as with any other technological device, there are costs associated with maintenance in order to guarantee expected performance.

While labor costs can be reduced by replacing labor with technology, there is a danger in the tendency of over-dependence on such options. CCTV cameras and various technologies can never replace the judgments that the wisdom of experienced maintenance managers can provide. Agencies must be attentive in each different scenario to ensure safety and a high level of service for the public.

2.3.3 **Overall Effectiveness of CCTV Cameras in Roadway Monitoring**

From the observed advantages, it can be seen that there is a significant potential in utilizing CCTV cameras to monitor and maintain roads more effectively. Boon and Cluett (2002) report that “the potential benefits of RWIS are substantial. Investments in RWIS can provide travelers with better information for safe and efficient travel, provide information useful for efficient scheduling of maintenance personnel, enable maintenance personnel to cost-effectively provide a higher level of service, and provide high quality observational data for improved weather forecasting.”

Although CCTV cameras have the capability to provide the benefits discussed above, the benefits result only when winter maintenance practices are significantly changed by taking advantage of RWIS capabilities (Boon and Cluett 2002). There are many CCTV cameras installed at roadsides not for road condition monitoring purposes. Unless a decision is made to make modifications to implement a system of utilizing CCTV cameras for the specific purpose of road condition monitoring, there could be inefficient use of such cameras, leading to a less effective use of CCTV cameras in road monitoring. However, if utilized to take advantage of RWIS capabilities, CCTV cameras could be utilized effectively in road condition monitoring.

2.4 Chapter Summary

In the U.S., there exists a significant challenge to maintain over 2.7 million miles of paved roads. When poor conditions on these roads exist, it produces direct and indirect costs, such as injuries and fatalities, traffic delay and congestion, and monetary costs. There is a need to provide a high level of service and ensure safety for the traveling public on these roads by reducing such costs. The purpose of this literature review was to assess the effectiveness of CCTV cameras in meeting the need for providing and ensuring high level of service and safety. In conclusion, the operational impact of the use of CCTV cameras in remote roadway condition monitoring could be substantial, and the use could be effective if maintenance practices are focused on embracing the implementation of CCTV cameras. With these results of literature review in mind, the remote monitoring system used by UDOT will be evaluated for its cost effectiveness and its impact in snow removal-related maintenance operations.

3 STUDY METHODOLOGY

In the literature review, the operational impact of the use of CCTV cameras in remote roadway condition monitoring was assessed. The CRVS remote monitoring system used by UDOT differs from conventional CCTV cameras as explained in the background section of the introduction. The purpose of this study was to evaluate the effectiveness of the CRVS system in snow removal-related maintenance operations. The research for this study was conducted in two parts. The first part involved interviews and a survey with selected maintenance station supervisors to understand opinions. The second part involved a quantitative analysis of snow removal-related maintenance costs. This chapter includes the following sections: 1) maintenance station supervisor opinion surveys, 2) maintenance cost analysis, and 3) chapter summary.

3.1 Maintenance Station Supervisor Opinion Surveys

The purpose of this study was to evaluate the use of the CRVS camera system for winter roadway maintenance operations. Not only is the concept of using cameras for snow-removal roadway monitoring new, but the CRVS camera system is different from traditional CCTV cameras used in remote monitoring as mentioned previously. The first part of this study to evaluate the effectiveness of the CRVS cameras in winter roadway maintenance operations was performed through opinion surveys of supervisors of maintenance stations that have received a

CRVS camera recently. The surveys were performed to collect and evaluate opinions of maintenance station supervisors who have experienced the use of the cameras first-hand.

The maintenance station supervisor opinion surveys were performed in two phases: the first phase was carried out by in-person interviews and the second phase was carried out by an online questionnaire. For the first phase, six maintenance stations that received a CRVS camera for the first time for the winter of 2012-2013 were selected. The supervisors of the six stations were visited for in-person interviews in the summer of 2013. It was presumed that the difference of having a camera and not for remote monitoring in maintenance operations would be fresh in memory of the maintenance station supervisors.

In the second phase, a set of questions developed based on the common responses and comments from the in-person interviews was developed into an online questionnaire using Qualtrics (2014), an online service to create surveys. This questionnaire was sent out to supervisors of nine maintenance stations that received a CRVS camera for the first time in the winter of 2011-2012.

3.2 Maintenance Cost Analysis

The second part of this study was performed through a quantitative analysis of snow removal-related maintenance costs. Snow removal-related maintenance cost data were provided by UDOT. The data were available from the years 2009 to 2013. Ten sets of maintenance stations with and without a CRVS camera in similar locations were selected to compare the snow removal-related maintenance costs to observe if there were reductions in trips checking road conditions with a camera installed. A statistical analysis was then performed to interpret the quantitative analysis on snow removal-related maintenance costs.

3.3 Chapter Summary

Chapter 3 presented the methodology used for this study. The purpose of this study was to evaluate the effectiveness of the CRVS camera system in road condition monitoring. The study was performed in two parts: the first part involved opinion surveys of the maintenance station supervisors using the CRVS cameras, and the second part was done through a quantitative analysis of snow removal-related roadway maintenance costs. Direct interviews and an online questionnaire were performed for the first part of the study to gather opinions of the maintenance station supervisors. For the second part of the study, data on snow removal-related maintenance costs were provided by UDOT for analysis. A statistical analysis was ultimately performed for interpretation of analysis and to reach a conclusion.

4 RESULTS OF OPINION SURVEYS

Supervisors of several maintenance stations that received CRVS cameras were contacted for the first part of this study. This was done in two methods. The first method was in-person interviews with the maintenance station supervisors. Six maintenance stations that received their first camera for the winter of 2012-2013, the most recent winter, were selected and visited for an interview. The second method was through an online questionnaire sent to selected maintenance station supervisors other than those interviewed in the first method. A survey was created and sent out to nine maintenance station supervisors. This chapter includes the following sections: 1) a summary of the direct interviews, 2) a summary of the online questionnaire, and 3) chapter summary.

4.1 In-Person Interviews

Visits were made to the six selected stations between the months of June to August in the summer of 2013. The questions asked and the matters discussed were focused on the effectiveness of the usage of the cameras in snow removal-related maintenance. The questions and responses varied slightly at each maintenance station. However, a set of common questions were developed in order to easily summarize and compare all responses. The set of common questions include the following: 1) length of employment as supervisor at the station, 2) start of camera usage, 3) frequency of camera usage, 4) change in snow-removal crew dispatch protocol,

5) camera access, 6) overall effectiveness of camera, and 7) other comments on camera usage. Station locations and supervisor names are withheld in the summaries. The entire summary of the responses received in the direct interviews is presented in Appendix A.

4.1.1 Length of Employment as Supervisor at the Station

The first common question asked to the supervisor at all stations was how long they have been responsible as the supervisor at the stations. This question was significant to determine if the supervisor has been at the station from before the installation of the camera. This allows the supervisor to compare maintenance operations both with and without the use of remote monitoring of roadway conditions through the cameras. The length of employment as supervisor at the station for the six supervisors varied from four years at shortest to 26 years at longest. All of the six supervisors have been at their respective maintenance stations before the installation of the camera. This implied that the responses to the questions pertaining to the effectiveness of the use of remote monitoring in winter road maintenance from all six supervisors would be reliable.

4.1.2 Start of Camera Usage

The second common question was the approximate date when the camera was first used. This question confirmed that the camera was actually used for snow removal-related maintenance operations for the winter of 2012-2013 at the respective maintenance stations. All supervisors replied that they started using the cameras around November or December in 2012.

4.1.3 Frequency of Camera Usage

The third common question was the approximate frequency of the usage of the cameras. This question was significant to observe the amount of direct use of the cameras. This indicated how significant the station supervisors considered the cameras to be in their maintenance operations. All station supervisors responded that they use the cameras multiple times a day depending on the weather. One station supervisor responded that he uses the camera on an average of about every three hours in snowy conditions.

4.1.4 **Change in Snow-Removal Crew Dispatch Protocol**

The fourth common question was whether the snow-removal crew dispatch protocols have changed at all due to the installation of the cameras. This question was significant to show if the cameras had a direct and substantial effect on maintenance operations. Four of the six station supervisors responded that there was a change in snow-removal crew dispatch protocol. They explained that the roadway condition could be easily checked where the camera was available, and fewer dispatches were sent out if the roadway conditions could be confirmed to be insignificant. The other two station supervisors responded that the protocols have not totally changed but some trips sent out to the area with a camera installed have been reduced.

4.1.5 **Usage of Cameras Installed in Other Maintenance Station Boundaries**

The fifth common question was whether the station supervisors used cameras installed within the boundaries of other maintenance stations. The maintenance station supervisors have access to all cameras installed throughout the state. This question was significant to determine if the maintenance station supervisors take advantage of the ability to utilize multiple cameras outside of their station boundaries to effectively manage maintenance operations of snow-removal. Five out of the six supervisors responded that they do use cameras installed in other maintenance stations all the time. Most supervisors explained that they generally view other cameras to predict weather patterns and plan snow-removal activities accordingly within their own station boundaries. One station supervisor responded that he has never used cameras in other maintenance stations.

4.1.6 Camera Access

The sixth common question asked whether anybody else besides the station supervisor at the maintenance station had access to the cameras. The station supervisors were asked how frequent they view the cameras in snowy weather conditions. The significance of this question was to see if the cameras are being viewed by other employees in the station crew and being utilized at times when the supervisor could not check the cameras directly. Four supervisors responded that others in the crew do have access and use the camera quite frequently. The other two supervisors responded that others do have access but haven't taken advantage of them as much.

4.1.7 Overall Effectiveness of Camera

For the last common question, the maintenance station supervisors were asked to evaluate the overall effectiveness of camera use in snow removal-related maintenance operations on a scale of one to five. The definitions of each scale were described as the following: 1 = not effective at all, 2 = less effective, 3 = no change, 4 = more effective than before, and 5 = definitely more effective. This question presented the main purpose of visit to collect the opinions of the maintenance station supervisors that have experienced the use of cameras in winter road maintenance operations. This question also helped transform the opinions into numerical values.

The responses from the six station supervisors were mostly positive in terms of the camera being effective in their maintenance operations. Two supervisors gave an effectiveness scale of 5. One supervisor gave a scale of somewhere between 4 and 5. Two supervisors gave a scale of 4. One supervisor gave a scale of 3, but explained that it would be higher if more cameras were installed and available.

4.1.8 Other Comments on Camera Usage

Finally, the interview was made open for other comments and thoughts from the station supervisors pertaining to the effectiveness of camera use in snow removal-related maintenance operations. The following list presents some of the common comments provided by the station supervisors.

- The ability to access the cameras from home or from a phone via the internet is useful and there have been many instances where unnecessary trips were reduced.
- Having the camera has helped with less anticipation and anxiety in snow-removal maintenance operations.
- It would be more useful if more cameras were installed.
- It would be an advantage if there was a way for the public to view the cameras.

There were also a few comments that resulted in both positive and negative responses from different station supervisors. Two supervisors commented that nighttime vision is fair on the cameras, whereas four supervisors commented that the camera has poor nighttime vision. Three supervisors said that the cameras were running and available when needed, whereas two supervisors said that some of the cameras hardly ever worked or were very slow due to poor cellular reception and thus it was frustrating to try to operate the camera.

Several station supervisors provided a rough assumption of cost amount that was saved in snow removal-related maintenance operations due to having a camera. One supervisor gave a rough estimate of about 40 to 50 labor hours plus equipment cost being saved for the winter of 2012-2013 with a newly installed camera. Another supervisor said roughly 15 to 20 percent unnecessary trips out to the location with a camera were reduced. Another supervisor said maybe about 25 percent of trips was reduced, but having the camera did not totally eliminate trips out to the area.

4.2 Online Questionnaire

Following the interviews with the supervisors of the six maintenance stations which received a camera for the first time for the winter of 2012-2013, a set of questions was developed based on the common responses and comments from the interviews. The set of questions was compiled into an online questionnaire using Qualtrics (Qualtrics 2014), an online service to create surveys, and sent to supervisors of nine maintenance stations that received a camera for the first time in the winter of 2011-2012. Out of the nine maintenance stations, eight maintenance station supervisors responded to the questionnaire and provided insights and comments on the effectiveness of camera use in snow removal-related maintenance operations. The questionnaire consisted of a set of questions related to the following topics: 1) date assigned as station supervisor at current station, 2) start of camera usage, 3) frequency of camera usage, 4) change in snow-removal crew dispatch protocol, 5) usage of cameras installed in other station boundaries, 6) camera effectiveness at night, 7) advantage of camera access from home, 8) overall effectiveness of camera, and 8) other comments on camera usage. The entire summary of the responses received in the online questionnaire is presented in Appendix B.

4.2.1 **Date Assigned as Station Supervisor at Current Station**

Similar to the direct interviews performed with the six maintenance station supervisors, it was significant to observe if the supervisor has been at the station at the time of installation of the camera. In the online questionnaire, the station supervisors were prompted to enter the month and year they were assigned as station supervisor at their current stations, and whether they were the station supervisor in the winter of 2011-2012 when the first camera was installed. The responses varied from as long as since April 2000 to the most recent as since February 2012. All station supervisors responded that they have been the supervisor at the time of installation of the first camera.

4.2.2 **Start of Camera Usage**

As done so in the direct interviews, it was significant to confirm that the camera was used for snow removal-related maintenance operations by the station supervisors responding to the questionnaire. The responses varied from as early as October 2010 to as late as February 2012. Two supervisors responded they started using the came as soon as it was installed and operating. Although one of the eight supervisors started using a camera before the winter of 2011-2012, their responses indicated that all station supervisors would use the camera for snow removal-related maintenance operations.

4.2.3 **Frequency of Camera Usage**

In the direct interviews, it was observed that the station supervisors would use the cameras quite frequently, though the frequency of camera use depends on weather conditions. The same question was included in the online questionnaire to see if same results would be seen for other station supervisors using the CRVS cameras. The responses to the online questionnaire did produce the same results, as all supervisors responded that they use the cameras multiple times a day.

4.2.4 Change in Snow-Removal Crew Dispatch Protocol

A change in snow-removal crew dispatch protocol due to having a camera indicates that the camera has an effect on snow removal-related maintenance operations. Several station supervisors responded that the camera has led to a change in protocol in the direct interviews. The same question was included in the online questionnaire. In the questionnaire, responses were specified in three levels: yes, maybe, or no. Two supervisors marked yes, meaning that protocols of snow-removal have changed after the installation of the camera. The other six supervisors marked maybe.

In the questionnaire, the station supervisors were then asked to explain how the protocols have changed. Several supervisors responded that the camera could be checked first to see if a trip needed to be made out to the area. One supervisor mentioned that having the camera "helped in quicker response times by watching storms earlier and being aware that a storm is coming." Others commented that having the camera did not help in reducing trips being made completely, but it did give an idea of snow patterns on the ground so responses could be improved. One supervisor responded that the camera is a great tool, but not so much later in the winter where there is heavier snow.

As part of this topic, the station supervisors were asked whether the number of dispatches sent out to check road conditions have decreased after the installation of the camera. If so the supervisors were asked to give a rough estimate of how much reduction they saw after the installation of the cameras. All eight supervisors responded that the number of dispatches sent out to check road conditions have been reduced after the installation of the camera. The amount of reduction estimated by the supervisors varied from as low as 10 percent to as high as 75 percent. One supervisor mentioned that one to five dispatches were reduced per season. The average of the percentages in reduction given in the responses was calculated to be about 33 percent.

4.2.5 **Usage of Cameras Installed in Other Station Boundaries**

From the direct interviews, five out of the six station supervisors said that they use cameras installed in other station boundaries. This indicated that the camera was not only useful for the maintenance station it was installed for, but also to maintenance employees in other stations. The question whether the station supervisors use cameras in other station boundaries was included in the online questionnaire. Out of the eight station supervisors, six responded "yes" and the other two "no."

4.2.6 **Camera Effectiveness at Night**

In the comments given by the station supervisors visited for an interview, several station supervisors commented on how the camera has poor night time vision. Since one of the possible advantages of the cameras is to be able to access the camera from home at night, this could be an important issue. Therefore, the question of whether or not the camera is effective at night was included in the online questionnaire. If the supervisor responded that the camera was not effective at night, the supervisor was asked to explain the reason.

Out of the eight supervisors, five answered "yes" and three answered "no" for the question whether or not the camera is effective at night. The three supervisors that responded "no" explained that there is limited or no light at night at the area so it is difficult to see the roadway.

4.2.7 **Advantage of Camera Access from Home**

It was assumed that one of the advantages of the camera was the ability to access the camera over the internet. This assumption was somewhat verified by the comments of some station supervisors from the direct interviews stating that being able to access the cameras from home was helpful in maintenance operations. In the online questionnaire, the question of whether or not it is an advantage to be able to access the camera from home was included to see if the assumption could be verified further. In the responses, all eight supervisors answered "yes," indicating that it is an advantage to be able to access the camera from home.

4.2.8 **Overall Effectiveness of Camera**

In the direct interviews, the station supervisors were asked to evaluate the overall effectiveness of the camera on a scale of one to five. This was effective in transforming the station supervisors' opinions on the effectiveness of the camera into a numerical value. Therefore, this was included in the online questionnaire. The same definitions for the scales of effectiveness were used.

The responses from the eight station supervisors showed a similar result as the responses from the direct interviews with the six station supervisors. Three supervisors gave an effectiveness scale of 5, four supervisors gave an effectiveness scale of 4, and one supervisor gave an effectiveness scale of 3.

In the online questionnaire, the supervisors were also asked to add an explanation of their choice of rating. To justify for the positive ratings of 5 and 4, supervisors listed a few reasons. One supervisor explained that having the camera saves time in using personnel. If the camera could be checked rather than sending someone out to the area, employees could be kept where they were needed. Another supervisor explained similarly how having a camera cuts down chasing storms and helps in assigning trucks where they need to be sooner. Another supervisor mentioned there were cost savings. To justify a neutral rating of 3, the supervisor explained that the cameras are not used for routine maintenance activities.

4.2.9 Other Comments on Camera Usage

The last question of the online questionnaire was left optional for station supervisors to write other comments pertaining to camera use in winter road maintenance operations. Three supervisors chose to write a comment. One supervisor expressed appreciation for having a camera and his frequent use. Another supervisor commented that having the camera does not "beat real-time information." Another supervisor described that "the cameras are effective for accidents if [there are] problems with back up of traffic during a storm."

4.3 Chapter Summary

Chapter 4 presented results obtained from opinion surveys performed on maintenance station supervisors that use CRVS cameras. The surveys were performed in two methods: through direct interviews and through an online questionnaire. The direct interviews were performed with six supervisors of stations that received CRVS cameras for the first time for the winter of 2012-2013. The online questionnaire was sent out to nine supervisors of stations that received CRVS cameras for the first time for the winter of 2011-2012. Eight responses were received for the online questionnaire.

Responses varied with each station supervisor. There were a few negative comments on the use of the CRVS cameras, but the responses mostly displayed positive reviews. A summary of the pertinent findings from the opinion surveys is presented in Table 4-1.

Table 4-1: Summary of Pertinent Findings from Opinion Surveys

Question	*Direct Interviews*	*Online Questionnaire*
Camera Usage Frequency	Multiple times a day	Multiple times a day
Change in Snow Removal Dispatch Protocol	Yes (4 responses)	Yes (2 responses)
	Not totally changed (2 responses)	Maybe changed (6 responses)
Overall Effectiveness	4.3 (average of 6 responses)	4.3 (average of 8 responses)
Reduction in Expedition Trips	23% (average of 2 responses)	33% (average of 8 responses)

5 SNOW REMOVAL-RELATED MAINTENANCE COST ANALYSIS

This chapter presents a summary of the results obtained by the quantitative analysis of maintenance costs. It was observed from the opinions of maintenance station supervisors presented in the previous chapter that the CRVS cameras are effective in roadway maintenance operations in the winter though the level of effectiveness reported was varied. A common response from the majority of the supervisors was how trips sent out to check the roads could be reduced with a camera in the area. One supervisor referred to this type of trip as an "expedition." For the purpose of this report, the trips that could be reduced with a camera will be referred to as an expedition because the nature of this type of trip is different from typical patrol runs. Two supervisors mentioned that there was a decrease in expedition trips on an average of about 23 percent after the installation of the cameras. Responses from a question in the online questionnaire with regards to a decrease in expeditions resulted in a rough estimate of approximately 33 percent of trips being reduced with a camera. An analysis was performed on snow removal-related maintenance costs to see if the station supervisor opinions could be supported quantitatively. This chapter consists of the following sections: 1) methodology, 2) data collection, 3) data reduction), 4) analysis results, 5) study limitations, and 6) chapter summary.

5.1 Methodology

In the direct interviews, a few supervisors mentioned that on expeditions, labor and equipment costs would be used but usually no material costs were required. To perform a quantitative analysis on whether the installation of a camera affected the costs of snow removal-related maintenance operations, the following hypothesis was set: the installation of the camera reduces the number of trips that do not require material costs. To test this hypothesis, an assumption was made that work orders that did not include material costs were possible expeditions made to check roadways for snow-removal work.

For this study, 10 maintenance stations in Utah that have received a CRVS camera were selected for analysis on snow removal-related maintenance costs. The 10 stations were selected because of the availability of a maintenance station nearby that has not received a CRVS camera for snow removal-related expedition cost comparison. The list of the set of maintenance stations selected for analysis is presented in Table 5-1. Costs for the station with a camera and the station without a camera were compared. Particularly, a statistical analysis was performed to test the set hypothesis and see if expeditions were reduced due to having a CRVS camera installed in the maintenance station.

Table 5-1: List of Maintenance Stations Selected for Analysis

Comparison	*Station with Camera*	*Adjacent Station without Camera*	*Installation of First Camera*
1	Clearfield	Clinton	2010-2011
2	Wellsville	Sardine Summit	2010-2011
3	Salt Lake West	Salt Lake Metro	2012-2013
4	Silver Summit	Parley's Canyon	2012-2013
5	Lehi	Provo Canyon	2011-2012
6	Tabiona	Kamas	2012-2013
7	Monticello	Blanding	2011-2012
8	Huntington	Emery	2012-2013
9	Long Valley Junction	Kanab	2010-2011
10	Beryl Junction	Cedar City	2012-2013

Maps showing the two stations in comparison and camera locations are provided in Appendix C.

5.2 Data Collection

Data on statewide snow removal-related maintenance costs were provided by UDOT. The data were separated into three types of cost: labor, equipment, and material. Cost data for the years of 2009 to 2013 were obtained.

Precipitation data were collected from the archived data provided by MesoWest (MesoWest 2014). MesoWest provides access to current and archived weather observation data across the United States. In Utah, there are several types of weather stations that provide different weather information at different locations. There are numerous sources of types of weather stations; however, the precipitation data are presented in different manners among them and do not directly reflect the amount of snowfall. Therefore, to maintain consistency and accuracy, the precipitation data used for this study were limited to data provided by the UDOT's RWIS stations, which were also available to collect from MesoWest. The precipitation data provided by the UDOT RWIS stations included both snow and rain. Precipitation data were collected to check if there was a correlation between snow removal-related costs and precipitation. Not all maintenance stations have a UDOT RWIS station nearby, thus limiting the selection of maintenance sheds for comparison.

5.3 Data Reduction

The data provided by UDOT included statewide snow removal-related cost records of labor, equipment, and material for the 88 maintenance stations from 2009 to 2013. For the analysis planned for this study, the data were reduced to cost records for the winter months of

November to March for four years and were compiled for the selected 20 maintenance stations. The data were also reduced by excluding activities that did not relate to direct activities of snow-removal. This allowed the data to be reduced to activities that relate to camera use for snow-removal work. The following maintenance cost records were excluded from the analysis: stockpiling of materials, snow fence and pole installation/removal, and Traveler Advisory Telephone System (TATS) reporting.

For weather data, the analysis was concentrated on the amount of precipitation. The UDOT RWIS stations provided precipitation amounts in the following four levels: no precipitation, light precipitation, moderate precipitation, and heavy precipitation. The four levels were first converted into numerical precipitation levels, i.e., 0 = no precipitation, 1 = light precipitation, 2 = moderate precipitation, and 3 = heavy precipitation. The UDOT RWIS stations provided data for every 10 minutes. Sometimes data were provided every 5 minutes. To obtain a daily precipitation level value, the weighted average was computed for each day of the winter months of November to March.

5.4 Results

The analysis results are presented in the following three parts: 1) precipitation/snow removal-related cost relation, 2) expedition cost comparison, and 3) statistical analysis.

5.4.1 Precipitation/Snow Removal-Related Cost Relation

Data on precipitation were collected for several of the locations selected for analysis. On MesoWest, the precipitation data were collected for maintenance stations only if a UDOT RWIS station was available nearby. Out of the 10 selected paired locations, five locations had a UDOT RWIS station nearby. Precipitation data were collected to check if there was a correlation between snow-removal related costs and precipitation in both maintenance stations with and without a CRVS camera. Snow conditions vary every winter, causing snow removal-related costs to fluctuate every year for each maintenance station. Therefore it was necessary to check the correlation between costs and precipitation. If there was a correlation, the comparison of expedition costs between the adjacent maintenance stations could be valid and the subsequent analysis would be meaningful.

For the five locations for which precipitation data were collected, all of them showed a strong correlation between precipitation and snow removal-related costs and the cost trends between the adjacent stations were similar. An example of the relation of the Tabiona and Kamas station pair in the winter of 2012-2013 is shown in Figure 5-1. The figures of the precipitation/snow removal-related cost relation of the five locations for all four winters are presented in Appendix D. The trend between precipitation and snow-related costs for the two adjacent stations is strong in all five locations for all winters as demonstrated in Figure 5-1. Therefore, it was assumed that the other five sets of stations would experience similar precipitation patterns between the station pairs, thus allowing a comparison of expedition costs of two adjacent maintenance stations.

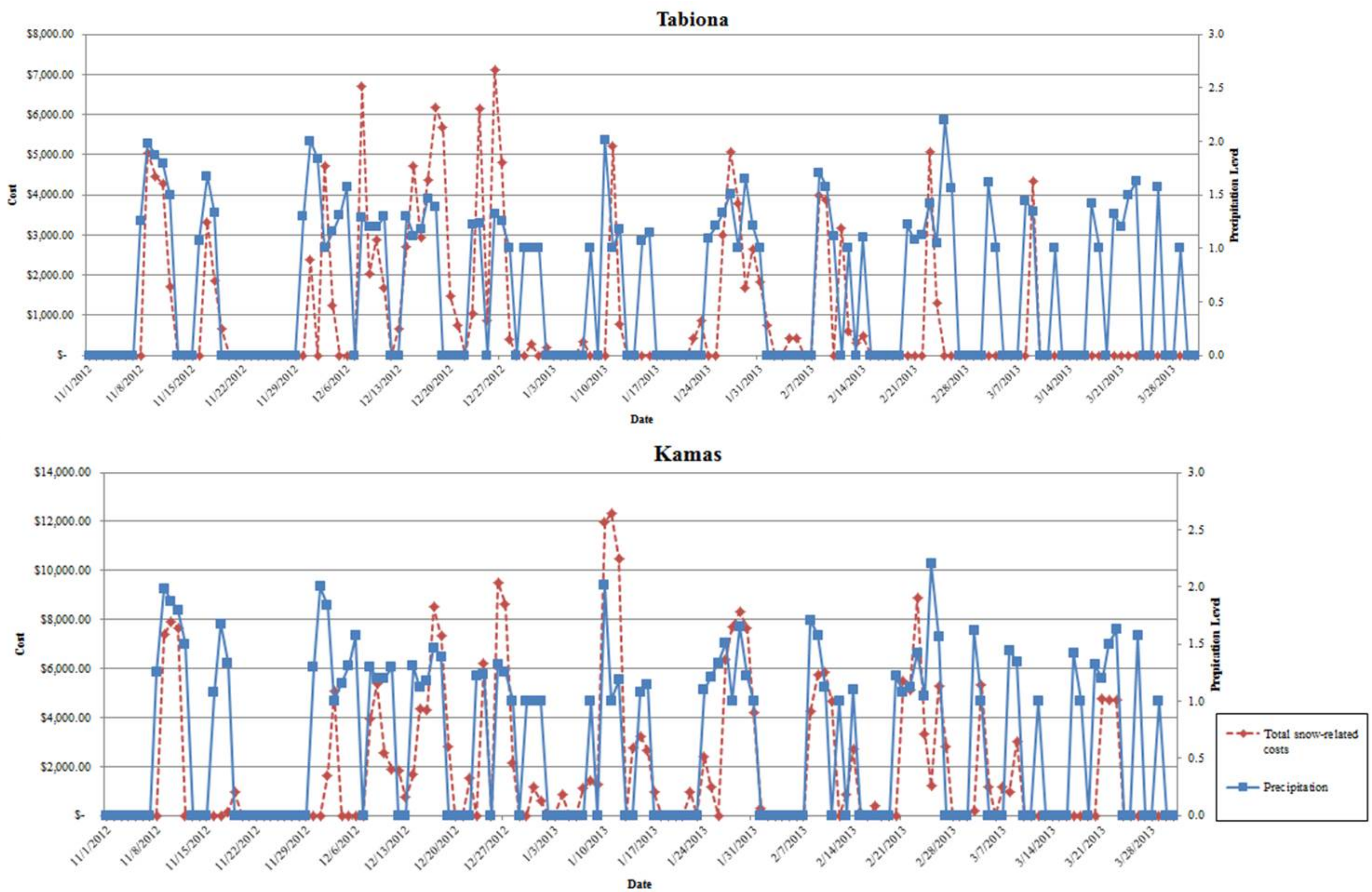

Figure 5-1: Example of Precipitation/Snow Removal-Related Cost Relation

5.4.2 Expedition Cost Comparison

It was found that the cost records between the two adjacent station pairs correlate with precipitation patterns obtained from precipitation data. The snow removal-related cost data for the 10 sets of maintenance stations with a camera and the maintenance stations without a camera were reduced from the data provided by UDOT. For each maintenance station, the total snow removal-related costs and assumed expedition costs that did not require material costs were compiled for the four winters from 2009 to 2013. The total amount of expedition costs were then compared between the two adjacent maintenance stations with and without a CRVS camera.

When comparing snow removal-related costs of the maintenance station with a camera and the station without a camera, there is a critical issue of differences in coverage area. Each maintenance station has different state routes they are responsible for. Due to geographical reasons, some stations hold maintenance responsibilities over larger areas than other stations. Also, some roadways experience more usage than others and might require more attention. Maintenance stations responsible over such roadways will experience more costs than other stations. To accommodate for this issue and make the analysis valid, the expedition costs of the maintenance stations without a camera was standardized using the relationship outlined in Equation 5-1:

$$\textbf{\textit{Standardized Expedition Cost of Station Without Camera}} = (\textbf{\textit{Expedition Cost of Station Without Camera}}) * \frac{(\textbf{\textit{Total Cost of Station With Camera}})}{(\textbf{\textit{Total Cost of Station Without Camera}})} \quad (5\text{-}1)$$

The ratio of the expedition costs of the station with a camera and the station without a camera was then determined using Equation 5-2:

$$\textbf{\textit{Ratio of Expedition Costs}} = \frac{\textbf{\textit{Expedition Cost of Station With Camera}}}{\textbf{\textit{Standardized Expedition Cost of Station Without Camera}}} \quad (5\text{-}2)$$

From this equation, a lower ratio implies more savings of expedition costs at the station with a camera than the station without a camera. This analysis was completed for the 10 selected sets of maintenance stations as described below.

5.4.2.1 Comparison Pair 1: Clearfield/Clinton

The first CRVS camera for the Clearfield Station was installed in January of 2011. Therefore, out of the four winters from 2009 to 2013, it was decided that the comparison of expedition costs between Clearfield and Clinton could be done for one winter without a CRVS camera and three winters with a camera for this study. The expedition cost comparison and resulting ratios of expedition costs are shown in Table 5-2. The years and ratios in bold font indicate the years that a camera was installed.

Table 5-2: Expedition Cost Comparison Summary for Clearfield and Clinton Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Clearfield	No	$ 285,557.48	$ 13,224.95	-	0.514
	Clinton	No	$ 135,989.92	$ 12,259.92	$ 25,743.91	
2010-2011	Clearfield	Yes	$ 265,800.60	$ 20,351.09	-	**0.776**
	Clinton	No	$ 120,929.16	$ 11,933.10	$ 26,228.79	
2011-2012	Clearfield	Yes	$ 161,598.47	$ 8,220.36	-	**0.389**
	Clinton	No	$ 84,924.47	$ 11,114.82	$ 21,149.83	
2012-2013	Clearfield	Yes	$ 352,953.07	$ 24,893.84	-	**0.386**
	Clinton	No	$ 190,437.14	$ 34,817.57	$ 64,530.31	

For all four winters, the ratio of expedition costs of Clearfield compared to Clinton was lower. This indicates that even prior to the installation of the CRVS camera, Clearfield spent less for expeditions than Clinton. The initial year of the installation of the CRVS camera in the 2010-

2011 winter showed a higher ratio than the year without a camera. However, after that, for the latter two winters, the ratio was lower. This implies a possible reduction in expedition costs at Clearfield by having a CRVS camera. This trend is shown in Figure 5-2.

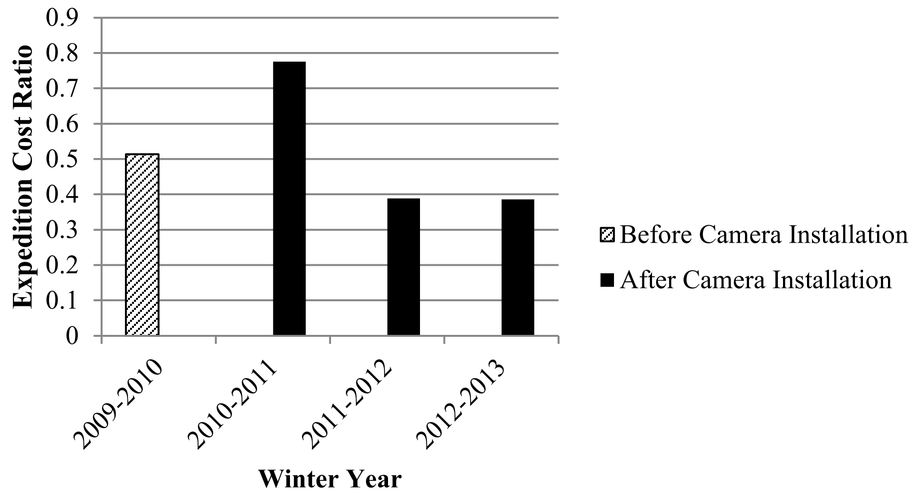

Figure 5-2: Trend in Expedition Cost Ratio for Clearfield and Clinton Station Pair

5.4.2.2 Comparison 2: Wellsville/Sardine Summit

The first CRVS camera was installed in the boundary of the Wellsville Station in February of 2011. It was decided that the comparison of expedition costs between Wellsville and Sardine Summit could be done for one winter without a CRVS camera and three winters with a camera for this study. The summary of the comparison of expedition costs is shown in Table 5-3.

Table 5-3: Expedition Cost Comparison Summary for Wellsville and Sardine Summit Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Wellsville	No	$ 176,459.97	$ 26,527.97	-	0.825
	Sardine Summit	No	$ 319,347.48	$ 58,223.43	$ 32,172.18	
2010-2011	Wellsville	Yes	$ 195,578.97	$ 21,795.28	-	**0.632**
	Sardine Summit	No	$ 342,591.22	$ 60,415.00	$ 34,489.80	
2011-2012	Wellsville	Yes	$ 117,891.12	$ 23,263.90	-	**5.238**
	Sardine Summit	No	$ 274,035.36	$ 10,323.79	$ 4,441.34	
2012-2013	Wellsville	Yes	$ 185,587.75	$ 7,639.59	-	**0.250**
	Sardine Summit	No	$ 351,100.61	$ 57,909.00	$ 30,610.03	

For this comparison of Wellsville and Sardine Summit, there was no apparent trend seen in the change in ratio of expedition costs. Two of the three winter years with a camera showed lower ratios, but the winter year of 2011-2012 showed a significantly higher ratio despite that the CRVS camera existed. This trend is presented in Figure 5-3.

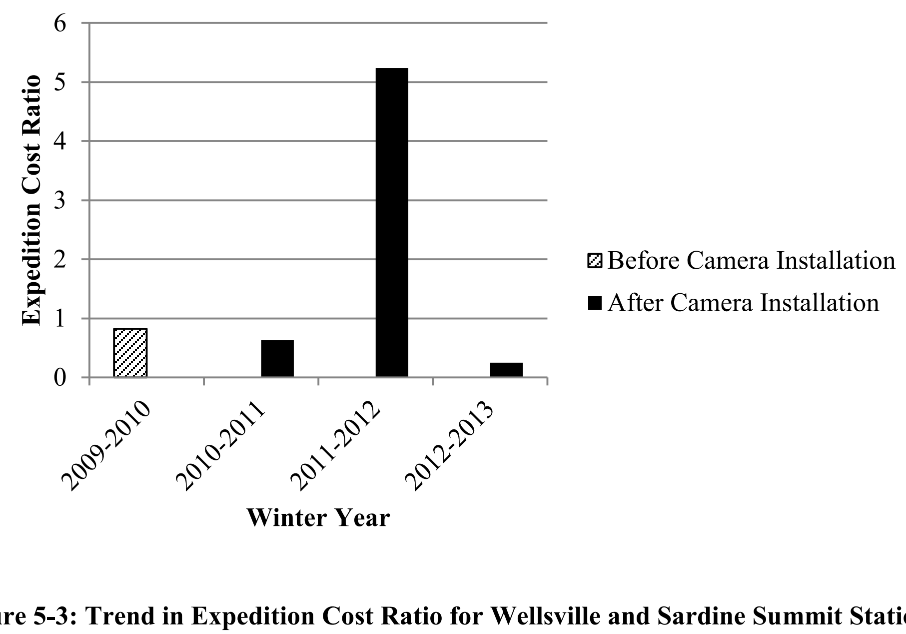

Figure 5-3: Trend in Expedition Cost Ratio for Wellsville and Sardine Summit Station Pair

5.4.2.3 Comparison 3: Salt Lake West/Salt Lake Metro

The first CRVS camera was installed in December of 2012 for the Salt Lake West Station. It was decided that the comparison of expedition costs between Salt Lake West and Salt Lake Metro could be done for three winters without a CRVS camera and one winter with a camera for this study. The summary of the comparison of expedition costs is presented in Table 5-4.

Table 5-4: Expedition Cost Comparison Summary for Salt Lake West and Salt Lake Metro Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Salt Lake West	No	$ 176,703.01	$ 18,746.66	-	3.239
	Salt Lake Metro	No	$ 218,074.73	$ 7,142.33	$ 5,787.33	
2010-2011	Salt Lake West	No	$ 334,395.92	$ 23,394.79	-	0.754
	Salt Lake Metro	No	$ 309,589.75	$ 28,729.30	$ 31,031.26	
2011-2012	Salt Lake West	No	$ 151,888.72	$ 2,918.24	-	0.188
	Salt Lake Metro	No	$ 135,150.02	$ 13,822.60	$ 15,534.57	
2012-2013	Salt Lake West	Yes	$ 474,137.77	$ 13,020.79	-	**0.364**
	Salt Lake Metro	No	$ 378,919.79	$ 28,572.14	$ 35,751.97	

The ratio of expedition costs for the year with a CRVS camera installed was lower than the first two winter years of analysis, but was higher than the previous year. It is difficult to conclude that there was a reduction in expedition costs due to the installation of the camera. The trend is shown in Figure 5-4.

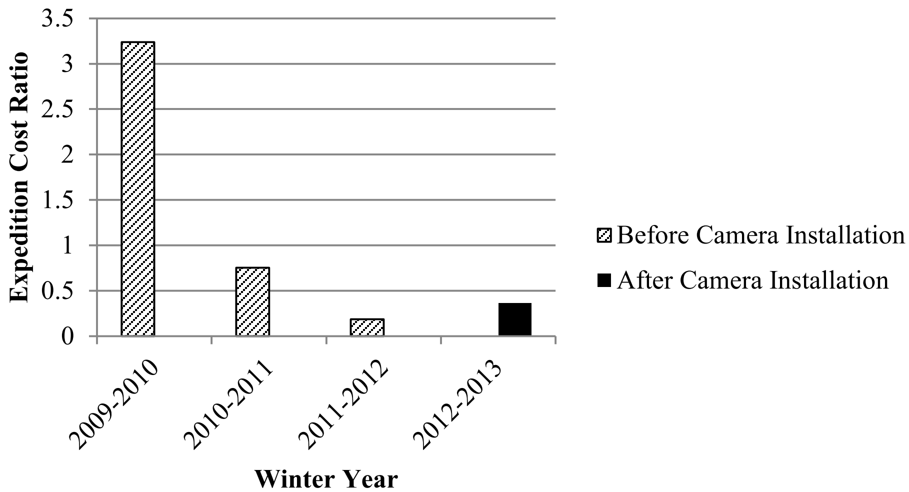

Figure 5-4: Trend in Expedition Cost Ratio for Salt Lake West and Salt Lake Metro Station Pair

5.4.2.4 Comparison 4: Silver Summit/Parley's Canyon

The first CRVS camera was installed in November of 2012 for the maintenance station at Silver Summit. It was decided that the comparison of expedition costs between Silver Summit and Parley's Canyon could be done for three winters without a CRVS camera and one winter with a camera for this study. The summary of the expedition comparison results are presented in Table 5-5.

For this comparison, the ratio of expedition costs was significantly lower for the year with a camera installed. This could imply that the camera had an effect on expedition costs. The trend is shown in Figure 5-5.

Table 5-5: Expedition Cost Comparison Summary for Silver Summit and Parley's Canyon Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Silver Summit	No	$ 426,567.15	$ 37,732.47	-	0.894
	Parley's Canyon	No	$ 376,227.70	$ 37,238.72	$ 42,221.28	
2010-2011	Silver Summit	No	$ 487,488.41	$ 27,430.74	-	0.972
	Parley's Canyon	No	$ 731,877.95	$ 42,373.50	$ 28,224.09	
2011-2012	Silver Summit	No	$ 330,261.74	$ 32,303.50	-	0.641
	Parley's Canyon	No	$ 489,380.47	$ 74,671.01	$ 50,392.24	
2012-2013	Silver Summit	Yes	$ 457,292.18	$ 8,386.75	-	**0.150**
	Parley's Canyon	No	$ 665,494.28	$ 81,115.94	$ 55,738.55	

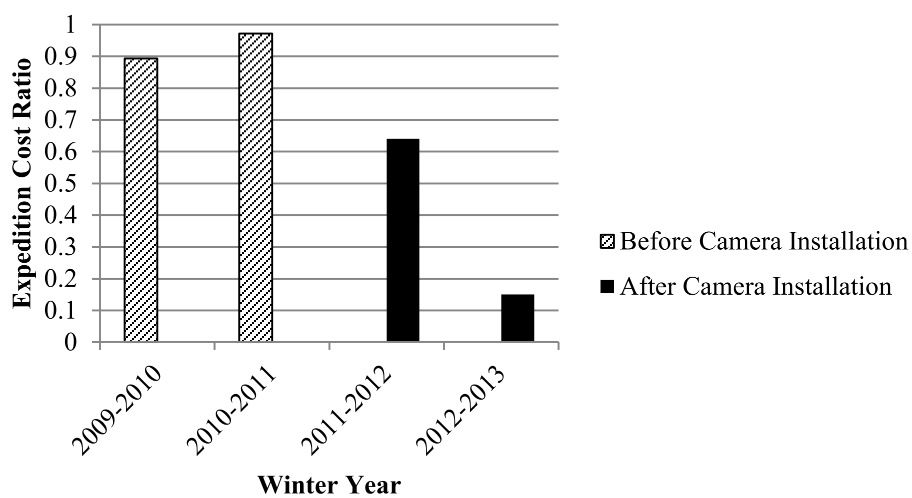

Figure 5-5: Trend in Expedition Cost Ratio for Silver Summit and Parley's Canyon Station Pair

5.4.2.5 Comparison 5: Lehi/Provo Canyon

The first CRVS camera for the Lehi Station was installed in September of 2011. It was decided that the comparison of expedition costs between Lehi and Provo Canyon could be done for two winters without a CRVS camera and two winters with a camera for this study. The summary of the expedition cost comparison results is presented in Table 5-6.

Table 5-6: Expedition Cost Comparison Summary for Lehi and Provo Canyon Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Lehi	No	$ 263,277.51	$ 1,438.48	-	0.065
	Provo Canyon	No	$ 182,669.83	$ 15,308.34	$ 22,063.53	
2010-2011	Lehi	No	$ 443,749.71	$ 10,306.69	-	3.137
	Provo Canyon	No	$ 231,041.17	$ 1,710.74	$ 3,285.74	
2011-2012	Lehi	Yes	$ 207,020.29	$ 3,027.93	-	**0.470**
	Provo Canyon	No	$ 137,840.58	$ 4,287.92	$ 6,439.95	
2012-2013	Lehi	Yes	$ 466,345.43	$ 23,648.04	-	**0.812**
	Provo Canyon	No	$ 226,892.54	$ 14,162.49	$ 29,108.99	

It is difficult to conclude if there was a reduction in expedition costs for the years with a camera for this comparison. The two years without a camera showed both a significantly low ratio and a significantly high ratio. With the camera installed, the ratio seems to be consistently lower, but this could fluctuate due to other factors. The trend of this comparison is shown in Figure 5-6.

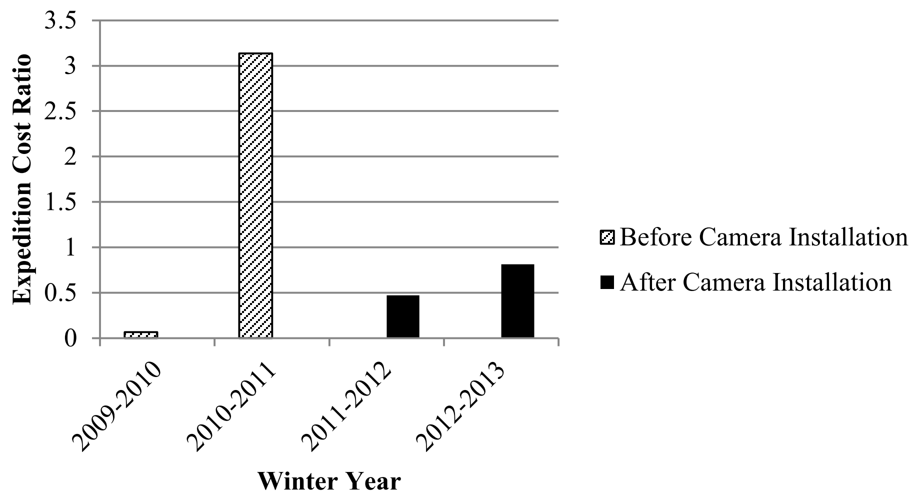

Figure 5-6: Trend in Expedition Cost Ratio for Lehi and Provo Canyon Station Pair

5.4.2.6 Comparison 6: Tabiona/Kamas

The first CRVS camera was installed for the Tabiona Station on November in 2012. It was decided that the comparison of expedition costs between Tabiona and Kamas could be done for three winters without a CRVS camera and one winter with a camera for this study. The summary of the expedition cost comparison results are presented in Table 5-7.

Table 5-7: Expedition Cost Comparison Summary for Tabiona and Kamas Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Tabiona	No	$ 137,002.29	$ 8,751.57	-	0.644
	Kamas	No	$ 326,131.35	$ 32,334.64	$ 13,583.24	
2010-2011	Tabiona	No	$ 179,017.16	$ 21,950.73	-	1.311
	Kamas	No	$ 430,135.62	$ 40,224.16	$ 16,740.80	
2011-2012	Tabiona	No	$ 113,628.33	$ 974.55	-	0.193
	Kamas	No	$ 236,642.21	$ 10,499.92	$ 5,041.74	
2012-2013	Tabiona	Yes	$ 143,695.82	$ 8,088.16	-	**0.739**
	Kamas	No	$ 276,495.08	$ 21,058.88	$ 10,944.40	

Again, it is difficult to observe an apparent trend in this comparison. The ratio was lower than one for the year with a camera installed, meaning that the expedition costs for the station with a camera was lower than the station without a camera. However, the ratio was higher for two of the three years before the camera was installed. The trend is shown in Figure 5-7.

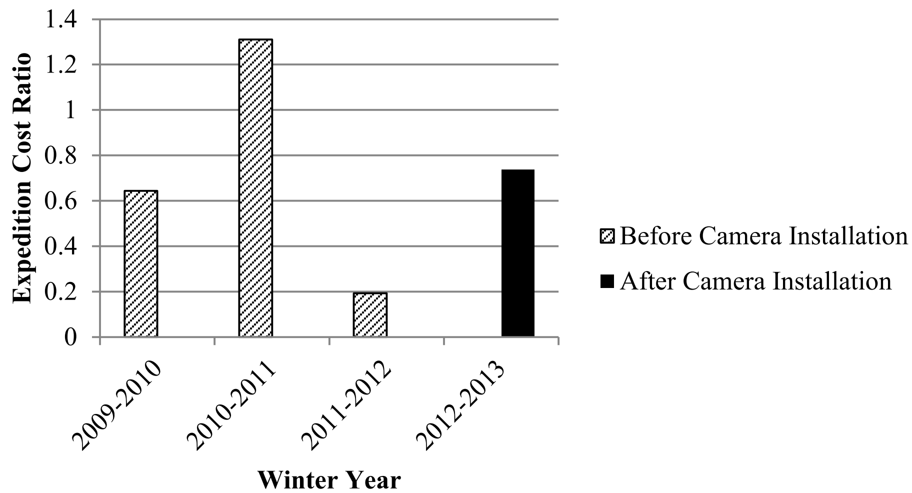

Figure 5-7: Trend in Expedition Cost Ratio for Tabiona and Kamas Station Pair

5.4.2.7 Comparison 7: Monticello/Blanding

The first CRVS camera for the Monticello Station was installed in May of 2011. It was decided that the comparison of expedition costs between Monticello and Blanding could be done for two winters without a CRVS camera and two winters with a camera for this study. The summary of the results is presented in Table 5-8.

Table 5-8: Expedition Cost Comparison Summary for Monticello and Blanding Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Monticello	No	$ 272,028.06	$ 72,063.02	-	145.25
	Blanding	No	$ 142,546.73	$ 259.98	$ 496.13	
2010-2011	Monticello	No	$ 162,106.03	$ 39,984.01	-	5.3552
	Blanding	No	$ 48,842.97	$ 2,249.65	$ 7,466.41	
2011-2012	Monticello	Yes	$ 179,342.59	$ 26,434.73	-	**5.3943**
	Blanding	No	$ 60,509.03	$ 1,653.40	$ 4,900.51	
2012-2013	Monticello	Yes	$ 238,030.31	$ 69,808.25	-	**-**
	Blanding	No	$ 77,039.55	$ -	$ -	

The ratios for Monticello showed that it used significantly more expedition costs than Blanding. The ratio for the year of 2012-2013 is not given because Blanding did not have any expedition costs and the ratio could not be calculated. It is difficult to come to a conclusion whether the camera caused expedition costs to be reduced in this comparison. The trend is shown in Figure 5-8.

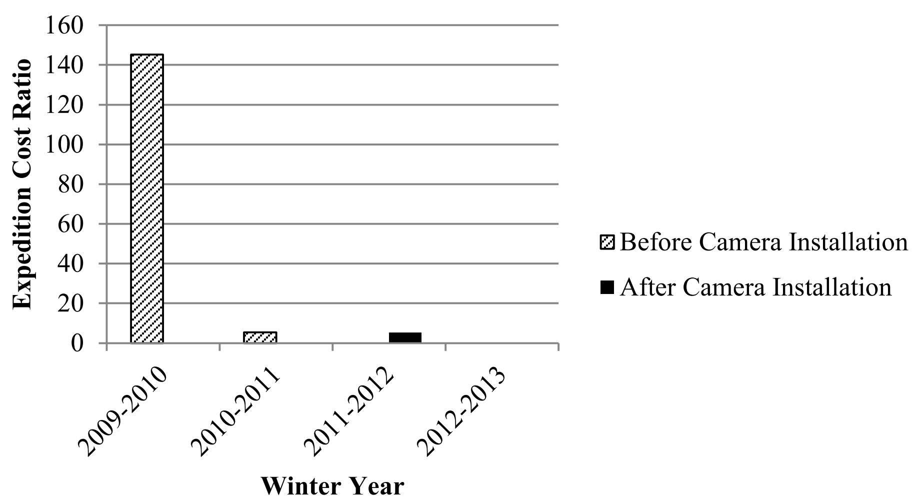

Figure 5-8: Trend in Expedition Cost Ratio for Monticello and Blanding Station Pair

5.4.2.8 Comparison 8: Huntington/Emery

The first CRVS camera was installed in January of 2013 for Huntington. It was decided that the comparison of expedition costs between Huntington and Emery could be done for three winters without a CRVS camera and one winter with a camera for this study. The summary of the expedition cost comparison results are presented in Table 5-9.

Table 5-9: Expedition Cost Comparison Summary for Huntington and Emery Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Huntington	No	$ 274,814.92	$ 19,657.97	-	1.842
	Emery	No	$ 171,852.80	$ 6,673.15	$ 10,671.23	
2010-2011	Huntington	No	$ 308,797.94	$ 46,831.83	-	0.447
	Emery	No	$ 71,857.35	$ 24,387.06	$ 104,800.33	
2011-2012	Huntington	No	$ 201,736.55	$ 51,812.66	-	2.423
	Emery	No	$ 78,454.08	$ 8,315.71	$ 21,382.99	
2012-2013	Huntington	Yes	$ 256,363.63	$ 42,739.67	-	**13.467**
	Emery	No	$ 105,893.52	$ 1,310.89	$ 3,173.61	

The ratio increased significantly for the year with a camera installed for this comparison. This indicates an increase in expedition costs after the installation of a camera. The trend is shown in Figure 5-9.

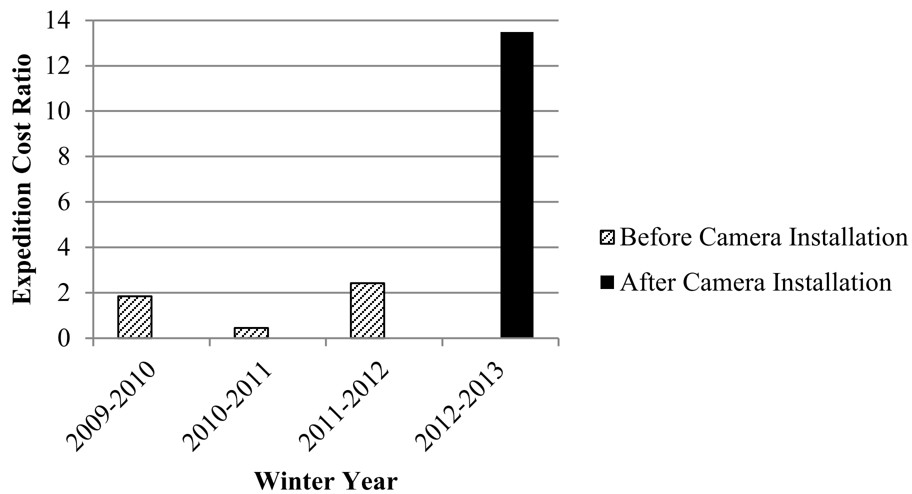

Figure 5-9: Trend in Expedition Cost Ratio for Huntington and Emery Station Pair

5.4.2.9 Comparison 9: Long Valley Junction/Kanab

The first CRVS camera for Long Valley Junction was installed in December of 2010. It was decided that the comparison of expedition costs between Long Valley Junction and Kanab could be done for one winter without a CRVS camera and three winters with a camera for this study. The summary of the comparison results are presented in Table 5-10.

Table 5-10: Expedition Cost Comparison Summary for Long Valley Junction and Kanab Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Long Valley Jct	No	$ 214,985.18	$ 21,127.77	-	1.686
	Kanab	No	$ 99,921.38	$ 5,824.27	$ 12,531.17	
2010-2011	Long Valley Jct	Yes	$ 199,929.25	$ 32,179.65	-	**0.890**
	Kanab	No	$ 44,936.23	$ 8,123.45	$ 36,142.67	
2011-2012	Long Valley Jct	Yes	$ 131,184.96	$ 7,283.22	-	**-**
	Kanab	No	$ 24,210.51	$ -	$ -	
2012-2013	Long Valley Jct	Yes	$ 173,212.20	$ -	-	**0.000**
	Kanab	No	$ 37,782.04	$ 1,865.25	$ 8,551.26	

The ratio is not given for the 2011-2012 year because no expedition costs were used at Kanab and the ratio could not be calculated. In this comparison, the ratio fluctuates each year, and it is difficult to see an apparent trend. Therefore, it is difficult to see the effect of the camera on expedition costs. The trend of this comparison is shown in Figure 5-10.

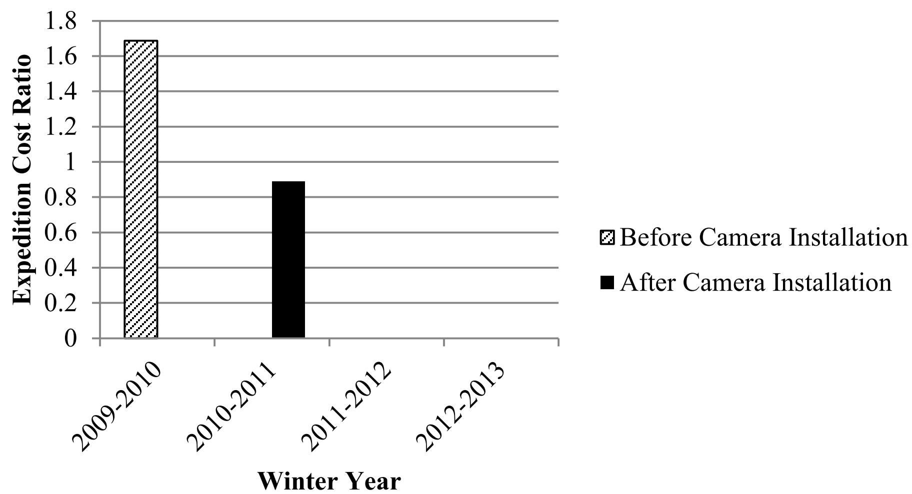

Figure 5-10: Trend in Expedition Cost Ratio for Long Valley Junction and Kanab Station Pair

5.4.2.10 Comparison 10: Beryl Junction/Cedar City

The first camera for Beryl Junction was installed in December of 2012. It was decided that the comparison of expedition costs between Beryl Junction and Cedar City could be done for three winters without a CRVS camera and one winter with a camera for this study. The summary of the comparison results are presented in Table 5-11.

Table 5-11: Expedition Cost Comparison Summary for Beryl Junction and Cedar City Station Pair

Year	*Maintenance Station*	*Camera Installed*	*Total Snow-Related Cost*	*Expedition Costs*	*Standardized Expedition Costs (Without CRVS)*	*Ratio*
2009-2010	Beryl Jct	No	$ 97,600.80	$ 1,492.53	-	0.096
	Cedar City	No	$ 163,934.30	$ 26,227.71	$ 15,615.07	
2010-2011	Beryl Jct	No	$ 75,893.45	$ 1,353.25	-	0.144
	Cedar City	No	$ 150,725.29	$ 18,608.22	$ 9,369.64	
2011-2012	Beryl Jct	No	$ 72,311.77	$ 300.00	-	0.061
	Cedar City	No	$ 149,713.39	$ 10,232.60	$ 4,942.36	
2012-2013	Beryl Jct	Yes	$ 76,168.20	$ -	-	**0.000**
	Cedar City	No	$ 176,418.38	$ 17,712.81	$ 7,647.46	

The ratios suggest that Beryl Junction used less expedition costs than Cedar City overall. For the year with a camera installed, the expedition costs of Beryl Junction were reduced to zero. This trend is shown in Figure 5-11.

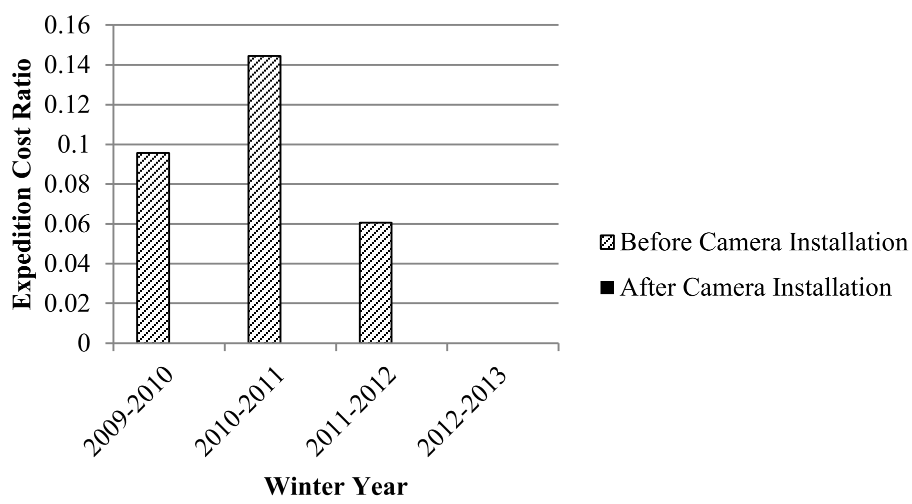

Figure 5-11: Trend in Expedition Cost Ratio for Beryl Junction and Cedar City Station Pair

5.4.3 **Statistical Analysis**

The comparison of expedition costs produced mixed results; reduction in expedition costs was observed in some maintenance stations but not in others. The results did not seem definitive, and it was difficult to infer whether the hypothesis that the cameras reduce trips that do not require material costs was true or not. To help with this analysis on expedition costs, a statistical analysis was performed to make an inference.

For this study, a Mixed Model Analysis of Variance (ANOVA) with blocking on the maintenance station was selected. The analysis was performed by the Statistical Analysis System (SAS) software (SAS 2010) to compare the two conditions of whether a camera was installed or not on the dependent variable, which is the expedition cost ratio. The mean, standard deviation, minimum value, and maximum value for the ten stations are presented in Table 5-12.

Table 5-12: Mean Procedure Statistics for Expedition Cost Ratios

Camera Installed	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
No	7.764	30.736	0.061	145.250
Yes	1.864	3.520	0.000	13.467

The standard deviation was rather large, showing a wide variability in the "No" dataset. The difference in standard deviations between the two datasets was very large too. The maximum value of 145.25 stands out as an outlier and controls the wide variance. In order to meet the condition for an ANOVA and reduce the variance, the ratios were transformed into natural logs for analysis. Some ratios presented a value of zero. A log transformation of zero is not defined. This issue was resolved by adding one to all ratios before being transformed into natural logs. The result of this ANOVA on natural log-transformed data is shown in Table 5-13.

Table 5-13: Mean Procedure Statistics for Expedition Cost Ratios in Natural Log

Camera Installed	*Mean*	*Standard Deviation*	*Minimum*	*Maximum*
No	0.856	1.048	0.059	4.985
Yes	0.678	0.760	0.000	2.672

The difference between standard deviations was now significantly reduced and viable for analysis. The data available for analysis were observed to be sufficient for an ANOVA and a normality check was not necessary. For the subsequent analysis, two outliers were excluded by limiting the log ratios to values less than 2.0 in the log-transformed dataset because having values greater than 2.0 may not be realistic. The least squares means were then taken for the dataset. The results of this are shown in Table 5-14.

Table 5-14: Least Squares Means for Expedition Cost Ratios in Natural Log without outliers

Camera Installed	*Estimate*	*Standard Error*	*Degrees of Freedom*	*t Value*	*Pr > |t|*	*Alpha*	*Lower Confidence Interval*	*Upper Confidence Interval*
No	0.4754	0.07266	7	6.54	0.0003	0.05	0.3036	0.6472
Yes	0.3425	0.08094	7	4.23	0.0039	0.05	0.1511	0.5339

The difference of least square means of the mixed model ANOVA test for the block locations of without and with a camera was then computed. When two outliers were removed, two station pairs were also removed from the subsequent analysis, leaving eight station pairs in the data set. The result of this ANOVA test is presented in Table 5-15. The difference is defined as the natural log transformation of the ratio of expedition costs for the period with no camera for the maintenance shed that has a camera minus the natural log transformation of the ratio of expedition costs for the period with camera for the maintenance shed that has a camera. Due to the nature of natural logarithm, when the difference in natural log transformation is converted back to the normal value from the logarithm, the normal value shows the ratio of the ratios of expedition cost before and after the camera installation at the maintenance stations with a camera.

Table 5-15: Differences of Least Squares Means

Estimate	*Standard Error*	*Degrees of Freedom*	*t Value*	*Pr > |t|*	*Alpha*	*Lower Confidence Interval*	*Upper Confidence Interval*
0.1329	0.0973	7	1.37	0.2142	0.05	-0.0972	0.3630

This is presented in natural log scale. The estimate of 0.1329 transformed back into a normal value is 1.142, which means the average ratio of the ratios of expedition costs before and after the camera installation was 1.142. The 95 percent confidence is transformed to 0.907 to 1.438. This suggests that before the installation of cameras, the ratio of expedition costs is estimated to be about 14 percent higher, with a 95 percent confidence interval of about 9 percent lower to 44 percent higher than the ratio of expedition costs after the camera installation. The probability of 0.2142 of the t-value is much higher than 0.05. This suggests that the estimate of 14 percent higher expedition costs before the installation of cameras is not statistically significant at the 95 percent confidence level. It is significant at about a 75 percent confident level. Nevertheless, for practical purposes, the difference may be considered practically significant.

5.5 Study Limitations

The statistical analysis implied that the result of a 14 percent higher ratio of expedition costs seen in maintenance stations that has received the camera before the camera installation cannot be confirmed with statistical significance, but the difference may have practical significance. In the quantitative analysis of snow removal-related maintenance costs, several issues were identified in this study, including 1) the assumptions made in the analysis could be uncertain, 2) there were some uncertainty in data reduction, and 3) the sample size was small for the statistical analysis.

5.5.1 Uncertainty in Work Type Assumptions

The first issue identified in the quantitative analysis of snow removal-related maintenance costs is that the assumptions made for the analysis may not be exactly reflecting the reality. Based on a comment made by a maintenance station supervisor from the in-person interviews, it was assumed that all work orders that did not include material costs were possible expeditions made to check roadways for snow-removal work. This assumption may not hold true for all cases, as not all work orders that did not include material costs would specifically be expedition trips. An example would be work orders that involve preparation/clean-up activities. In the data reduction, work orders that did not relate to camera use were excluded, but not all work orders not related to camera use were able to be singled out due to limited information. This might cause some discrepancies in the analysis of the expedition costs.

5.5.2 Uncertainty in Data Reduction

The second issue was the uncertainty in data reduction performed in the analysis. The expedition records of snow-removal activities were filtered and limited to activities that relate to camera use as much as possible. The activities of stockpiling of materials, snow fence and pole installation/removal, and TATS reporting were excluded from the data. Other activities were excluded if they could be distinguished as not related to camera use from supervisor comments in the cost records. The cost records varied by how each supervisor recorded work orders. Some station supervisors provided details of each work order in comments, while others did not provide any. Therefore it was difficult to limit cost data exclusively to activities related to camera use.

Most maintenance stations only have one or two cameras within their boundaries. One camera cannot cover the whole area the maintenance station is responsible for, but rather a limited section of the area that the station covers. The cost records did not include information on location covered for each work order. This made it difficult to differentiate trips made to the locations covered by the cameras from trips to other locations. The analysis would have been more effective if this information was available, so that analysis could be performed to see if there was a reduction of trips to the specific locations where cameras were installed.

5.5.3 Limited Sample Size

One of the major reasons for the analysis result to be not significant statistically may be attributed to the limited sample size. Only 10 sets of maintenance stations were available for analysis. The CRVS cameras are installed and they are widely spread throughout the State of Utah by the time the study was conducted. Therefore, the number of maintenance stations with a CRVS camera located next to a station without a CRVS camera was limited. The 10 sample sets that were selected were the only available sets of maintenance stations located next to each other with one having a CRVS camera and the other not.

5.6 Chapter Summary

The snow removal-related maintenance cost analysis was performed in three parts: a precipitation/snow removal-related cost relation analysis, expedition cost comparison, and a statistical analysis. Analysis revealed that the snow removal-related costs are closely related to precipitation patterns and the pattern of snow-related costs was similar to adjacent maintenance stations selected for the analysis, which made the comparison valid. It was difficult to make any definitive inferences from the simple comparison of expedition costs of the 10 sets of maintenance stations because the results were not consistent. Hence, a statistical analysis was performed using the Mixed Model ANOVA. This resulted in an average of 14 percent higher ratio of expedition costs at maintenance stations with a CRVS camera before the installation of the camera compared to the ratio of expedition costs after the installation of the camera, indicating that the installation of CRVS cameras was on the average helpful in reducing expedition costs although the difference was not statistically significant at the 95 percent confidence level. Nevertheless, for practical purposes the difference may be considered practically significant.

6 CONCLUSIONS AND RECOMMENDATIONS

There is a constant challenge for a State DOT in a cold region to maintain all roadways in winter weather conditions and ensure safety and adequate service to the public. It is a challenge to allocate limited resources to the many miles of roadway DOTs are responsible over, and DOTs are looking for methods to efficiently and effectively allocate resources. Among different methods is the use of video camera-based remote condition monitoring of highways in snow removal-related maintenance. Remote monitoring has been widely used in traffic operations, but has not been commonly used for roadway maintenance purposes and is a new concept. UDOT has implemented this new concept by using a remote monitoring system referred to as CRVS cameras provided by Live View Technologies. The purpose of this study was to evaluate the effectiveness of the use of the CRVS camera system in snow removal-related maintenance operations in the state of Utah.

This study was performed in two parts. The first part was conducted by performing opinion surveys with supervisors of maintenance stations that have received and have access to a CRVS camera within their maintenance boundaries. The second part of the study was conducted by a quantitative analysis of snow removal-related maintenance costs provided by UDOT. An inference was made using a statistical analysis. This chapter 1) reviews the conclusions derived by the study and 2) provide recommendations for this type of analysis in the future.

6.1 Conclusions

The first part of the study was to perform opinion surveys with maintenance station supervisors that use the CRVS cameras. This was done by two methods. The first method was done by in-person interviews with supervisors of six maintenance stations that received a CRVS camera for the first time in the most recent winter of 2012-2013. Various responses and comments were received pertaining to camera use, but there were common responses as well. All six supervisors used the CRVS cameras quite frequently in winter weather conditions by viewing them multiple times a day. Most supervisors admitted that having the ability to view the cameras has helped in reducing some trips sent out to check roadway conditions. When asked to evaluate the effectiveness of use of the CRVS cameras on a scale of 1 to 5 (1 being the least effective and 5 being the most effective), the average of the numbers given by the six supervisors was 4.3, i.e., effective.

Responses from the online questionnaire produced results quite similar to the responses received from the direct interviews. All eight supervisors that responded indicated that they used the CRVS cameras multiple times a day. When asked whether protocols of snow-removal have changed after the installation of the camera, all supervisors responded yes or maybe. All supervisors indicated that the number of dispatches sent out to check roadway conditions has decreased after the installation of the camera. The supervisors were asked to evaluate the effectiveness of the use of the CRVS cameras on a scale of 1 to 5 as was done so in the direct interviews. The average of the numbers given by the eight supervisors that responded was calculated to be 4.3, which was the same as the average of the six supervisors from the direct interviews. The supervisors were asked to give an estimate percentage of reduction of trips sent out to check roadway conditions in the online questionnaire. The average of the responses was calculated to be about a 33 percent reduction in trips after the installation of the CRVS cameras.

The averages of the effectiveness of the CRVS cameras on a scale of 1 to 5 given by maintenance station supervisors were calculated to be 4.3 from both the direct interviews and the online questionnaire. This average is rather high, indicating that the maintenance station supervisors who use the cameras seem to think they are effective in snow removal-related maintenance. Also, responses from the online questionnaire produced a result of an average of about 33 percent reduction in expedition trips after the installation of the camera.

For the second part of this study, a quantitative analysis on snow removal-related maintenance costs was performed to see if there was a reduction in expedition costs after the installation of the CRVS cameras. For this analysis, 10 sets of maintenance stations with a camera and without a camera were selected for comparison to see whether there was a reduction in costs on expedition trips at the maintenance stations after installation of a camera. A comparison of precipitation data and snow removal-related costs showed a strong correlation of precipitation and snow removal-related costs, validating the similarity of weather patterns at each set of locations and the practicality of the expedition cost comparison. The comparison of expedition costs did not produce definitive results, and it was difficult to infer a conclusion that there was a reduction in expedition costs at the stations with a camera after installation. Therefore, a Mixed Model ANOVA was performed to obtain a statistical inference on the comparison. The statistical analysis showed 14 percent in the mean difference in expedition cost ratio but the difference was not significant at the 95 percent confidence level. (It was significant at the 75 percent confidence level.) However, for practical purposes, the difference may be considered practically significant.

6.2 Recommendations

The results of this study were not statistically conclusive regarding the effectiveness of video camera-based remote roadway condition monitoring on snow removal-related maintenance operations when evaluated quantitatively due to several study limitations. This study was performed after UDOT had implemented the CRVS cameras in multiple locations for a while. The first CRVS camera was activated in December of 2008. The CRVS cameras have been available at many maintenance stations. There were 145 active CRVS cameras within Utah at the time of this study. Therefore, it was difficult to collect and analyze data of two maintenance stations nearby with one station having a camera and the other not having one. This limited sample size necessary for a conclusive statistical analysis. To perform a similar analysis done in this study, it is recommended that the analysis be performed in early stages of camera installation to have a larger sample size of expedition cost comparisons.

Another concern in this study was the uncertainty that existed in the content of snow removal-related maintenance records. This was mainly caused by inconsistencies in how the costs were recorded by different station supervisors. Many of the cost records did not include adequate detail to judge whether the snow removal-related maintenance cost was related to expeditions or not. The records also did not include detail of specific locations or date/time of trips that took place. An analysis on the specific location of where the CRVS cameras are available could have been performed if such information was available. It is recommended that more detailed and consistent maintenance cost records be prepared to enable accurate analysis of cost records for this type of analysis and any other cost-related analyses that may be performed in the future.

Overall, the installation of the CRVS cameras did display positive results and added benefits to UDOT. The maintenance station supervisors who utilize the cameras generally gave positive feedback, and there was a difference in expedition costs after the installation of the cameras with a practical significance. There are several added values from the installation of the CRVS cameras that were not examined in this study. One of the added values includes benefits experienced from the usage of the cameras by parties other than the supervisors of the maintenance stations that the cameras are installed in. This includes users such as other UDOT employees, the highway patrol, and others who have login access to the CRVS cameras.

Another added value is the reduction of external costs associated with a reduction in expedition trips after the installation of the cameras. The analysis in this study strictly focused on the reduction in snow removal-related maintenance costs. There are other benefits to reducing expedition costs. For example, every time a trip is reduced, the pre-trip inspections of the equipment are also reduced. There are Occupational Safety and Health Administration (OSHA) standards for inspections that are required before every trip is made. A UDOT employee mentioned that this could take a significant amount of time, sometimes up to an hour. An avoidance of this inspection due to a reduction in an expedition trip is an added benefit. Fewer trips also reduce the risk of accidents, improving the chance of increased safety.

The results of this study and the added values that were not examined in this study suggest that there are benefits to UDOT by implementing the CRVS cameras. Therefore, it is recommended that UDOT considers the installation of more CRVS cameras within the state.

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APPENDIX A. SUMMARY OF RESPONSES FROM THE DIRECT INTERVIEWS

1. How long have you been station supervisor here?
    - 25 – 26 years (Station Supervisor 1)
    - 10 years (Station Supervisor 2)
    - 4 years (Station Supervisor 3)
    - 14 years (Station Supervisor 4)
    - 5 years (Station Supervisor 5)
    - 14 years (Station Supervisor 6)
2. When did you start using the camera?
    - Around November and December in 2012 (Station supervisors 1, 2, 3, 4, and 5)
3. During winter conditions, how often do you access the camera?
    - Depending on weather, sometimes multiple times a day (Station supervisors 1, 2, 3, 5, and 6)
    - Average of about every 3 hours (Station Supervisor 4)
4. Has the snow removal crew dispatch protocol changed after the installation of the camera?
    - Yes. With the camera being available, the roadway condition there can be easily checked. Fewer dispatches were sent out if the conditions could be checked on the camera. (Station supervisors 1, 2, 3, and 6)
    - Not totally, but it has reduced some trips sent out the area. (Station supervisors 4 and 5)
5. Do you use cameras installed within the boundaries of other maintenance stations other than the camera in own station boundary?
    - Yes, all the time. (Station supervisors 1, 2, 3, 4, and 6)
    - No. (Station supervisor 5)
6. Besides you, is there anybody else that has access to the cameras?
    - Yes, others on the crew access them quite frequently too. (Station supervisors 1, 2, 3 and 4)
    - Yes, but others haven't taken advantage of them as much. (Station supervisors 5 and 6)
7. On a scale of 1 to 5 (1=not effective at all, 2=less effective, 3=no change, 4=more effective than before, 5=definitely more effective) how effective would you say the camera is to maintenance operations?
    - 5 (Station supervisor 1 and 2)
    - Somewhere between 4 and 5 (Station supervisor 3)
    - 4 (Station supervisor 4 and 6)

- 3 (Station supervisor 5)

8. Other comments
   - It is really useful to access the camera from home or from the phone. There have been many instances where unnecessary trips were reduced by being able to view the camera from home. (Station supervisors 1, 2, 3)
   - Having the camera has helped with less anticipation and anxiety in snow removal. (Station supervisors 1, 2, 3)
   - Would be useful if more cameras were installed (Station supervisors 1, 2, 3, 4, 6)
   - The night time vision is fair due to infrared (Station supervisor 1, 2)
   - The camera is difficult to view at night even with infrared, and sometimes the lens gets dirty or fogged up (Station supervisor 3)
   - The camera has poor nighttime vision (Station supervisors 4,5, and 6)
   - The cameras were up and running and available when needed (Station supervisors 1, 2, 4)
   - One of the newer cameras on MP 27.5 on US-40 hardly ever worked (Station supervisor 3)
   - The camera is very slow due to poor cellular reception, and it is frustrating to try to operate (Station supervisor 5)
   - Something that would be nice to have is the ability to take still pictures on the cameras for liability issues. (Station Supervisor 6)
   - It would be a great advantage if there was a way for the public to view the camera. People call in all the time to ask about road conditions. (Station supervisor 5)
   - Roughly about 40-50 man hours plus equipment cost was saved this past winter. (Station supervisor 4)
   - There was probably roughly 15-20% less unnecessary trips out to the location. (Station supervisor 6)
   - The camera did help a little bit and reduced trips out there by maybe 25% (rough estimate) but it didn’t totally reduce trips out there. (Station supervisor 5)

APPENDIX B. SUMMARY OF RESPONSES FROM THE ONLINE QUESTIONNAIRE

1. When did you become station supervisor at your current station?
    - February 2012 (Station Supervisor 1)
    - July 2006 (Station Supervisor 3)
    - October 2008 (Station Supervisor 4)
    - September 2009 (Station Supervisor 5)
    - January 2007 (Station Supervisor 6)
    - September 2009 (Station Supervisor 7)
    - April 2000 (Station supervisor 8)
2. Were you the station supervisor in the winter of 2011/2012 when the first camera was installed in your boundary?
    - Yes (All station supervisors)
3. When did you begin using the camera?
    - February 2012 (Station supervisor 1)
    - October 2010 (Station supervisor 3)
    - October 2011 (Station supervisors 4, 8)
    - November or December 2011 (Station supervisor 5)
    - As soon as it was up and running (Station supervisors 6, 7)
4. During winter conditions, how often do you access the cameras?
    - Multiple times a day (All station supervisors)
5. Have protocols of snow removal changed in your opinion after the installation of the camera?
    - Yes (Station supervisors 1, 4,)
    - Maybe (Station supervisors 2, 3, 5, 6, 7, 8)
6. How have the protocols of snow removal changed?
    - I would check the camera first to make sure we needed to be there. Then someone would be sent to each required route. (Station supervisor 1)
    - I do not have to drive 30 miles to check road conditions. (Station supervisor 3)
    - It helped in quicker response times by watching storms earlier and being aware that a storm is coming. (Station supervisor 4)
    - I have areas that I cannot see with camera so I have to send numerous trucks either way, but it does give me an idea when the snow starts to stick so it may improve response if that occurs during my work hours. (Station supervisor 5)
    - I can check the condition of the road by accessing the camera instead of making a trip out on the road. (Station supervisor 6)

- I have the ability to look at our summit. However, we have about 30 miles of canyon that I cannot see unless I send someone out to look. So, for early storms that are only forecasted to snow around 8000 ft., the camera is a great tool, but later in the winter not so much. (Station supervisor 7)
- I can see if I need to send someone all the way out to the far end of our road section. (Station supervisor 8)

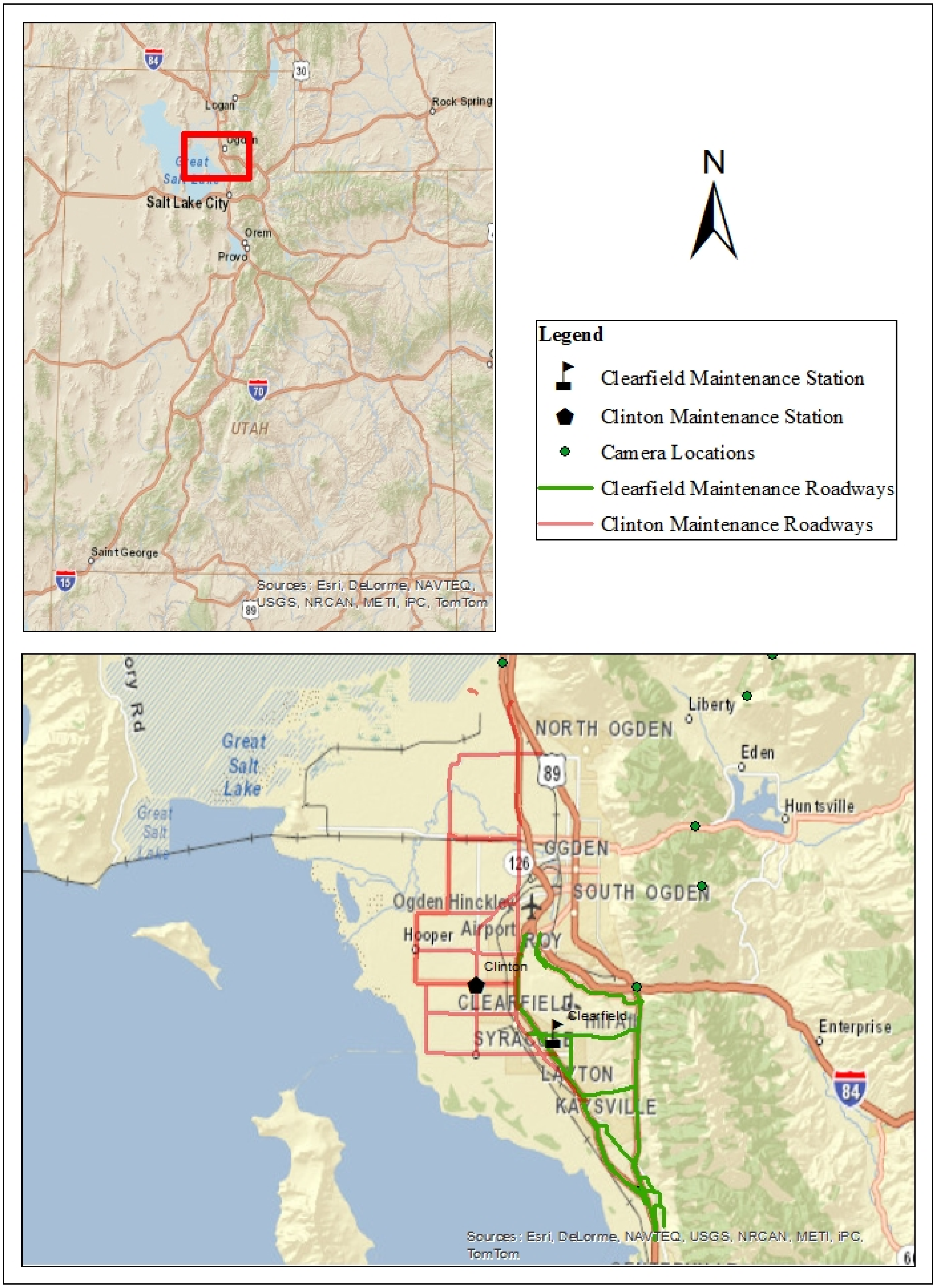
7. Have the number of dispatches you send out (to check road conditions) decreased after the installation of the camera?
    - Yes (All station supervisors)
8. How much reduction have you seen in the number of dispatches sent out?
    - 10 - 20% (Station supervisor 1)
    - 25% (Station supervisor 2)
    - 35% (Station supervisor 3)
    - 15 – 20% (Station supervisor 4)
    - 1 to 5 dispatches per season (Station supervisor 5)
    - 50% (Station supervisor 6)
    - 10% (Station supervisor 7)
    - 75% (Station supervisor 8)
9. Do you use cameras in other station boundaries?
    - Yes (Station supervisors 1, 2, 3, 4, 5, 7)
    - No (Station supervisors 6, 8)
10. Is the camera effective at night? (Does it have fair night vision?)
    - Yes (Station supervisors 2, 3, 5, 7, 8)
    - No (Station supervisors 1, 4, 6)
11. Why is it not effective at night?
    - There is no light or not sure how to use it if there is. The internet connection is slow at this location so reloading pictures takes a long time. (Station supervisor 1)
    - If there is no traffic it is hard to see roadway. (Station supervisor 4)
    - It is hard to see the road surface at night. (Station supervisor 6)
12. Is it an advantage to be able to access the camera from home?
    - Yes (All station supervisors)
13. If funds become available, where would you want more cameras to be installed?
    - SR 92/North County Blvd.
    - US-89/Geneva Road
    - North County Blvd./1 block south of Lone Peak High School
    - SR-146/Cedar Hills city building
    - End of SR-144
    - SR-191 MP 145
    - SR-313 MP 8
    - SR-128 MP 14.5
    - I-15 MP 122
    - I-15 MP 123.3
    - I-15 MP 126
    - I-15 MP 141

- I-70 MP 4.5
- I-70 MP 72
- I-70 MP 64
- I-70 MP 50
- I-70 MP 206
- I-70 MP 182

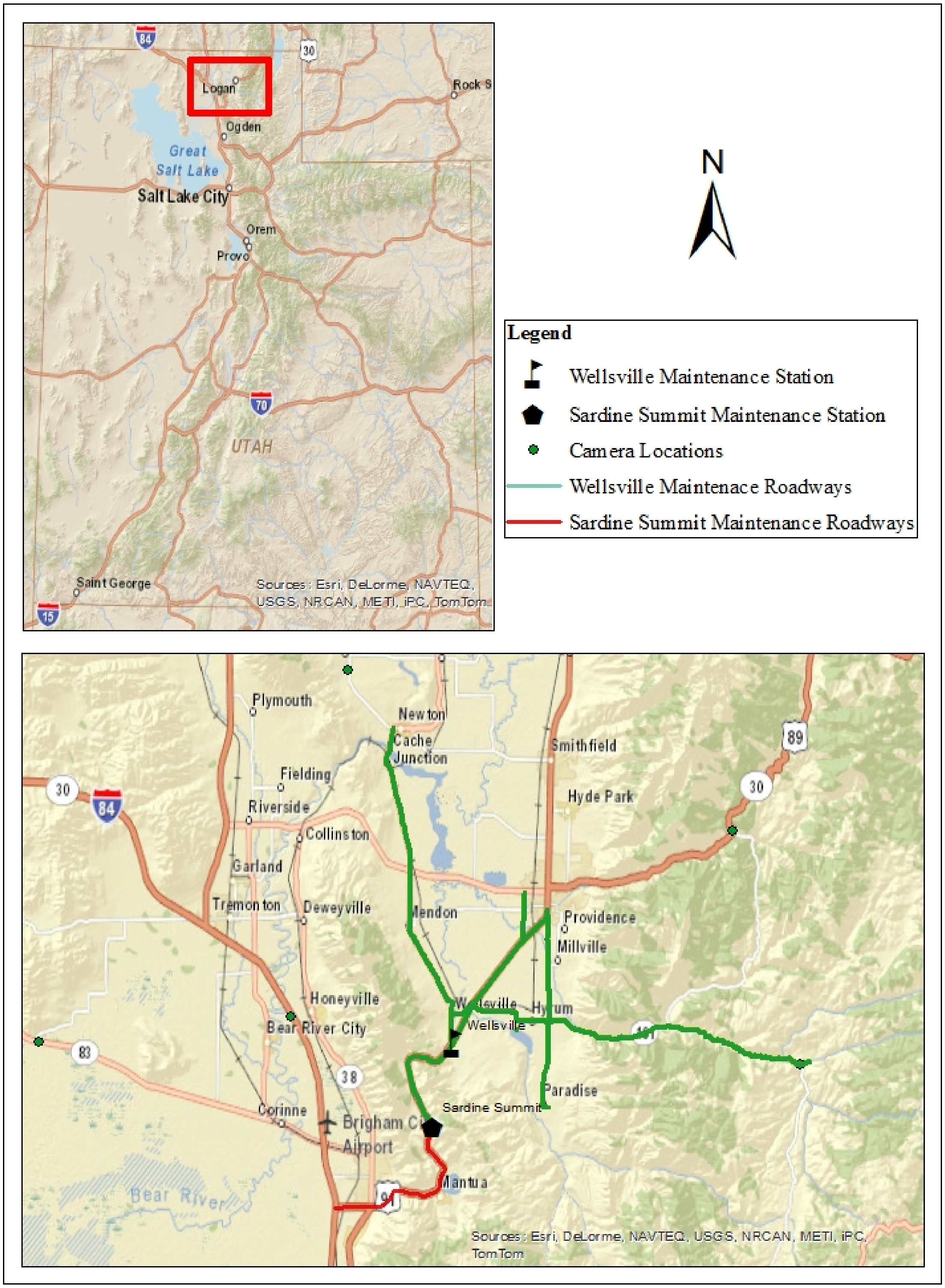
14. On a scale of 1 to 5 (1=not effective at all, 2=less effective, 3=no change, 4=more effective than before, 5=definitely more effective) how effective would you say the camera is to maintenance operations?
    - 5 (Station supervisors 1, 6, 8)
    - 4 (Station supervisors 2, 3, 5, 7)
    - 3 (Station supervisor 4)
15. Please note why you chose your certain rating on a scale of 1 to 5.
    - It saves time, meaning personnel. With our area gaining new roads and lane miles each year, our employees are getting more work. If I can just look at the camera instead of sending an employee where they may not be needed, I can keep them where they are needed. (Station supervisor 1)
    - There are cost savings. (Station supervisor 2)
    - It cuts down chasing storms and I am able to get trucks where they need to be sooner. (Station supervisor 3)
    - We don't use the cameras when doing routine maintenance activities. (Station supervisor 4)
    - The cameras are a benefit to me in my snow plow operations and save me from checking roads manually by driving. (Station supervisor 5)
    - I check the cameras to check on road conditions and weather. (Station supervisor 6)
    - There are some benefits especially in the spring and fall. (Station supervisor 7)
    - Being able to see the conditions from home before I call people out helps a lot. (Station supervisor 8)
16. Other comments
    - I really like having cameras for my section and I use them quite a bit. (Station supervisor 1)
    - The cameras are effective for accidents if we have problems with back up of traffic during a storm. (Station supervisor 4)
    - You can't beat real-time information. (Station supervisor 8)

APPENDIX C. MAPS OF MAINTENANCE STATION PAIRS

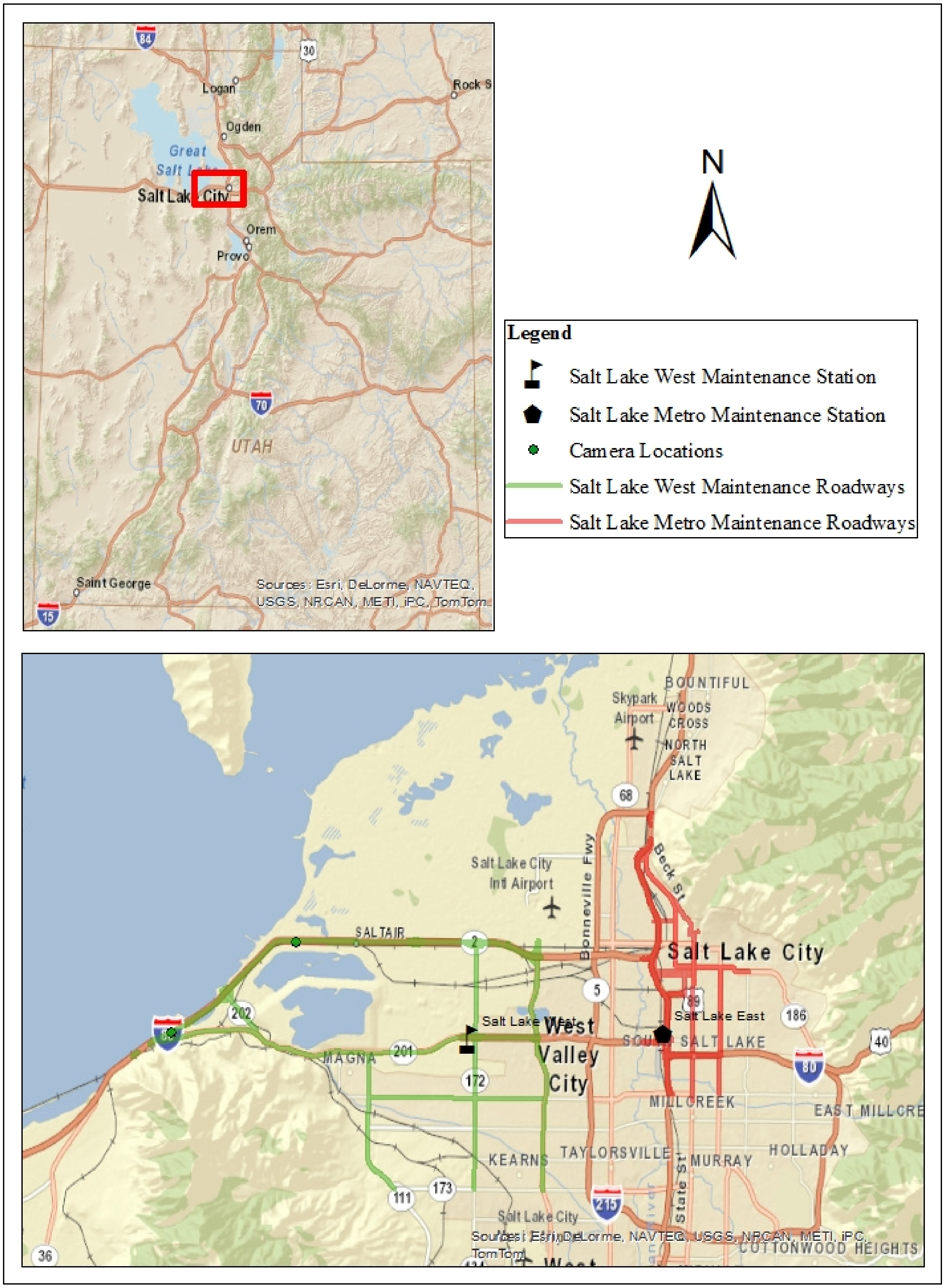
C.1 Comparison Pair 1: Clearfield and Clinton



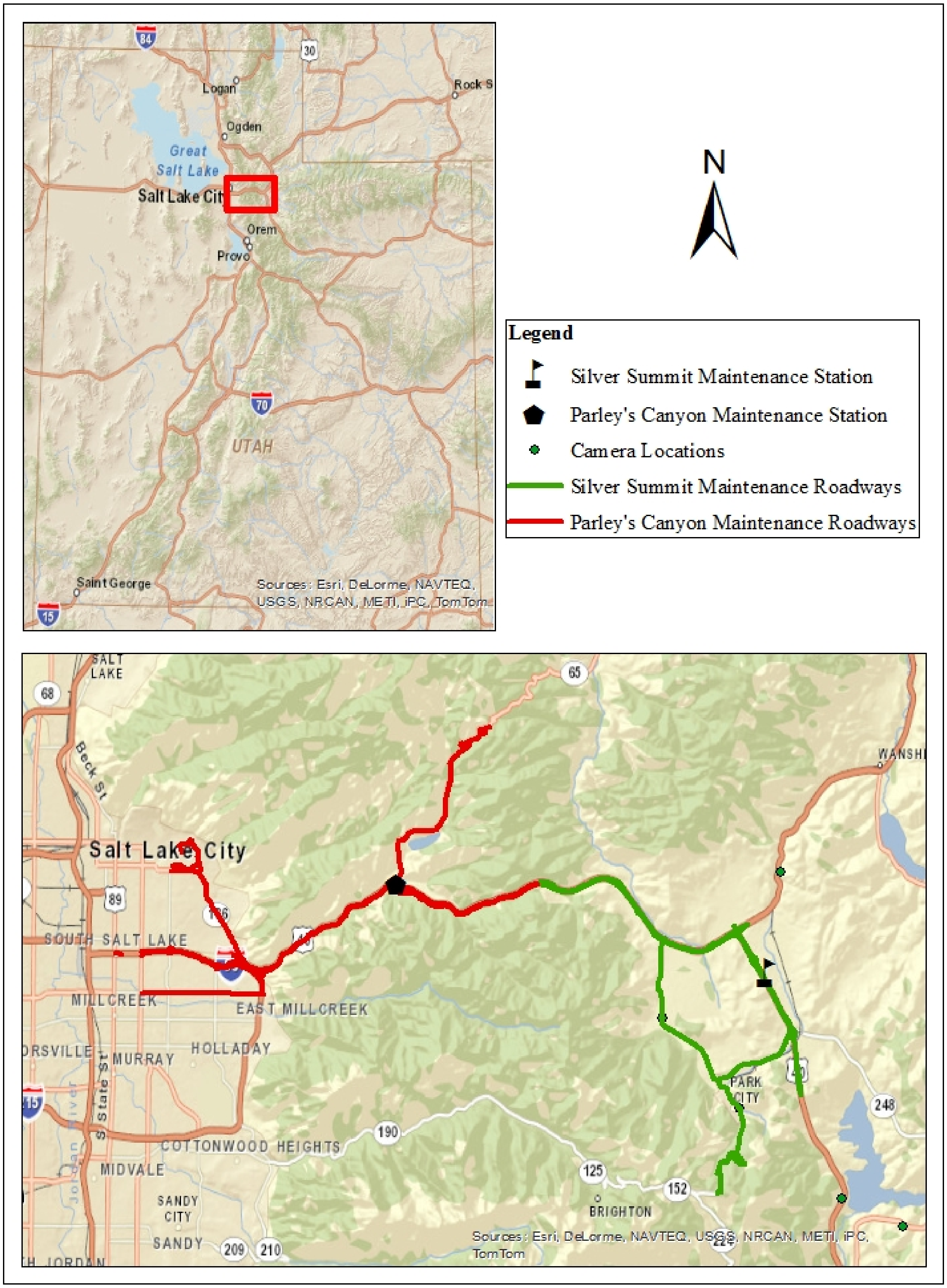
C.2 Comparison Pair 2: Wellsville and Sardine Summit



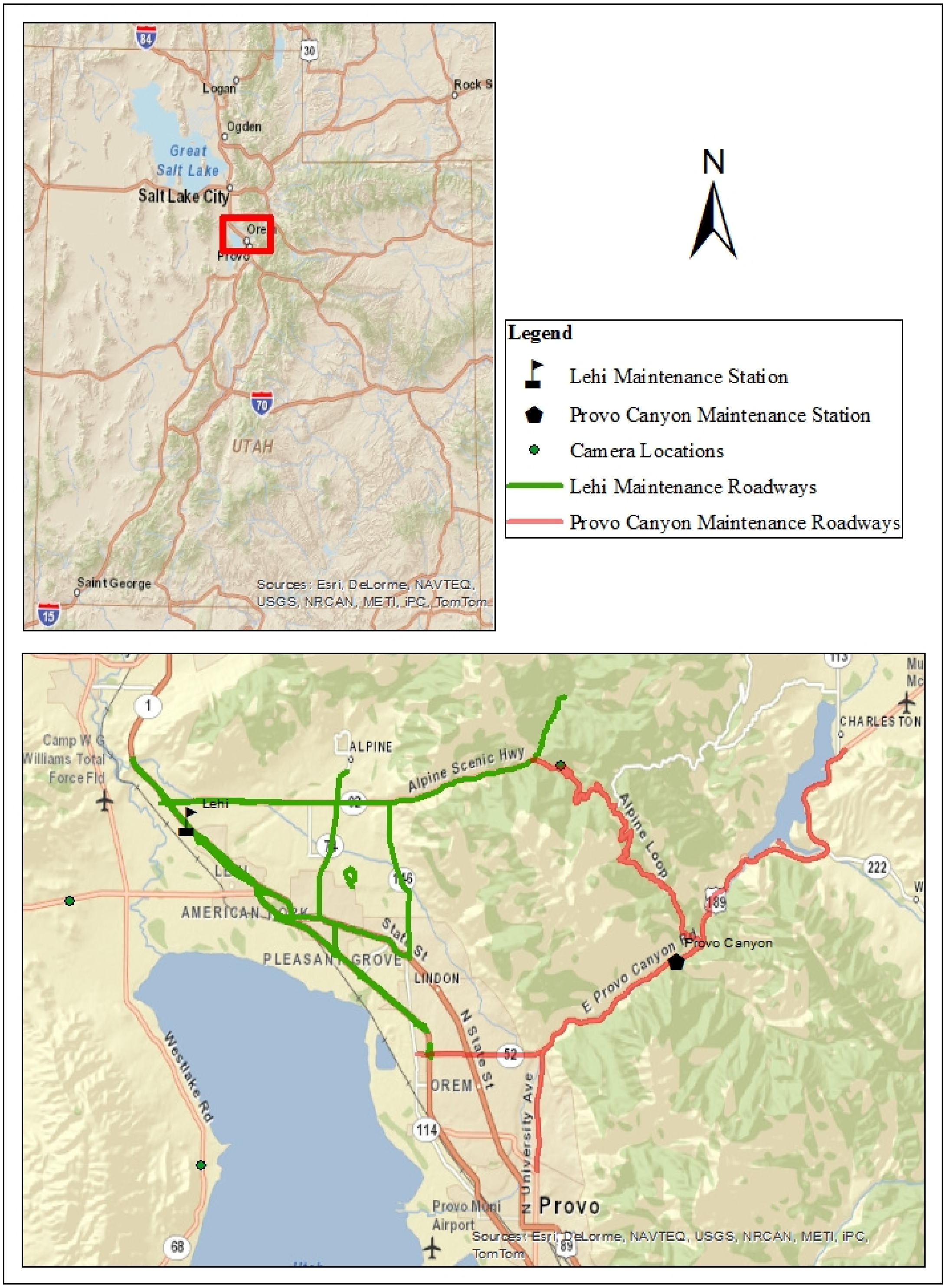
C.3 Comparison Pair 3: Salt Lake West and Salt Lake Metro



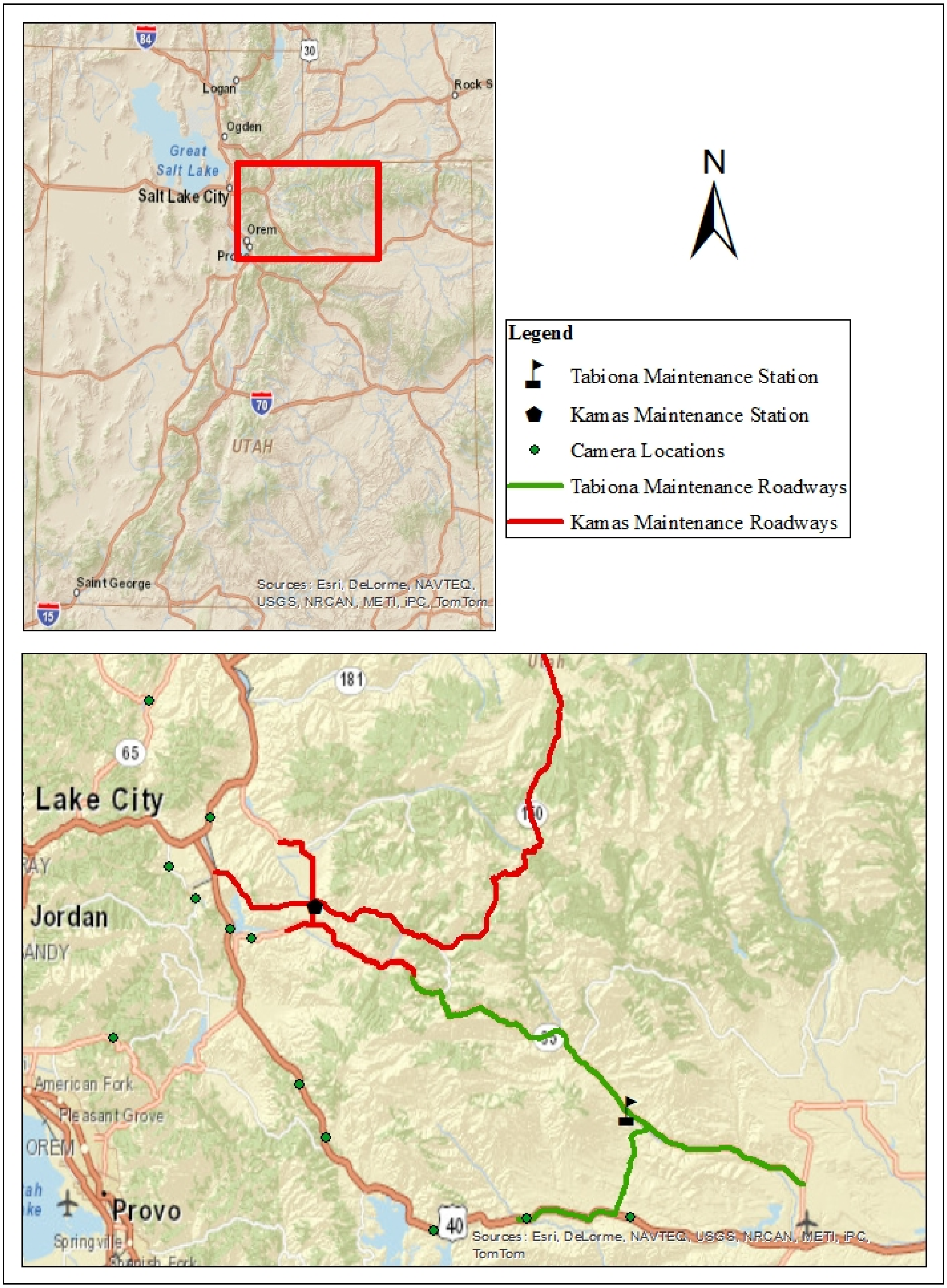
C.4 Comparison Pair 4: Silver Summit and Parley’s Canyon



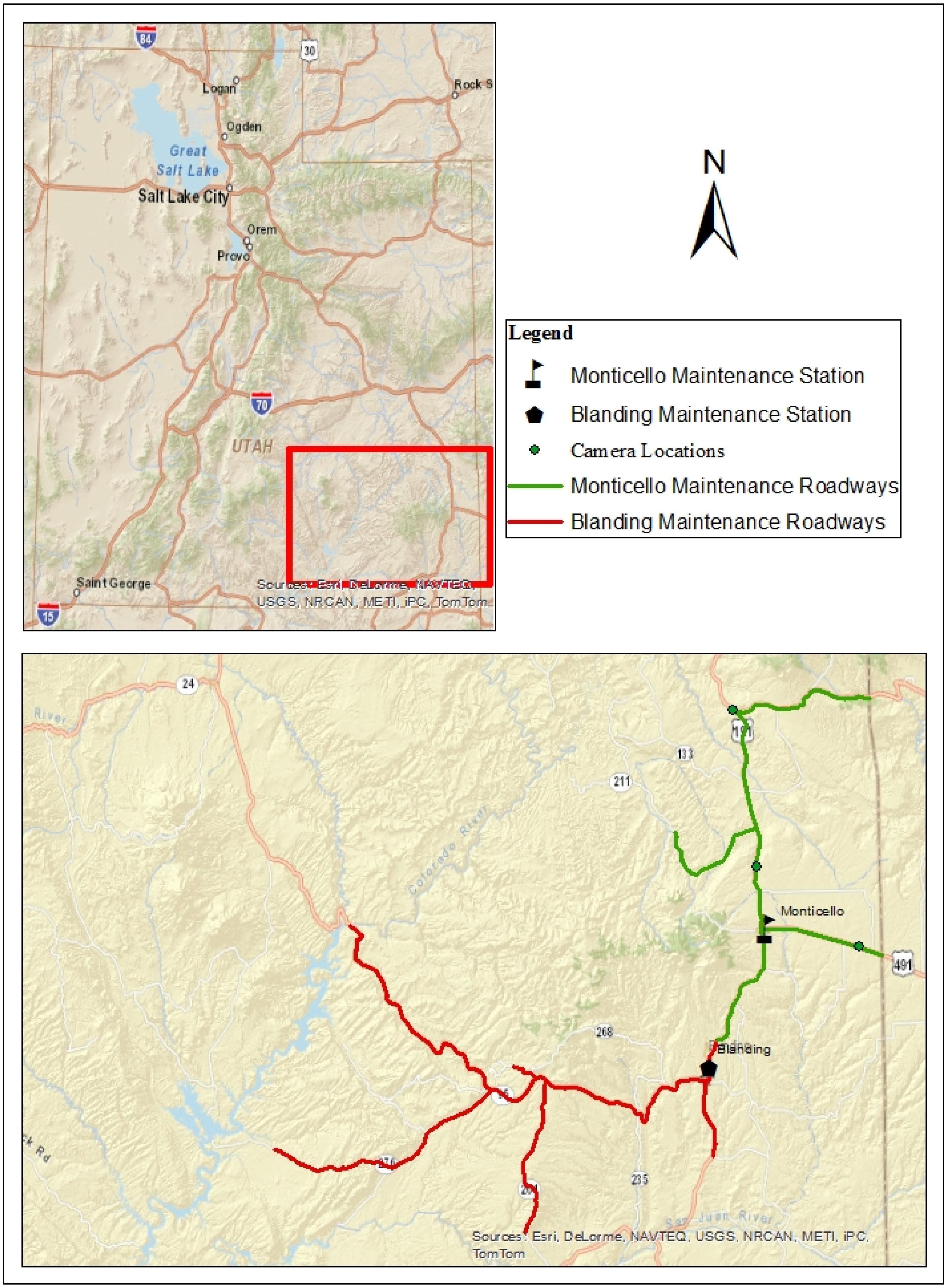
C.5 Comparison Pair 5: Lehi and Provo Canyon



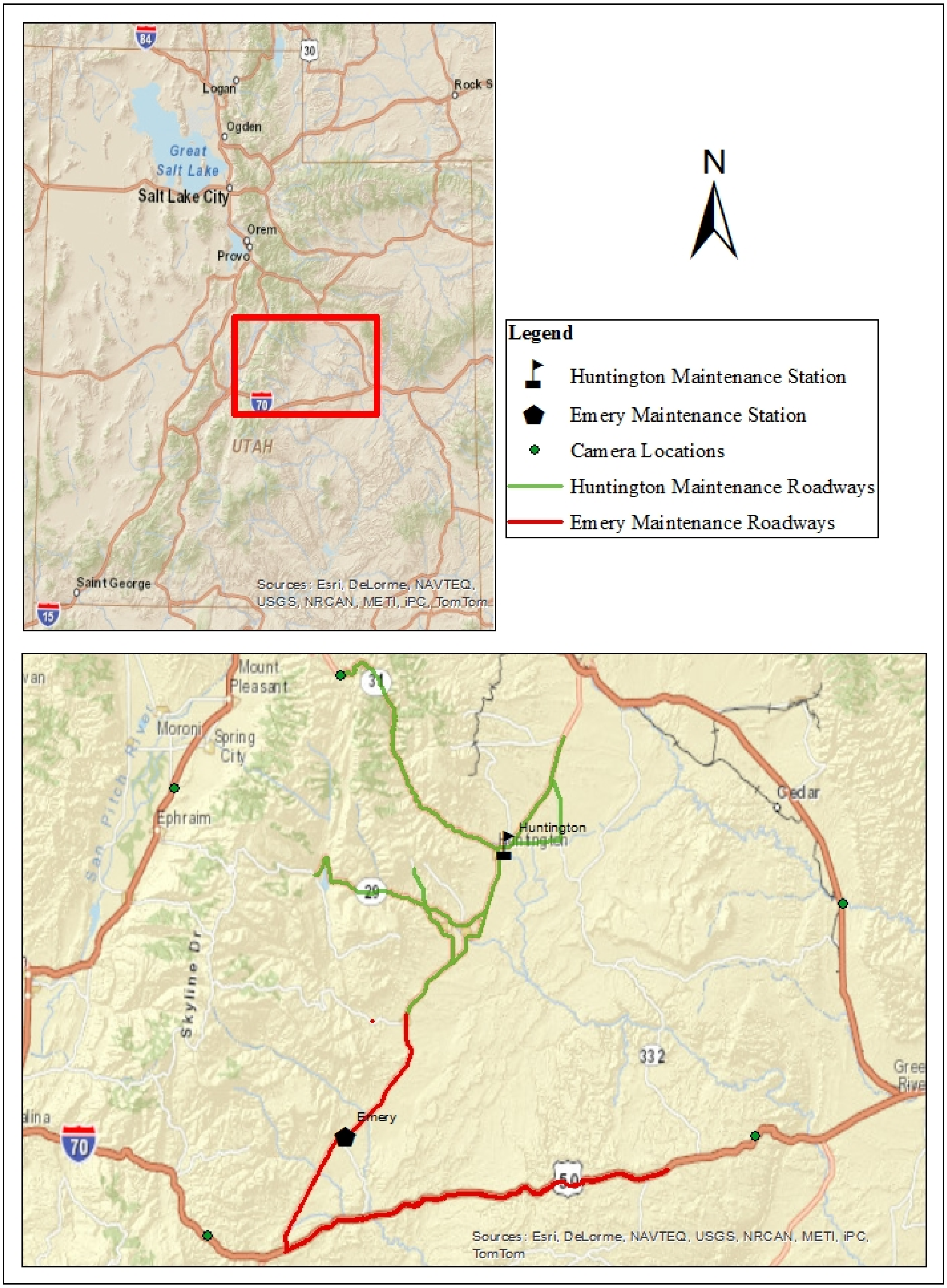
C.6 Comparison Pair 6: Tabiona and Kamas



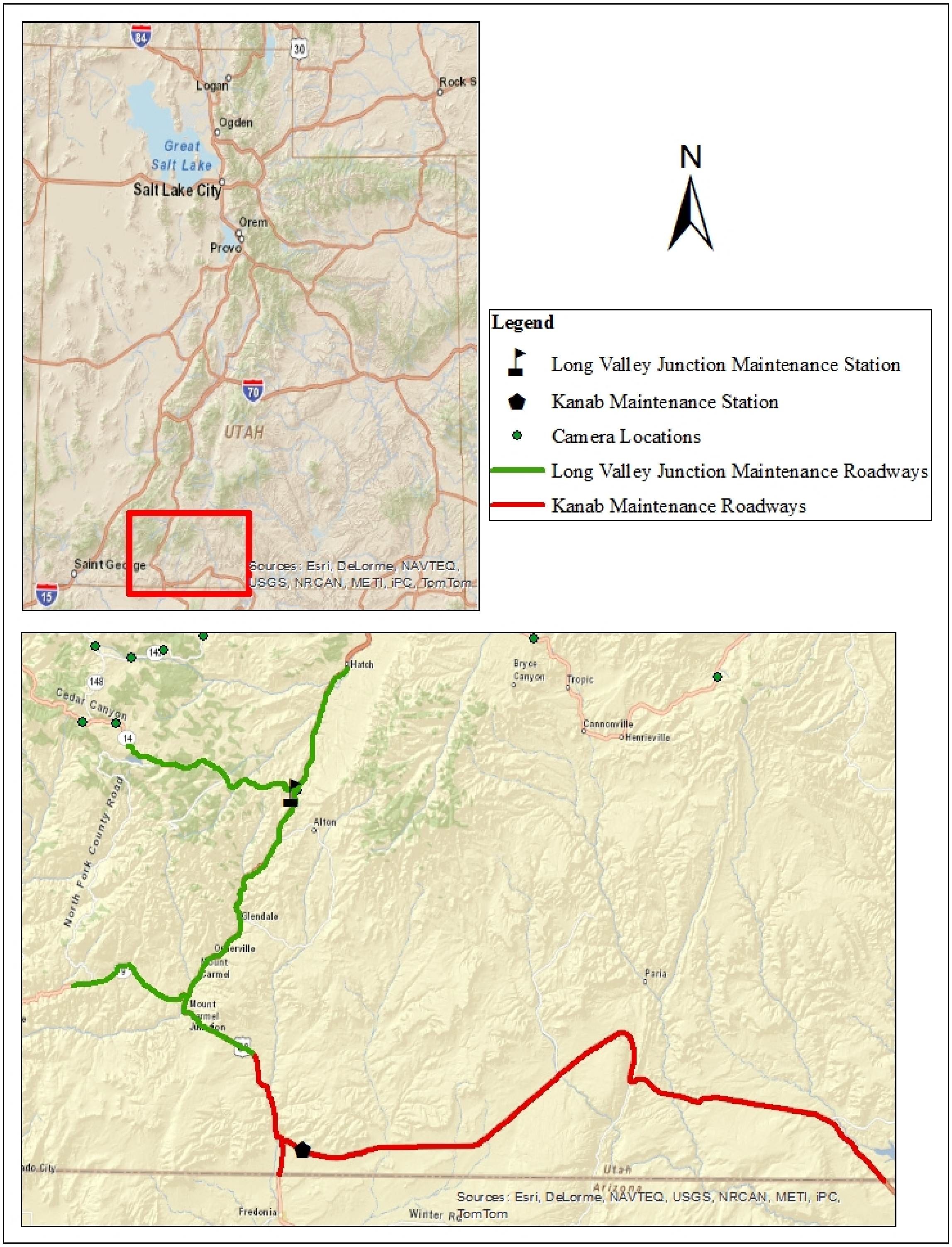
C.7 Comparison Pair 7: Monticello and Blanding



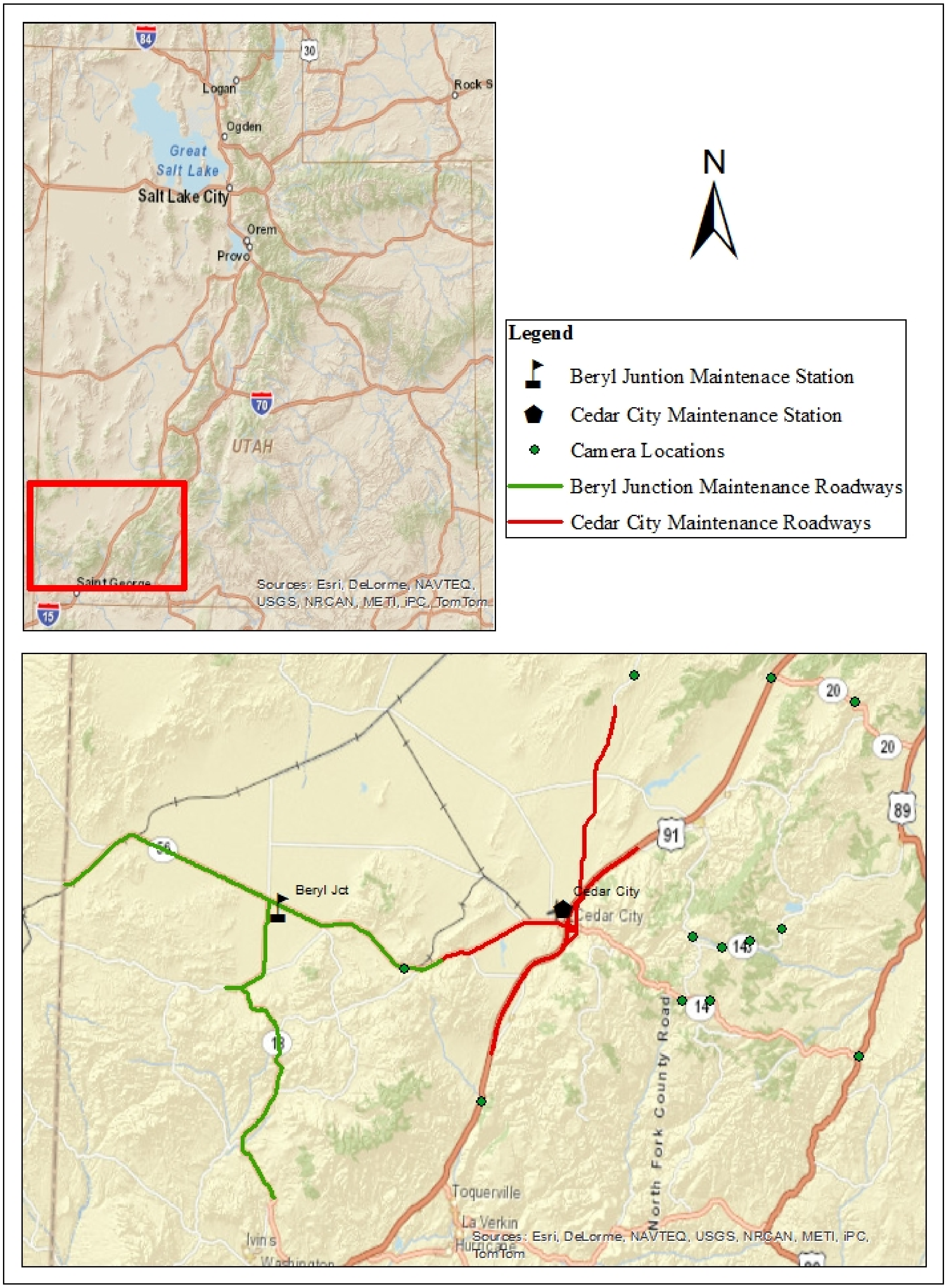
C.8 Comparison Pair 8: Huntington and Emery



C.9 Comparison Pair 9: Long Valley Junction and Kanab

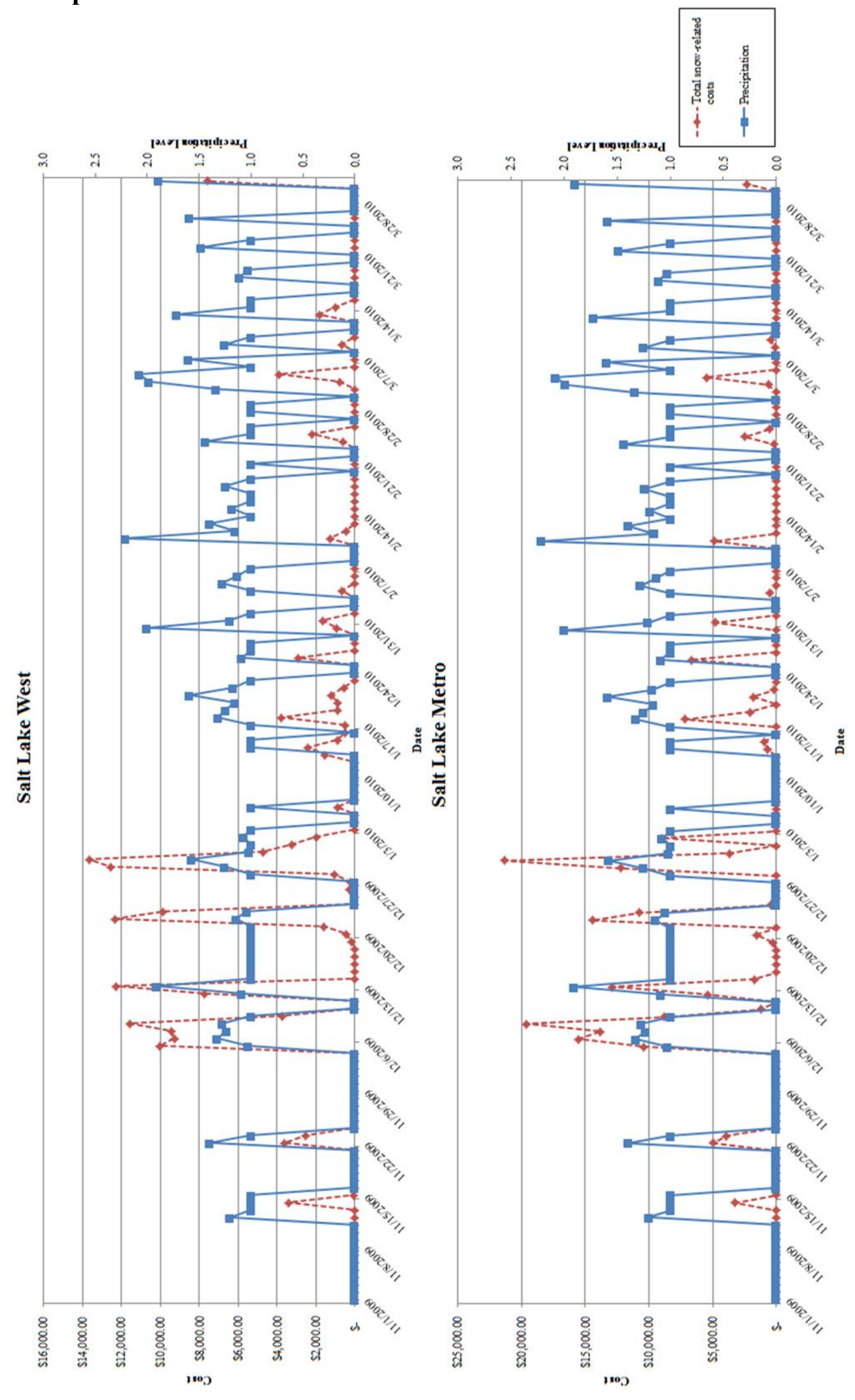


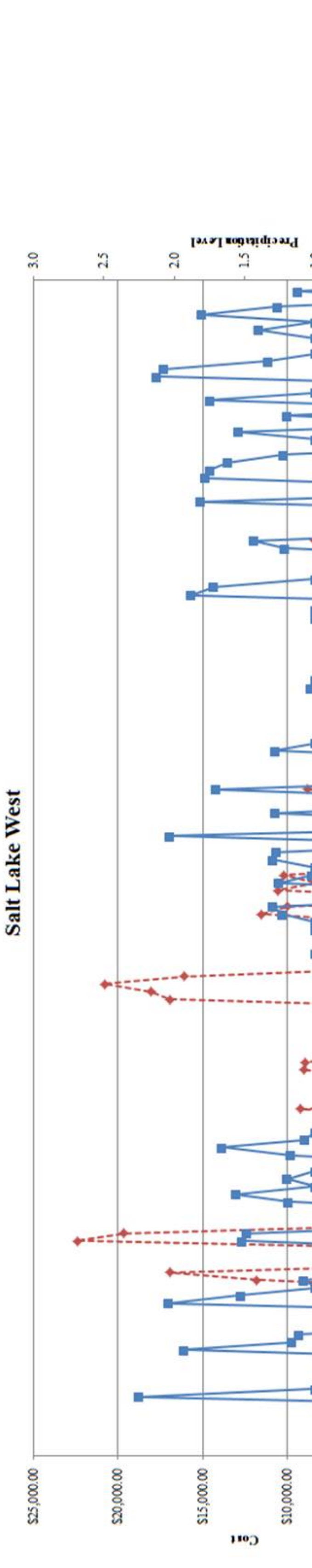
C.10 Comparison Pair 10: Beryl Junction and Cedar City



APPENDIX D. PRECIPITATION/SNOW REMOVAL-RELATED COST RELATION FIGURES

D.1 Salt Lake West and Salt Lake Metro Precipitation/Snow Removal-Related Cost Comparison




Salt Lake West
Precipitation Level
Cost
Date
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
11/1/2010
11/8/2010
11/15/2010
11/22/2010
11/29/2010
12/6/2010
12/13/2010
12/20/2010
12/27/2010
1/3/2011
1/10/2011
1/17/2011
1/24/2011
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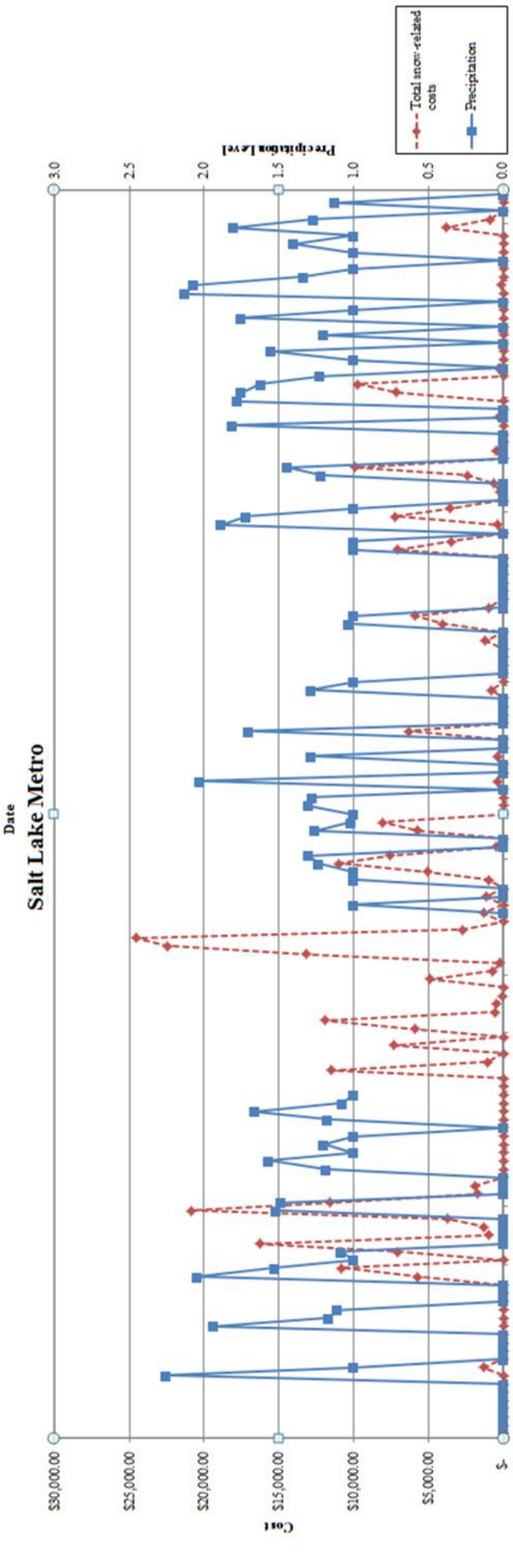
3/21/2011
3/28/2011


Salt Lake Metro
Precipitation Level
Cost
Date
Total snow-related costs
Precipitation
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
11/1/2010
11/8/2010
11/15/2010
11/22/2010
11/29/2010
12/6/2010
12/13/2010
12/20/2010
12/27/2010
1/3/2011
1/10/2011
1/17/2011
1/24/2011
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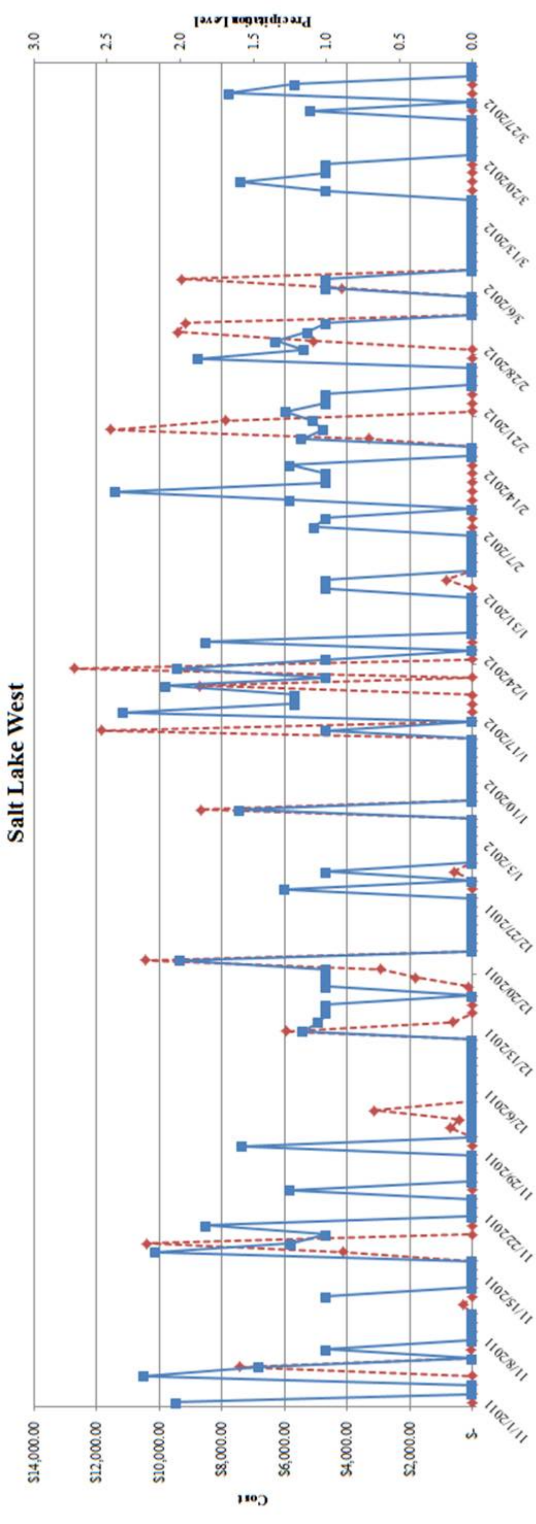
3/21/2011
3/28/2011


Salt Lake West
Cost
Precipitation Level
Date
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
3.0
2.5
2.0
1.5
1.0
0.5
0.0
11/1/2011
11/8/2011
11/15/2011
11/22/2011
11/29/2011
12/6/2011
12/13/2011
12/20/2011
12/27/2011
1/3/2012
1/10/2012
1/17/2012
1/24/2012
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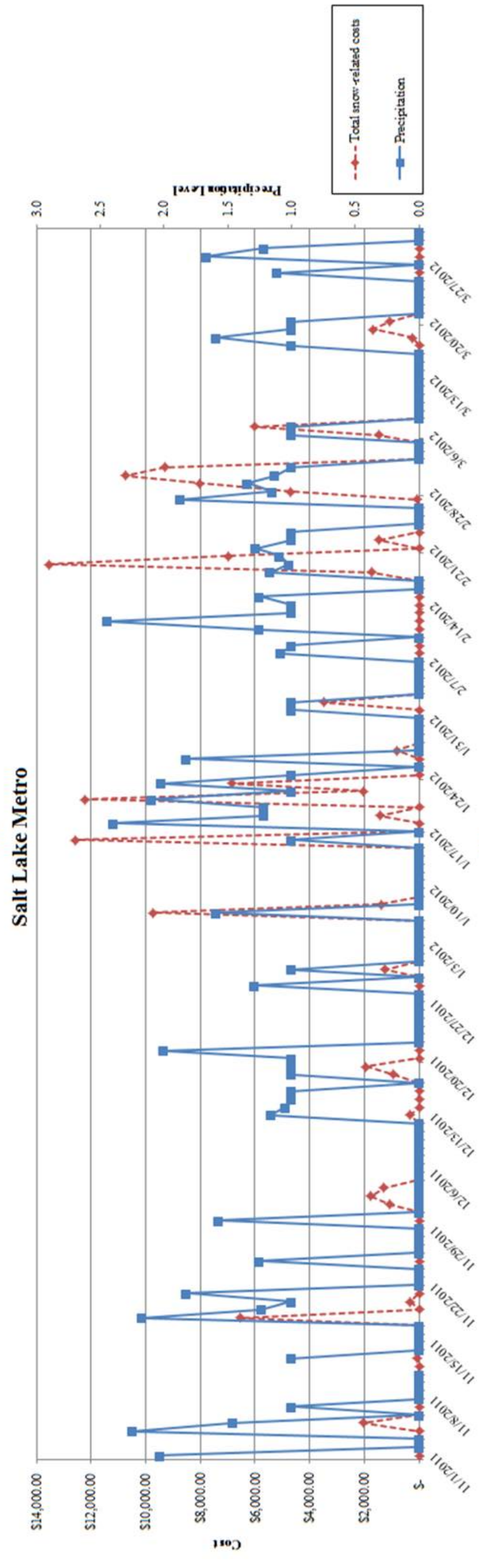
3/20/2012
3/27/2012


Salt Lake Metro
Cost
Precipitation Level
Date
Total snow-related costs
Precipitation
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
3.0
2.5
2.0
1.5
1.0
0.5
0.0
11/1/2011
11/8/2011
11/15/2011
11/22/2011
11/29/2011
12/6/2011
12/13/2011
12/20/2011
12/27/2011
1/3/2012
1/10/2012
1/17/2012
1/24/2012
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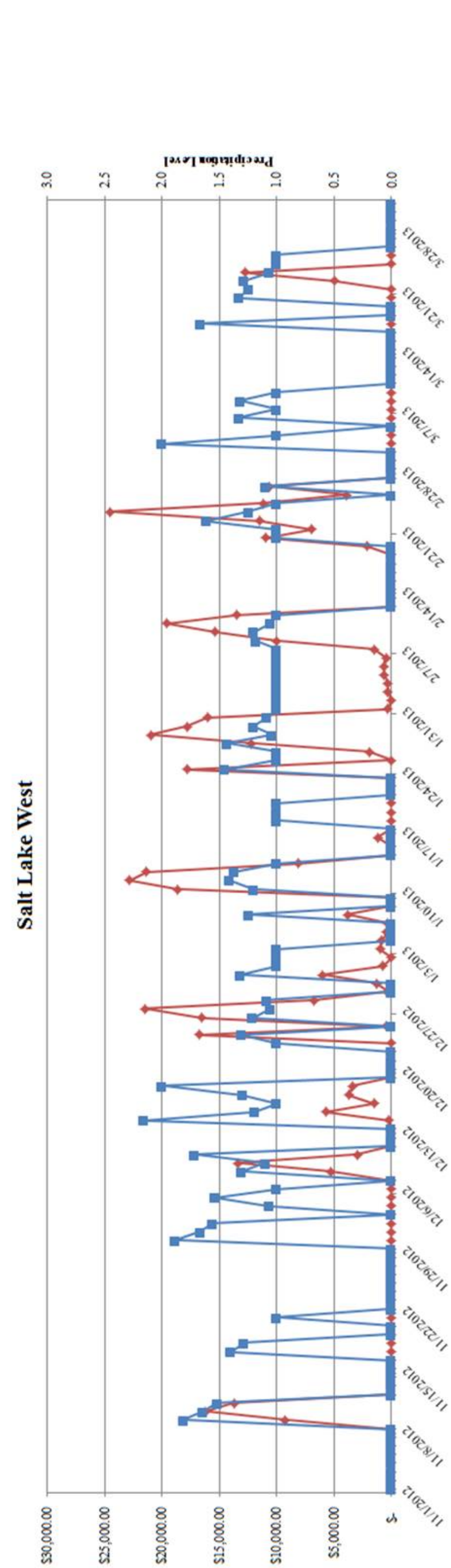
3/20/2012
3/27/2012


Salt Lake West
Cost
Precipitation Level
Date
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
3.0
2.5
2.0
1.5
1.0
0.5
0.0
11/1/2012
11/8/2012
11/15/2012
11/22/2012
11/29/2012
12/6/2012
12/13/2012
12/20/2012
12/27/2012
1/3/2013
1/10/2013
1/17/2013
1/24/2013
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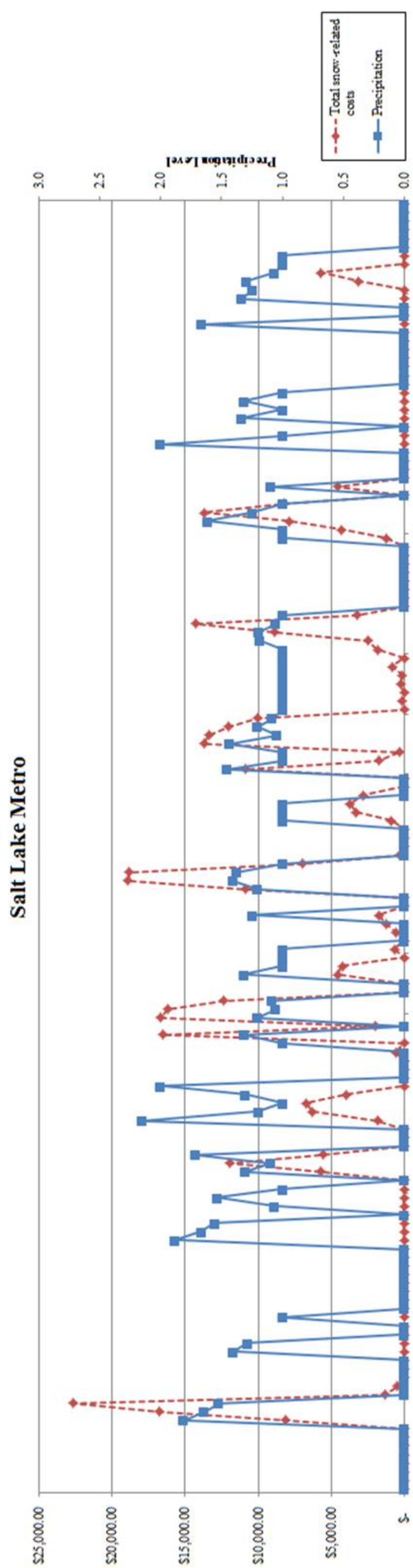
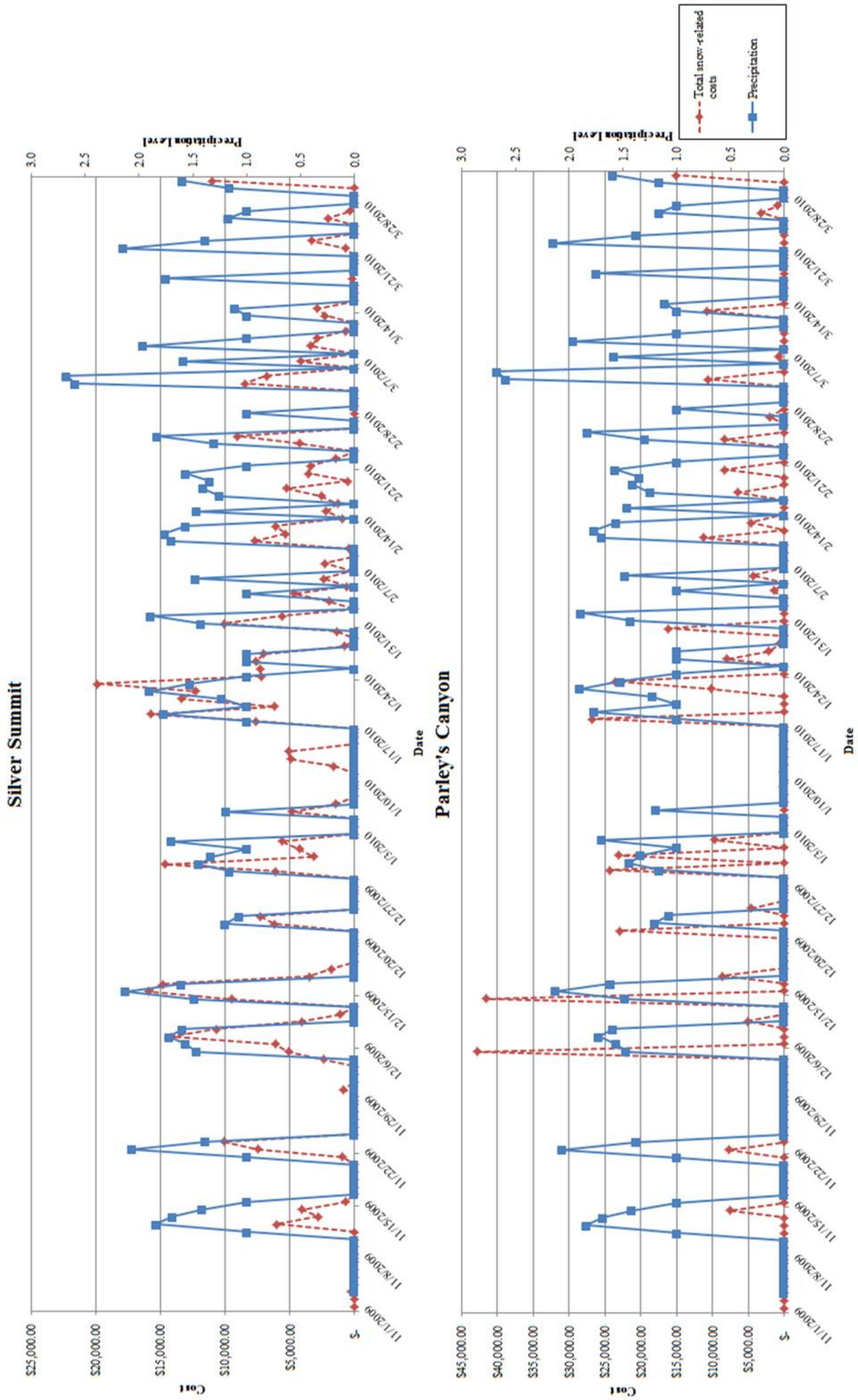
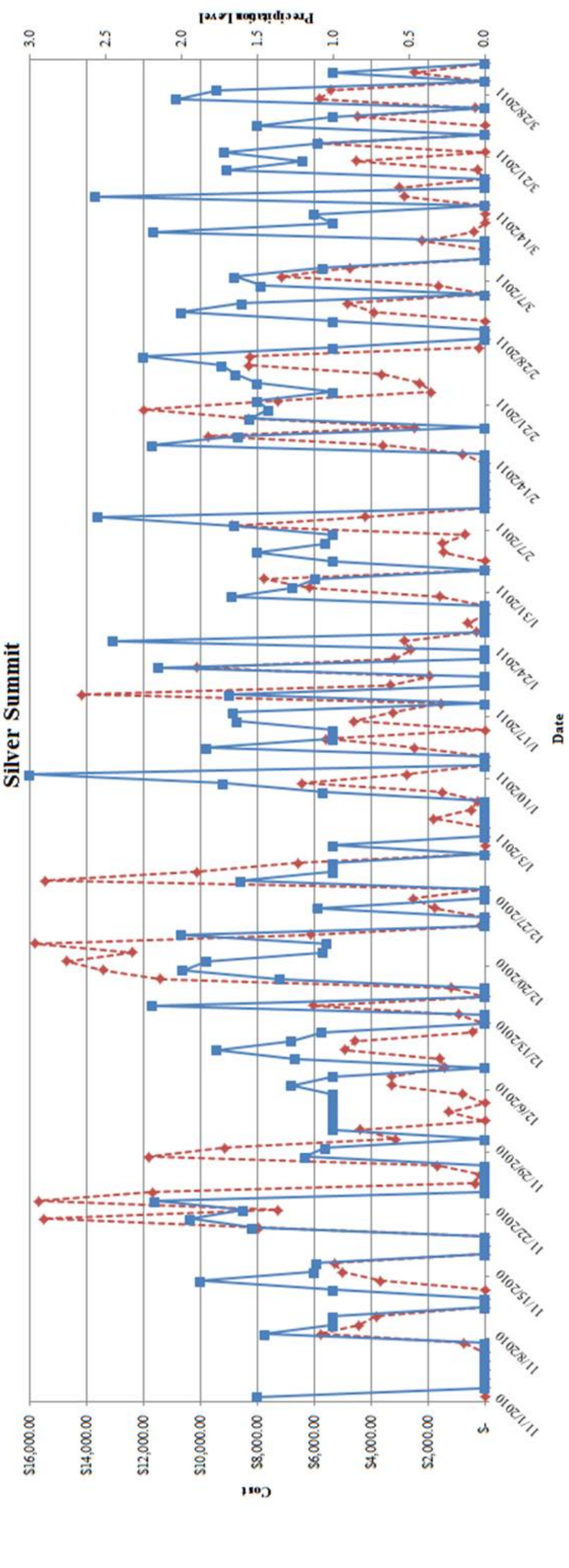
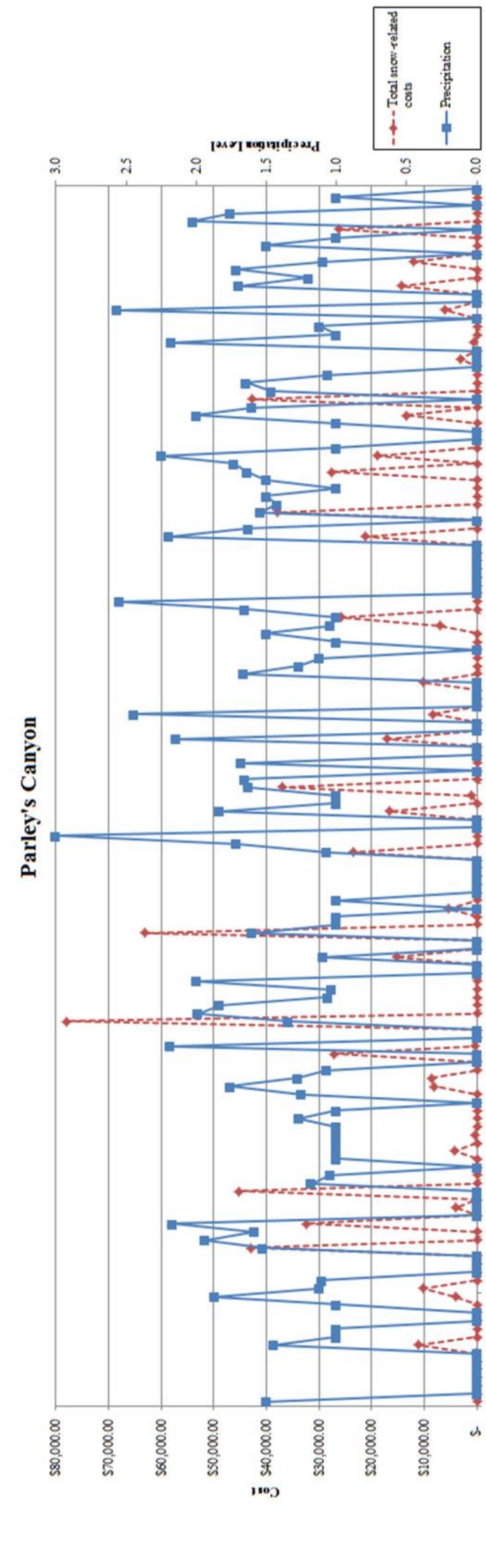
3/14/2013
3/21/2013
3/28/2013


Salt Lake Metro
Cost
Precipitation Level
Date
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
3.0
2.5
2.0
1.5
1.0
0.5
0.0
11/1/2012
11/8/2012
11/15/2012
11/22/2012
11/29/2012
12/6/2012
12/13/2012
12/20/2012
12/27/2012
1/3/2013
1/10/2013
1/17/2013
1/24/2013
1/31/2013
2/7/2013
2/14/2013
2/21/2013
2/28/2013
3/7/2013
3/14/2013
3/21/2013
3/28/2013
Total snow-related costs
Precipitation

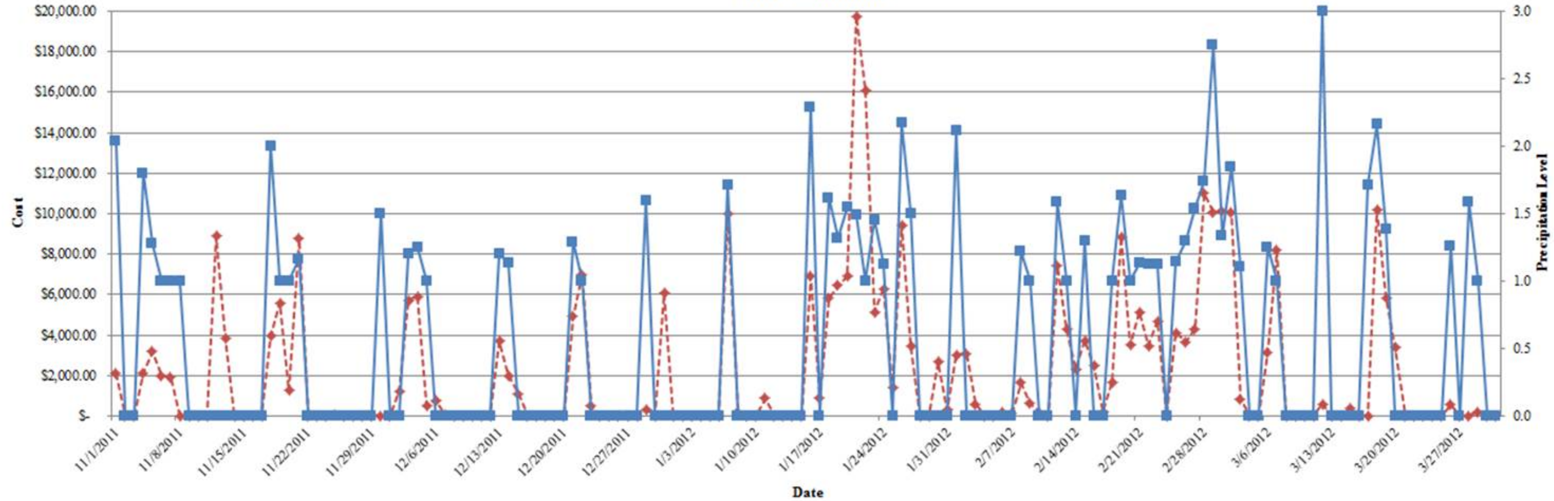
D.2 Silver Summit and Parley's Canyon Precipitation/Snow Removal-Related Cost Comparison



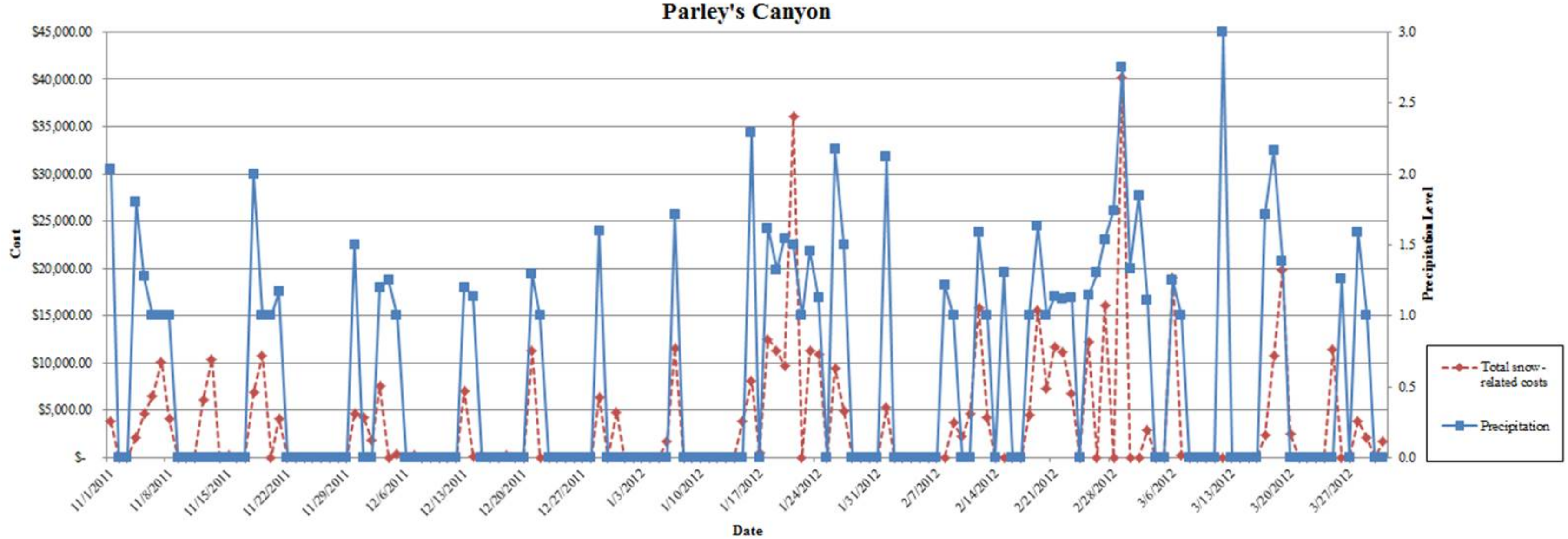

Silver Summit
Cost
Date
Precipitation Level


Parley's Canyon
Cost
Date
Precipitation Level
Total snow-related costs
Precipitation

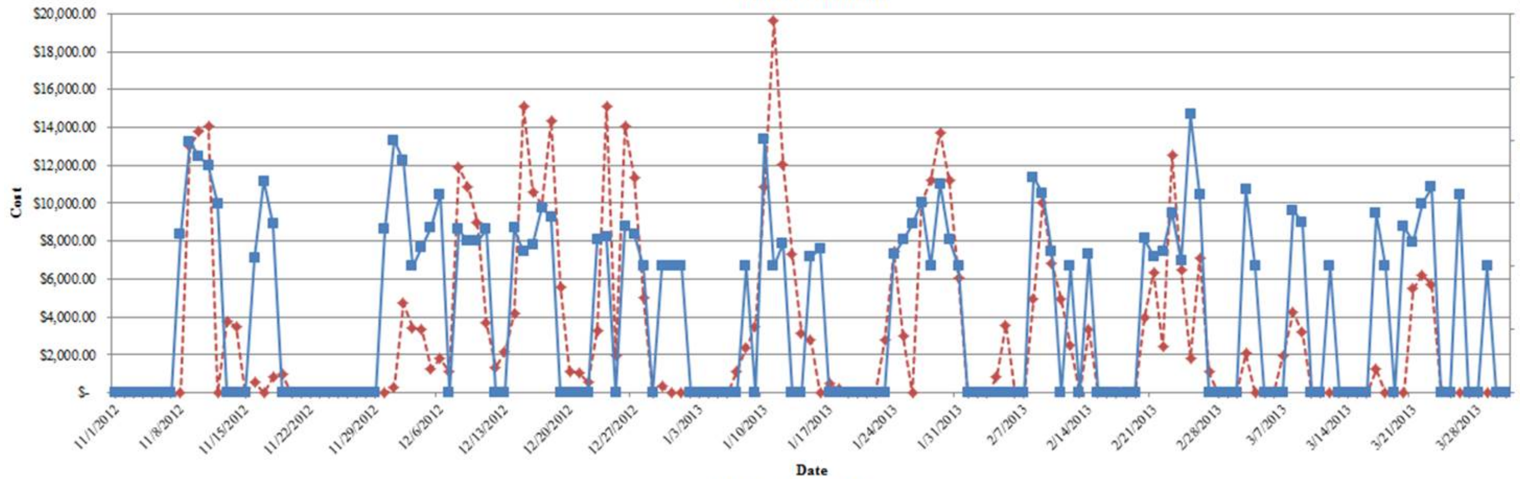
Silver Summit



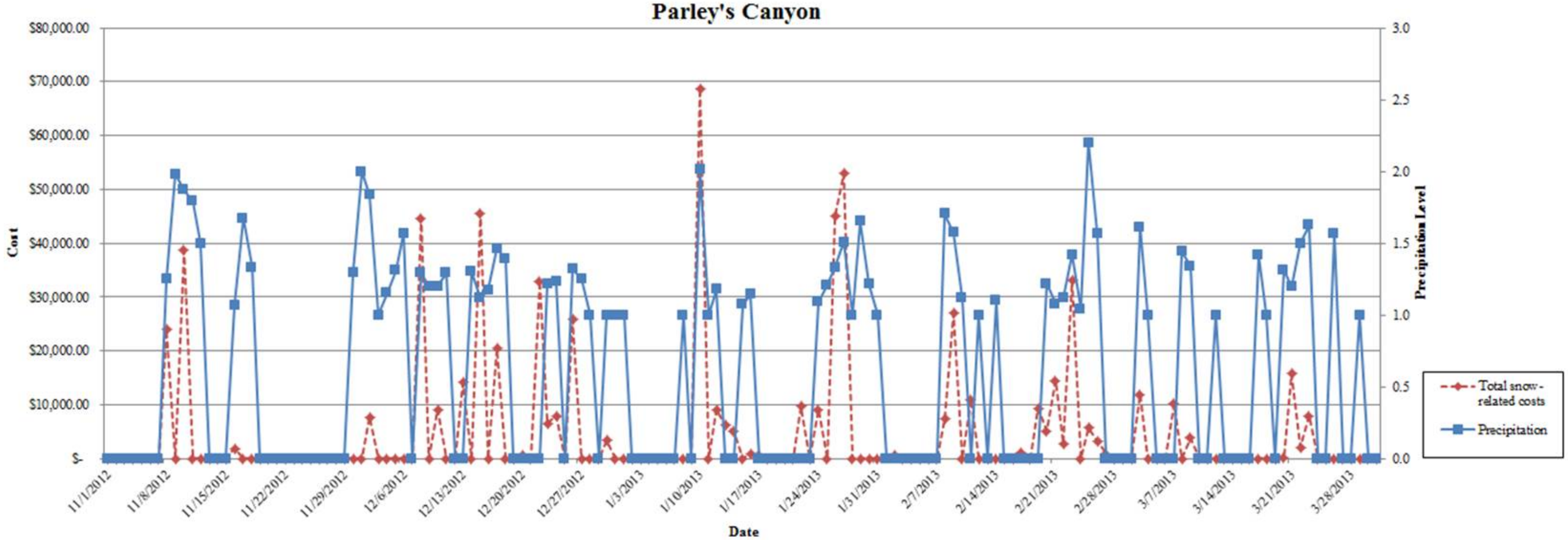
Parley's Canyon



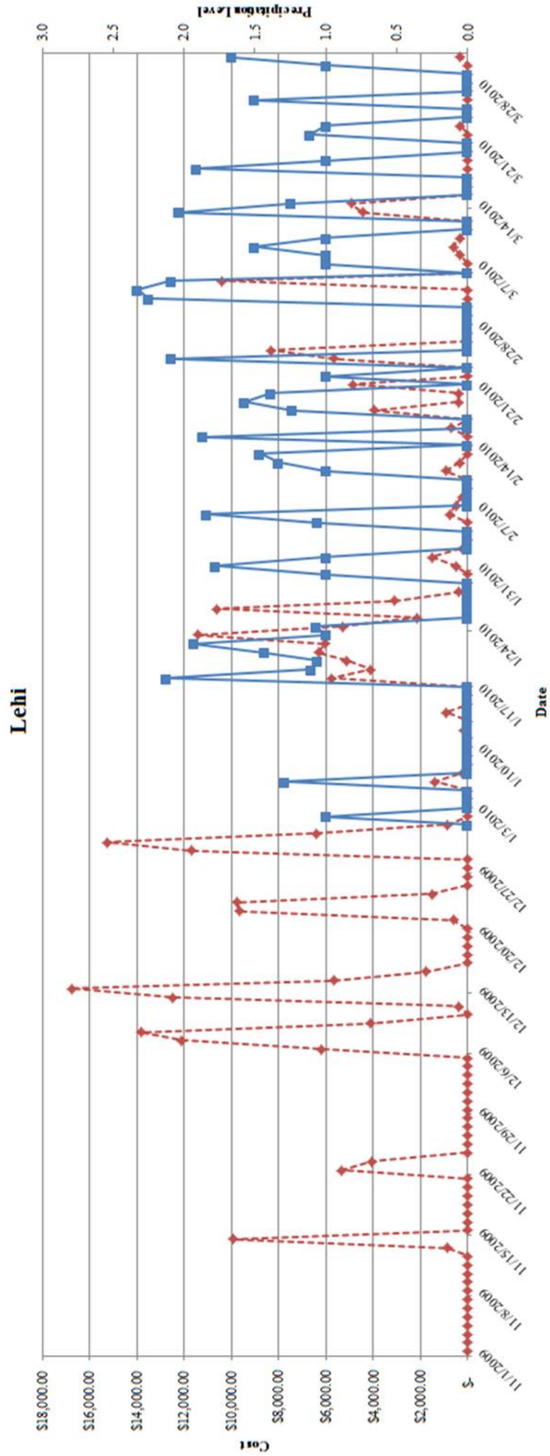
Silver Summit

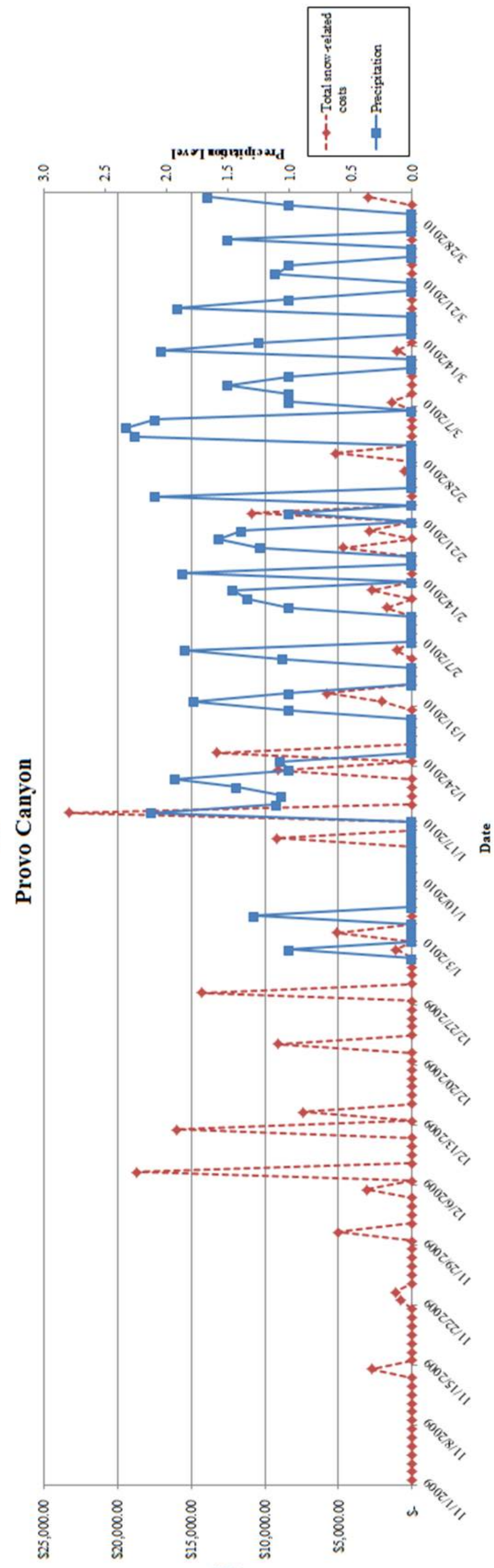


Parley's Canyon

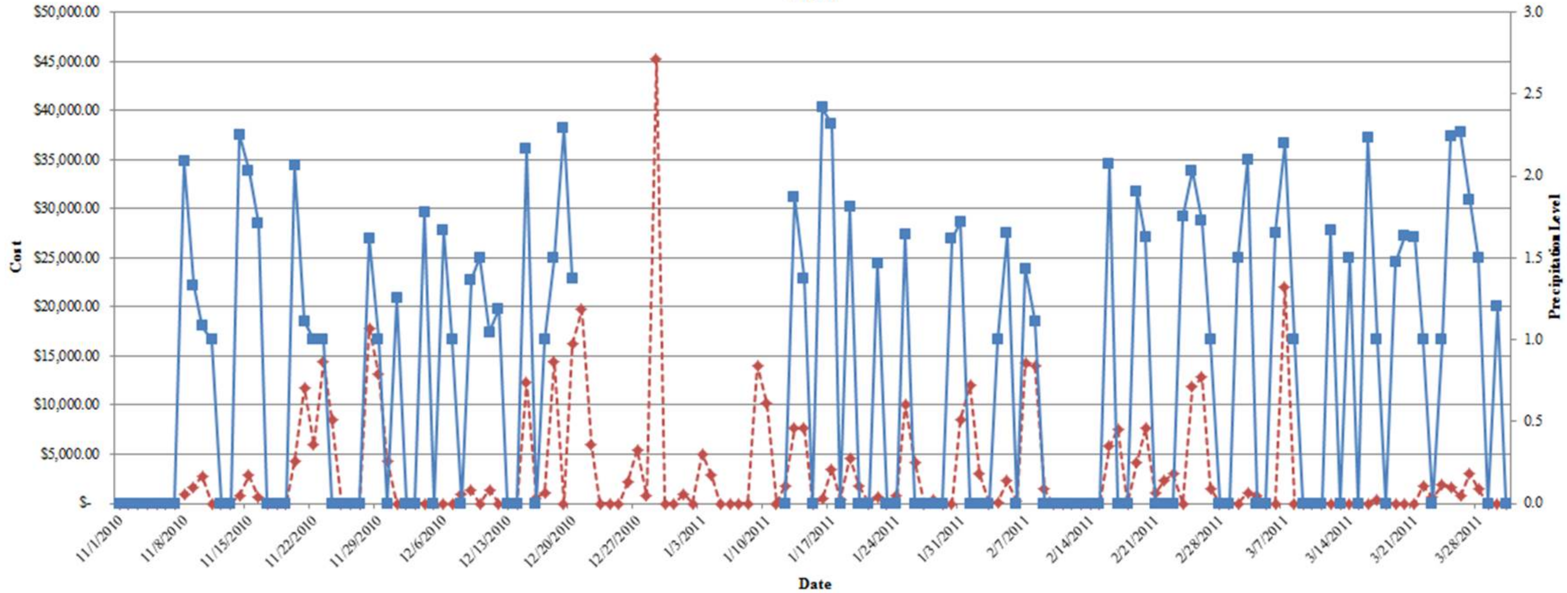


D.3 Lehi and Provo Canyon Precipitation/Snow Removal-Related Cost Comparison

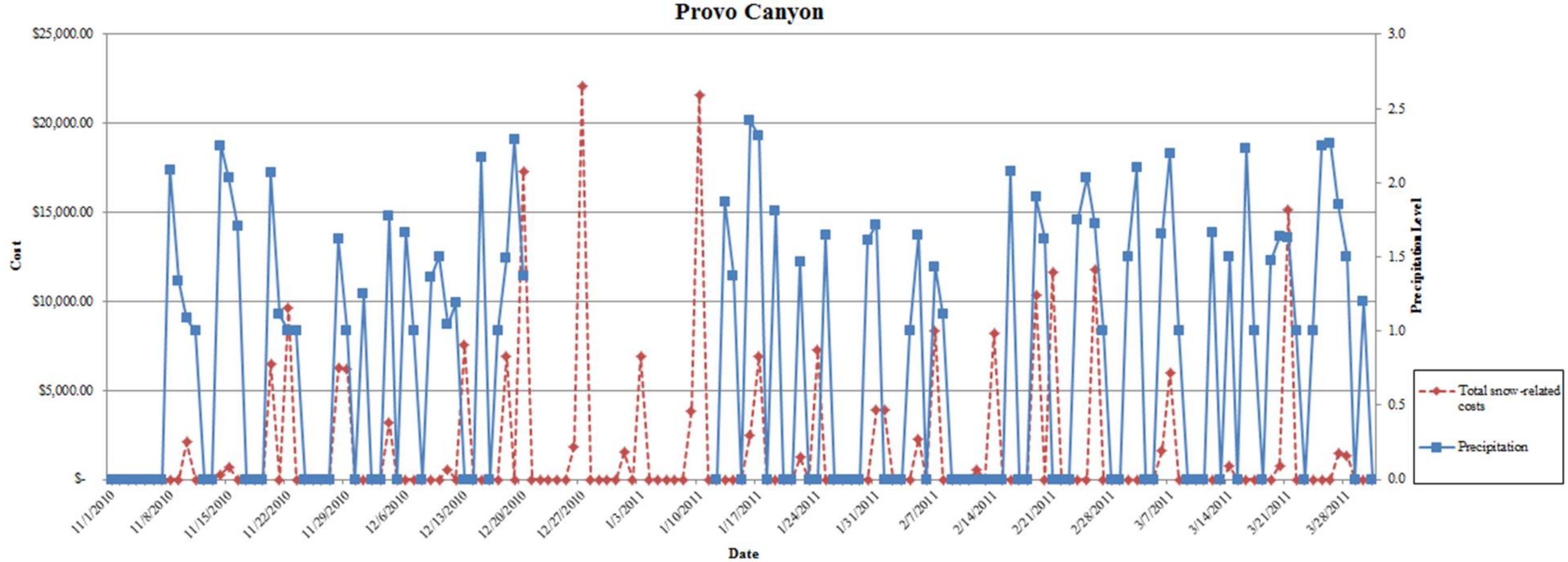


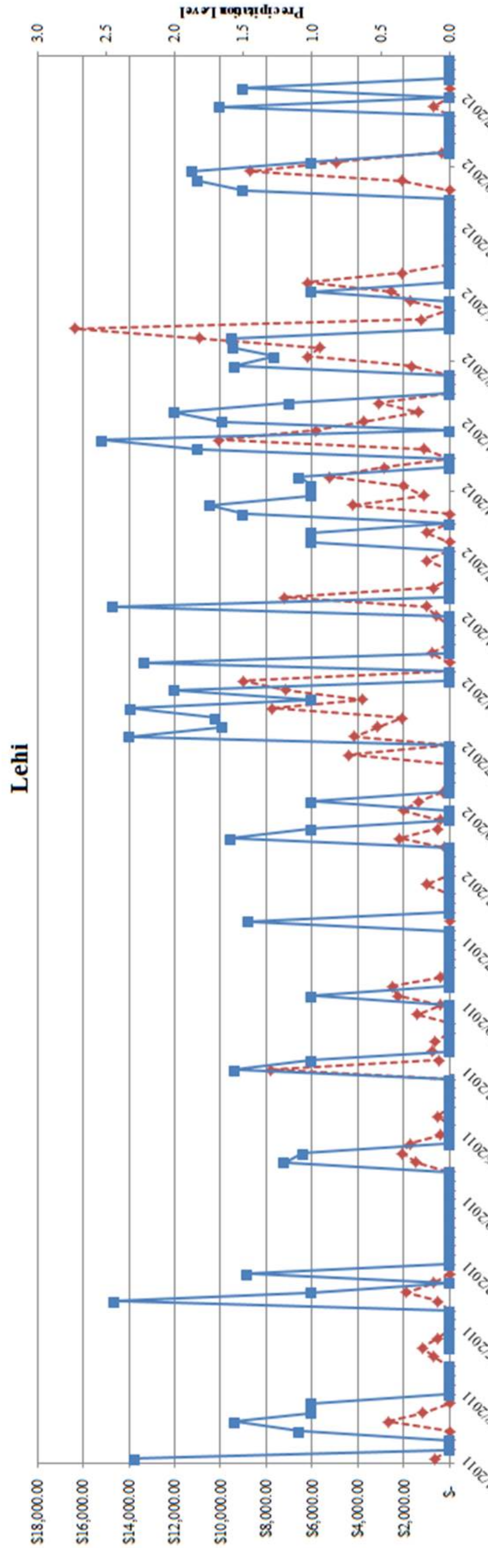


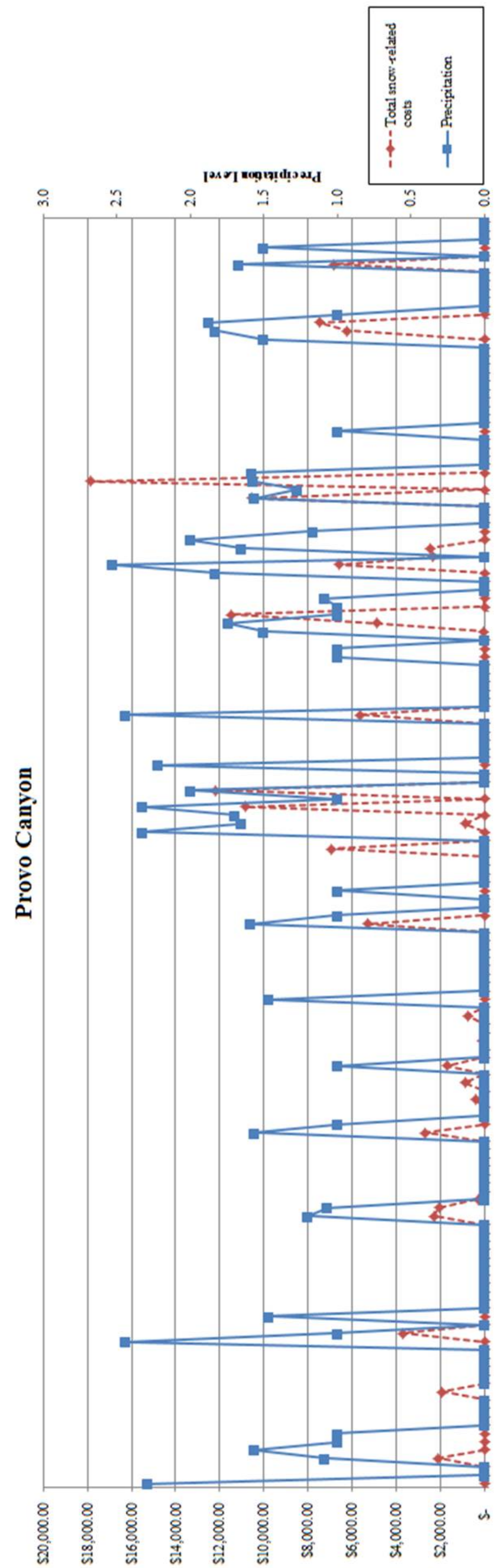
Lehi

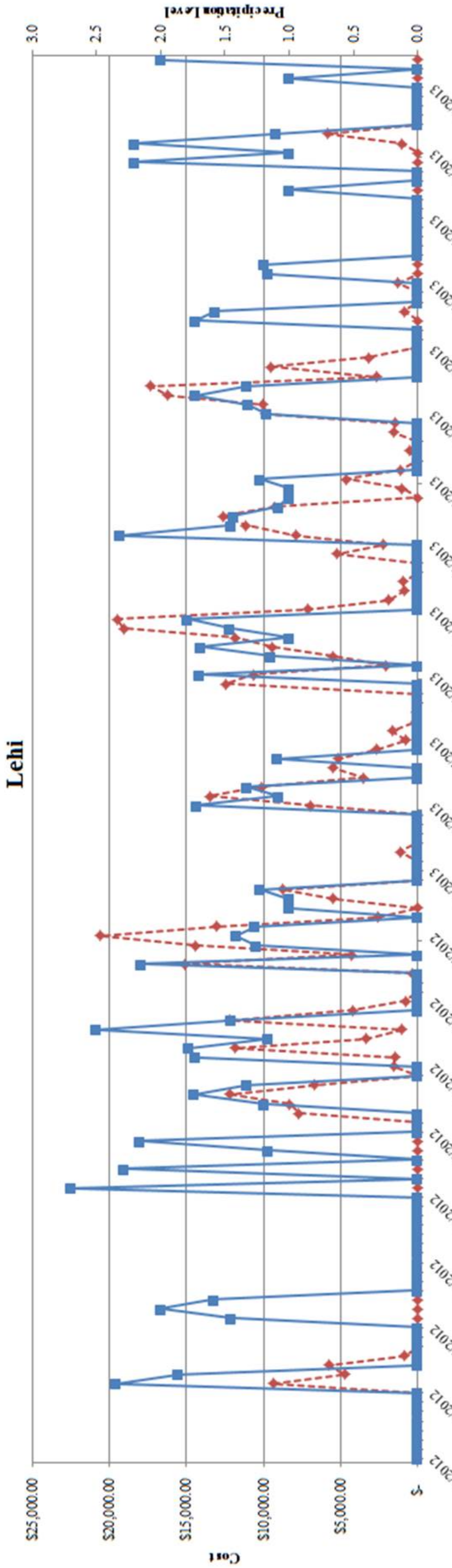


Provo Canyon




Lehi
Cost
Date
Precipitation Level


Provo Canyon
Cost
Date
Precipitation Level
Total snow-related costs
Precipitation


Lehi
Cost
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
Precipitation Level
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Date
11/1/2012
11/8/2012
11/15/2012
11/22/2012
11/29/2012
12/6/2012
12/13/2012
12/20/2012
12/27/2012
1/3/2013
1/10/2013
1/17/2013
1/24/2013
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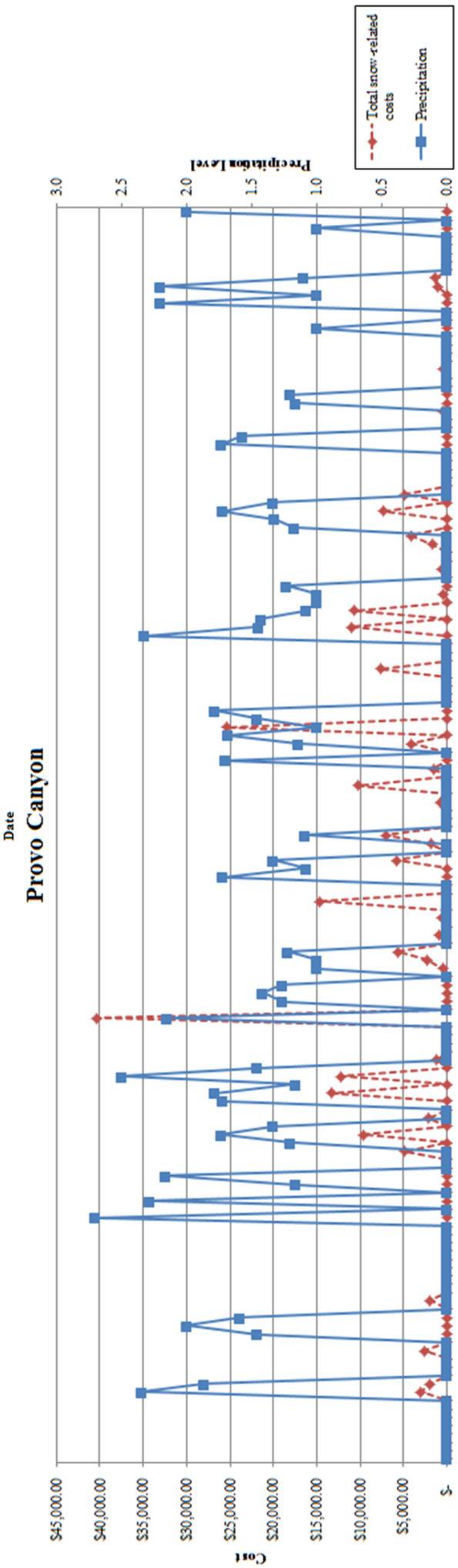
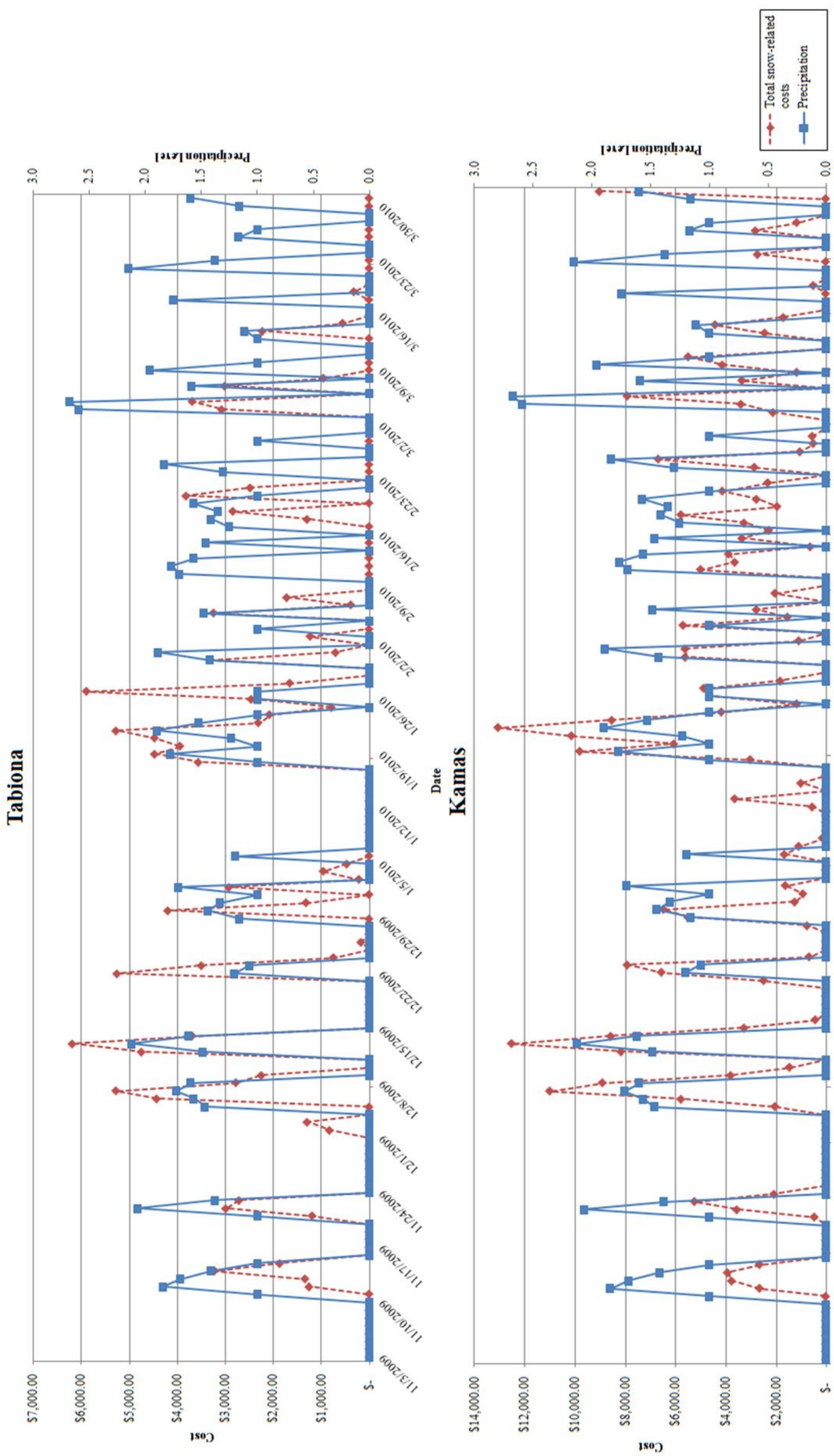
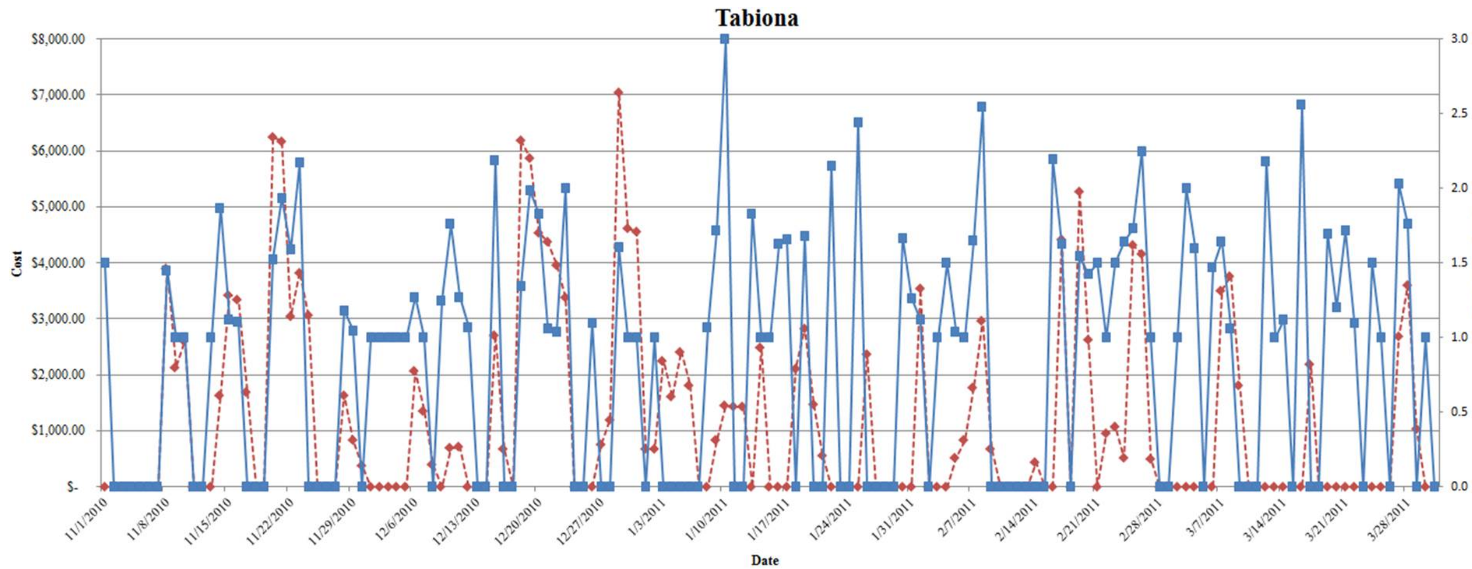
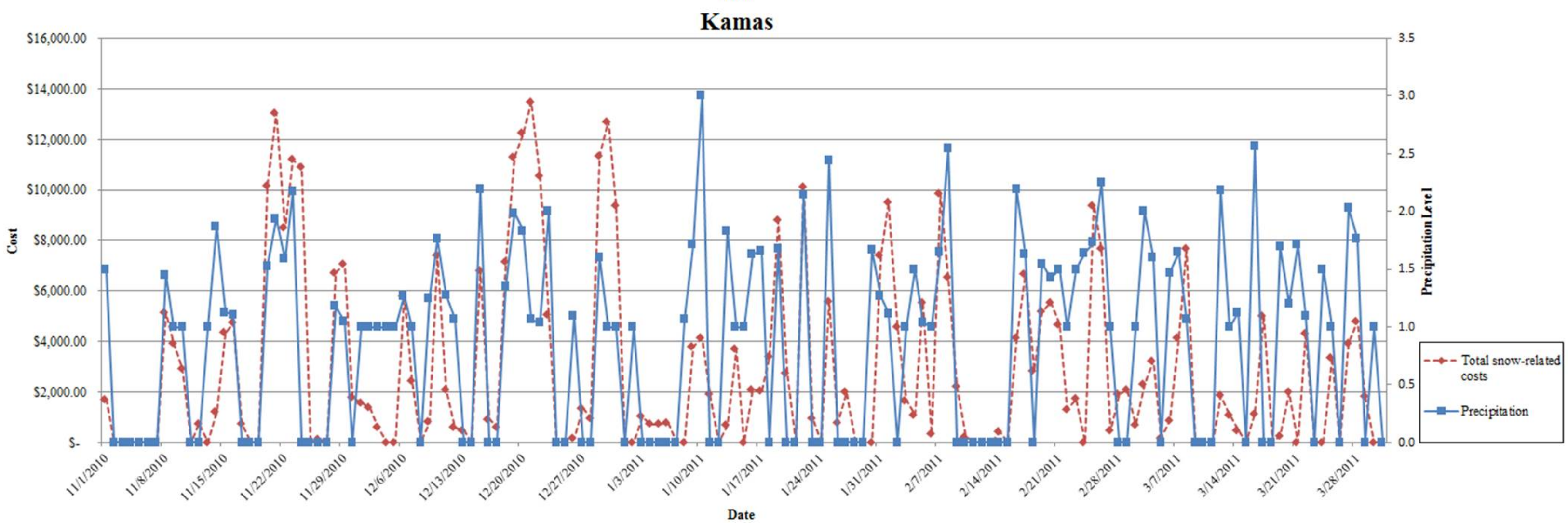
3/21/2013
3/28/2013

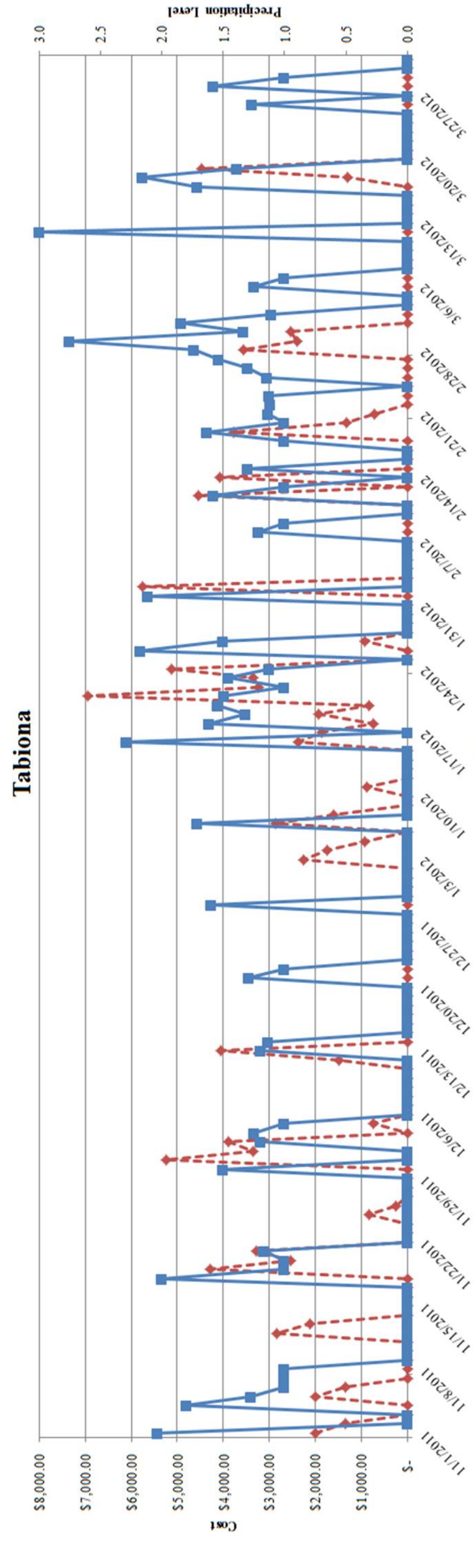

Provo Canyon
Cost
$45,000.00
$40,000.00
$35,000.00
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
Precipitation Level
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Date
11/1/2012
11/8/2012
11/15/2012
11/22/2012
11/29/2012
12/6/2012
12/13/2012
12/20/2012
12/27/2012
1/3/2013
1/10/2013
1/17/2013
1/24/2013
1/31/2013
2/7/2013
2/14/2013
2/21/2013
2/28/2013
3/7/2013
3/14/2013
3/21/2013
3/28/2013
Total snow-related costs
Precipitation

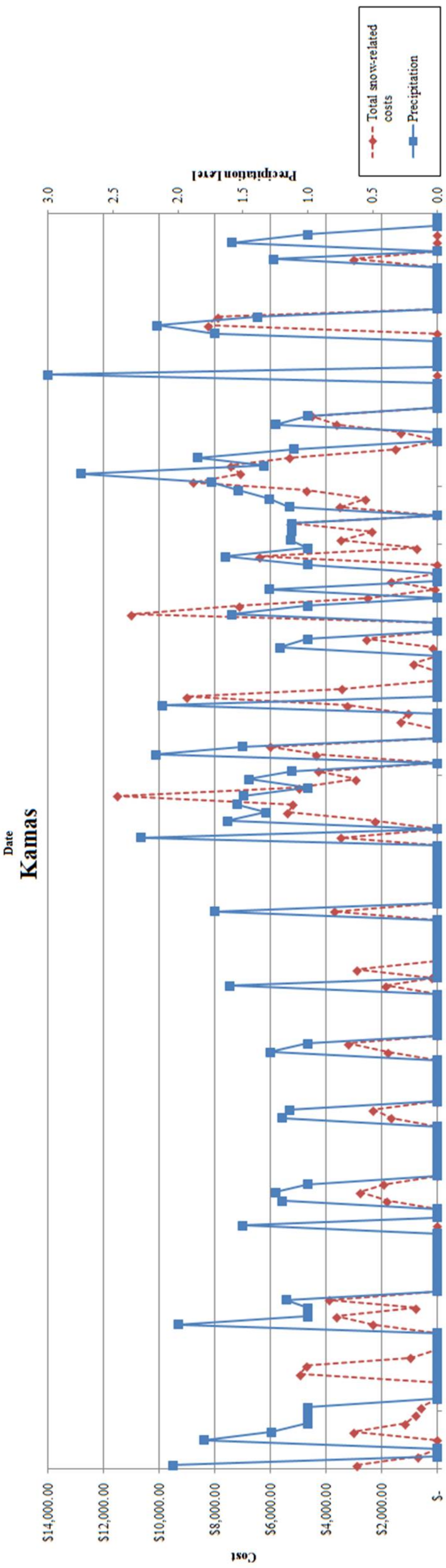
D.4 Tabiona and Kamas Precipitation/Snow Removal-Related Cost Comparison

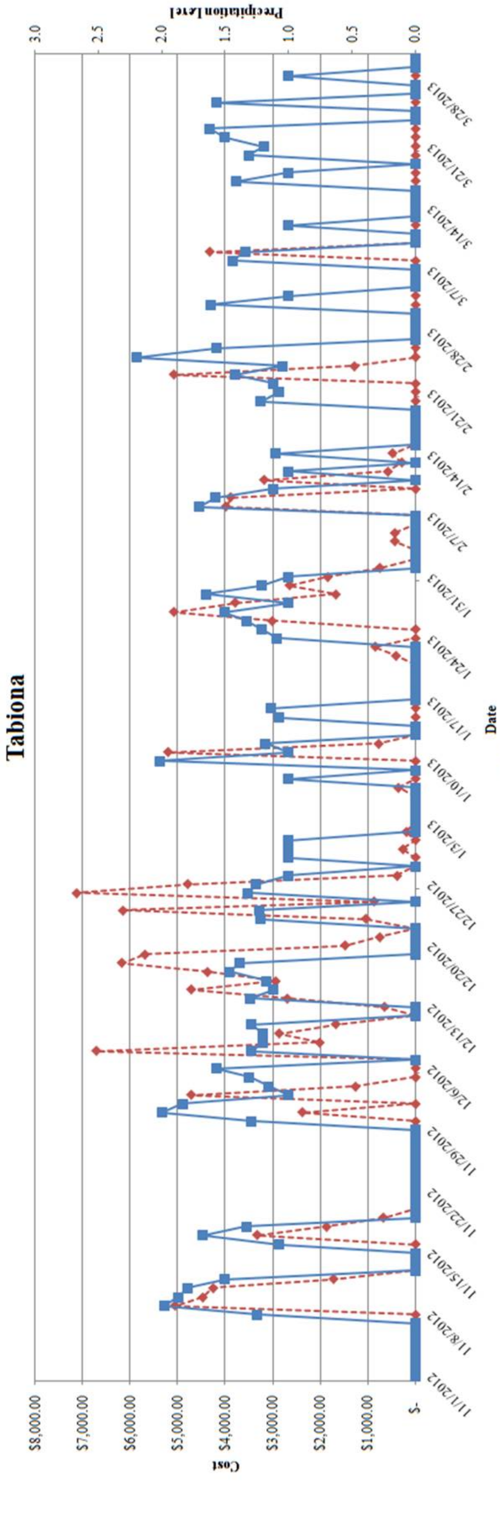



Tabiona
Cost
Precipitation Level
Date


Kamas
Cost
Precipitation Level
Date
Total snow-related costs
Precipitation


Tabiona
Cost
Precipitation Level
Date


Kamas
Cost
Precipitation Level
Date
Total snow-related costs
Precipitation


Tabiona
Cost
$8,000.00
$7,000.00
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$-
Precipitation Level
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Date
11/1/2012
11/8/2012
11/15/2012
11/22/2012
11/29/2012
12/6/2012
12/13/2012
12/20/2012
12/27/2012
1/3/2013
1/10/2013
1/17/2013
1/24/2013
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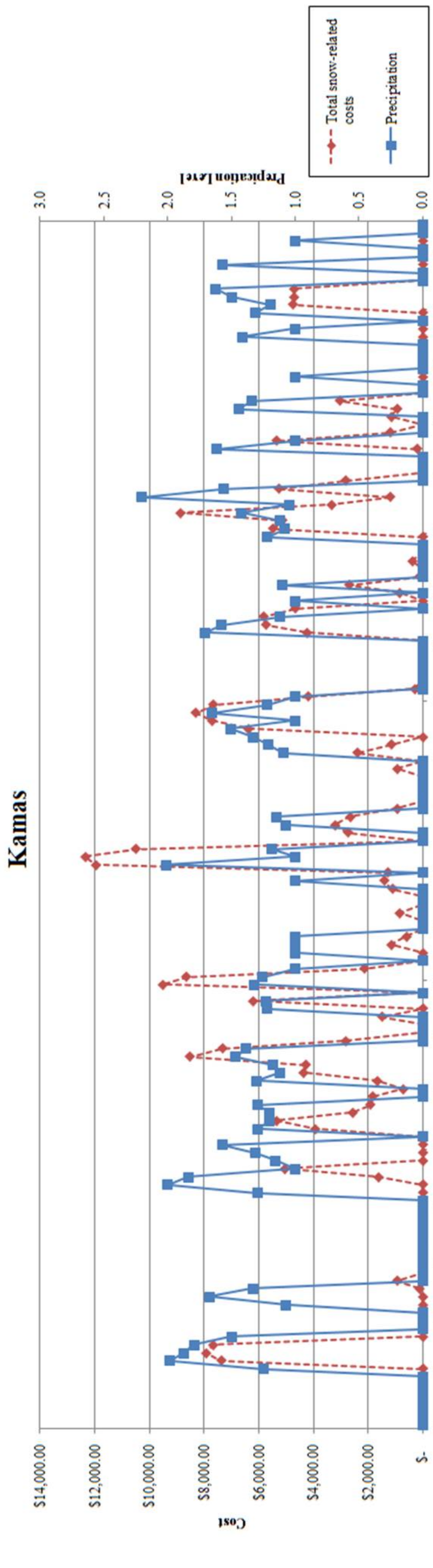
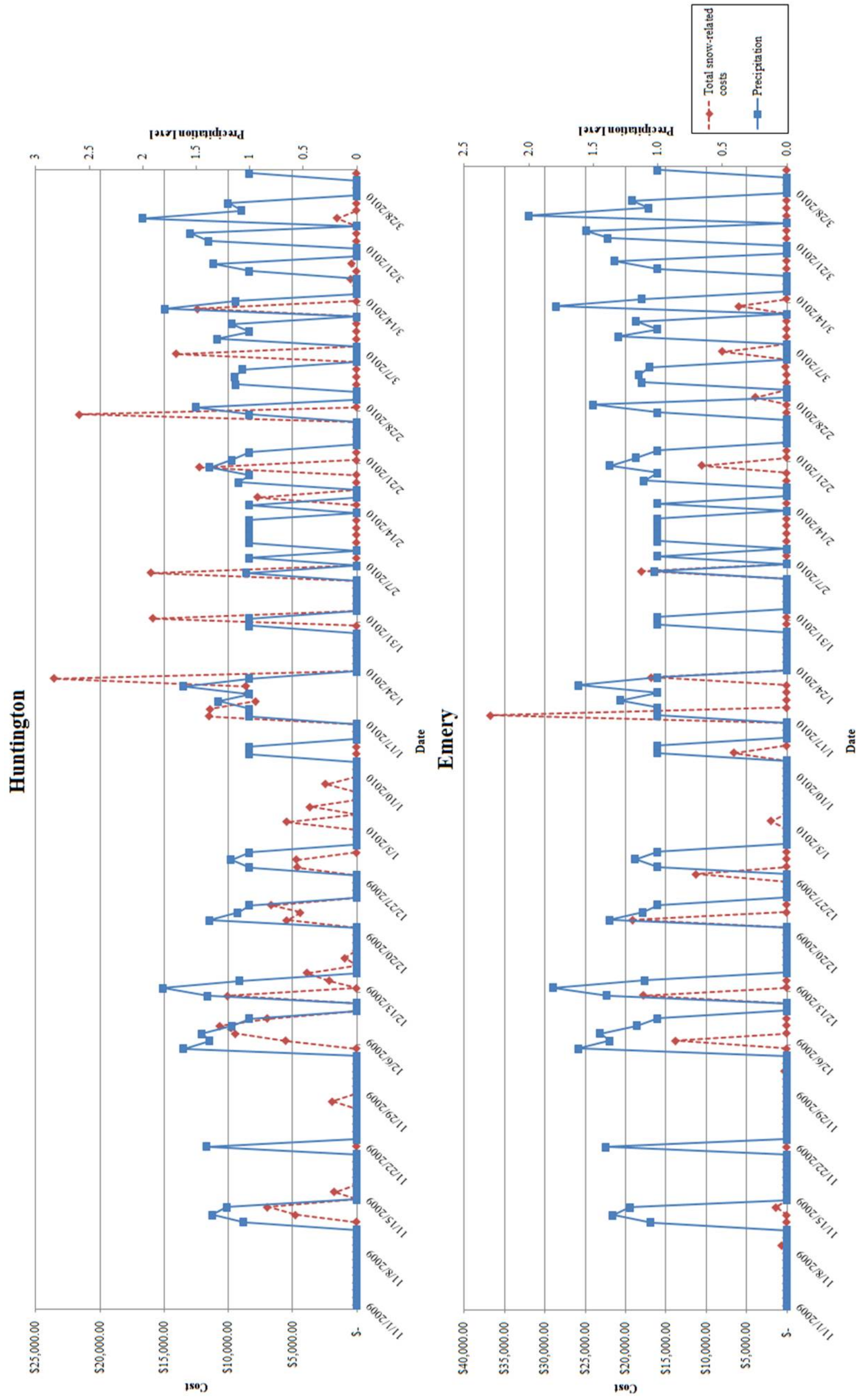
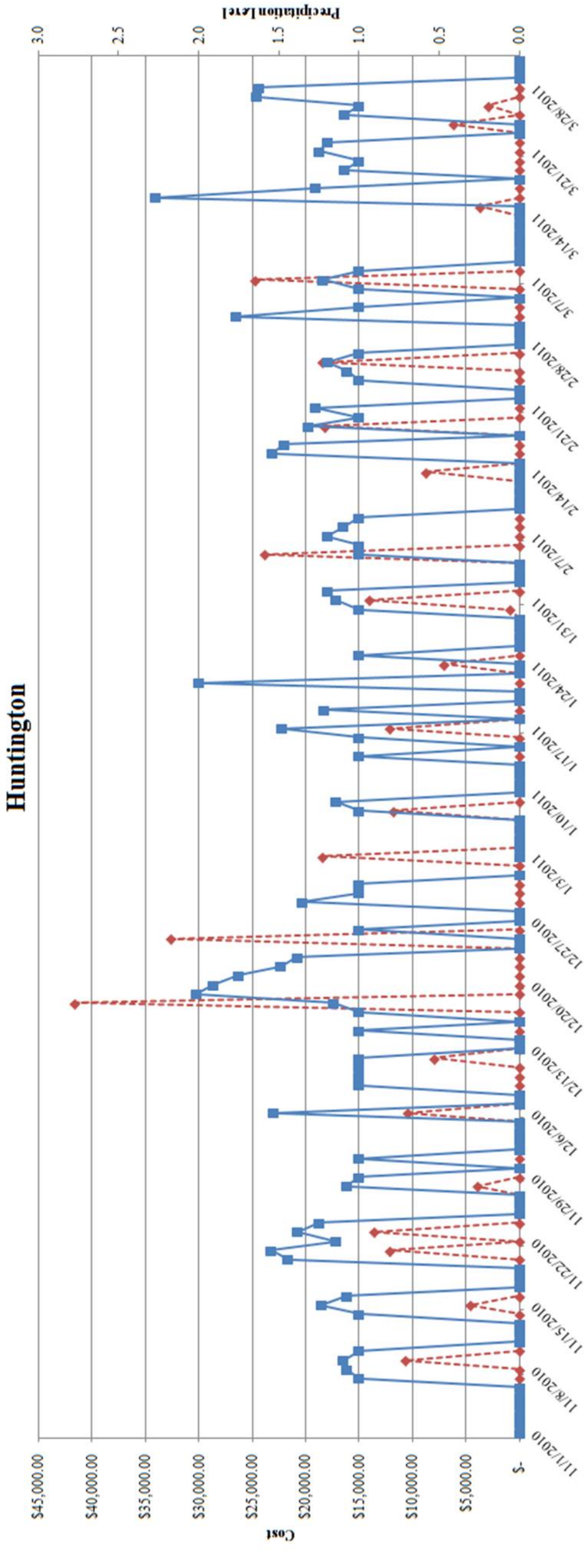
3/21/2013
3/28/2013


Kamas
Cost
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
Prepication Level
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Date
11/1/2012
11/8/2012
11/15/2012
11/22/2012
11/29/2012
12/6/2012
12/13/2012
12/20/2012
12/27/2012
1/3/2013
1/10/2013
1/17/2013
1/24/2013
1/31/2013
2/7/2013
2/14/2013
2/21/2013
2/28/2013
3/7/2013
3/14/2013
3/21/2013
3/28/2013
Total snow-related costs
Precipitation

D.5 Huntington and Emery Precipitation/Snow Removal-Related Cost Comparison




Huntington
Cost
Precipitation Level
Date
$45,000.00
$40,000.00
$35,000.00
$30,000.00
$25,000.00
$20,000.00
$15,000.00
$10,000.00
$5,000.00
$-
3.0
2.5
2.0
1.5
1.0
0.5
0.0
11/1/2010
11/8/2010
11/15/2010
11/22/2010
11/29/2010
12/6/2010
12/13/2010
12/20/2010
12/27/2010
1/3/2011
1/10/2011
1/17/2011
1/24/2011
1/31/2011
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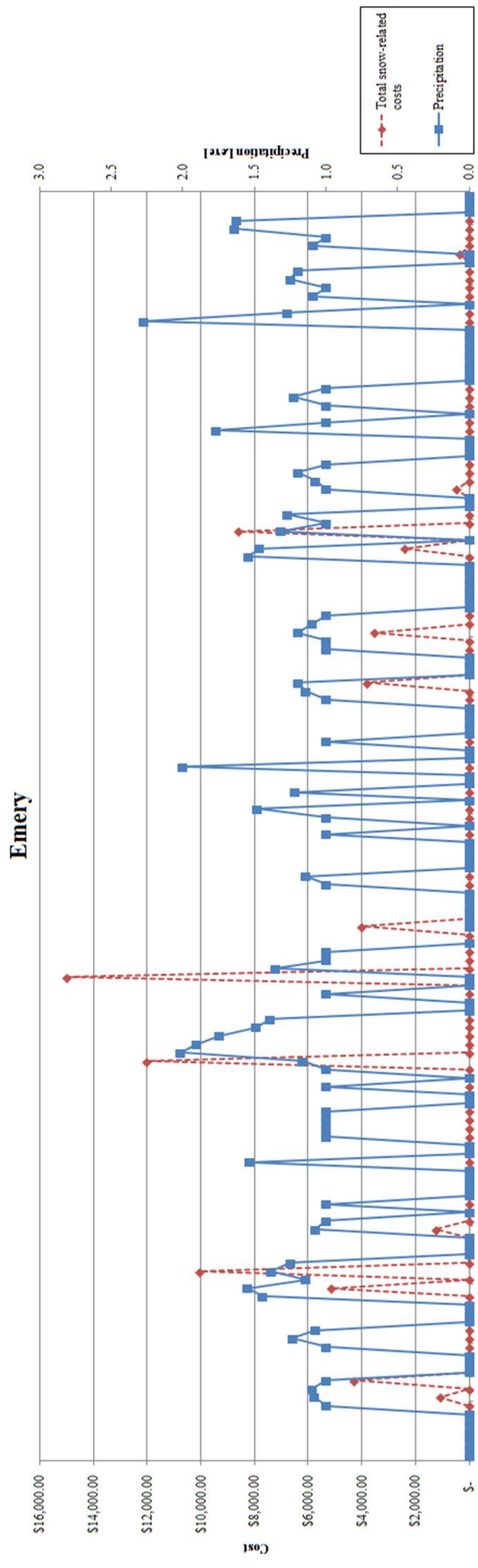
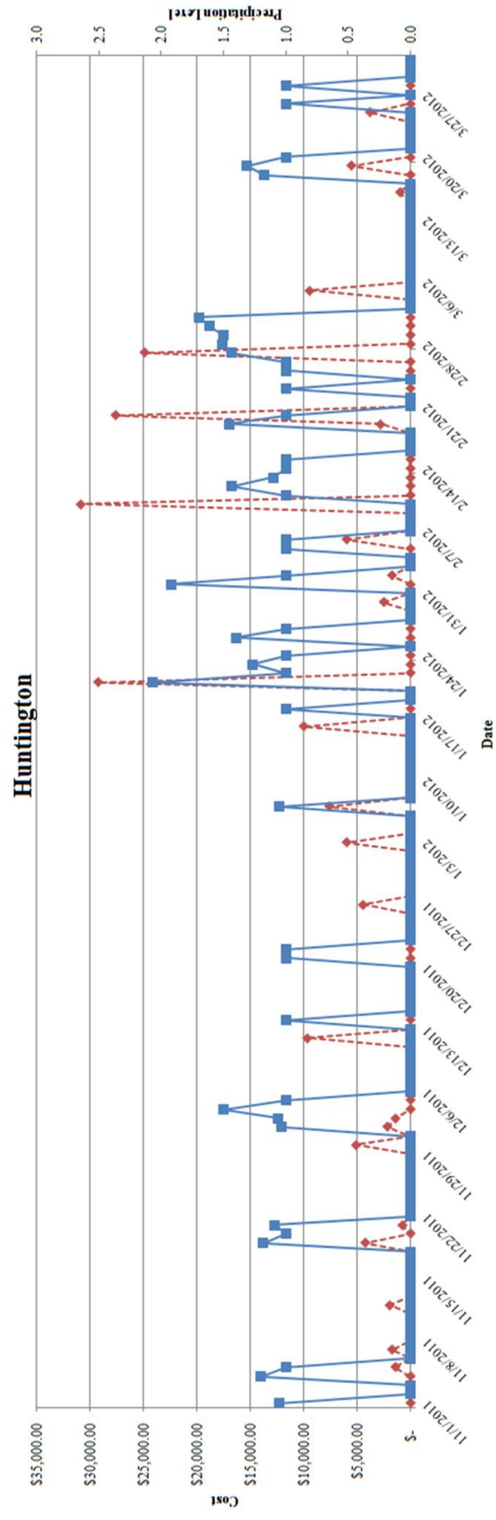
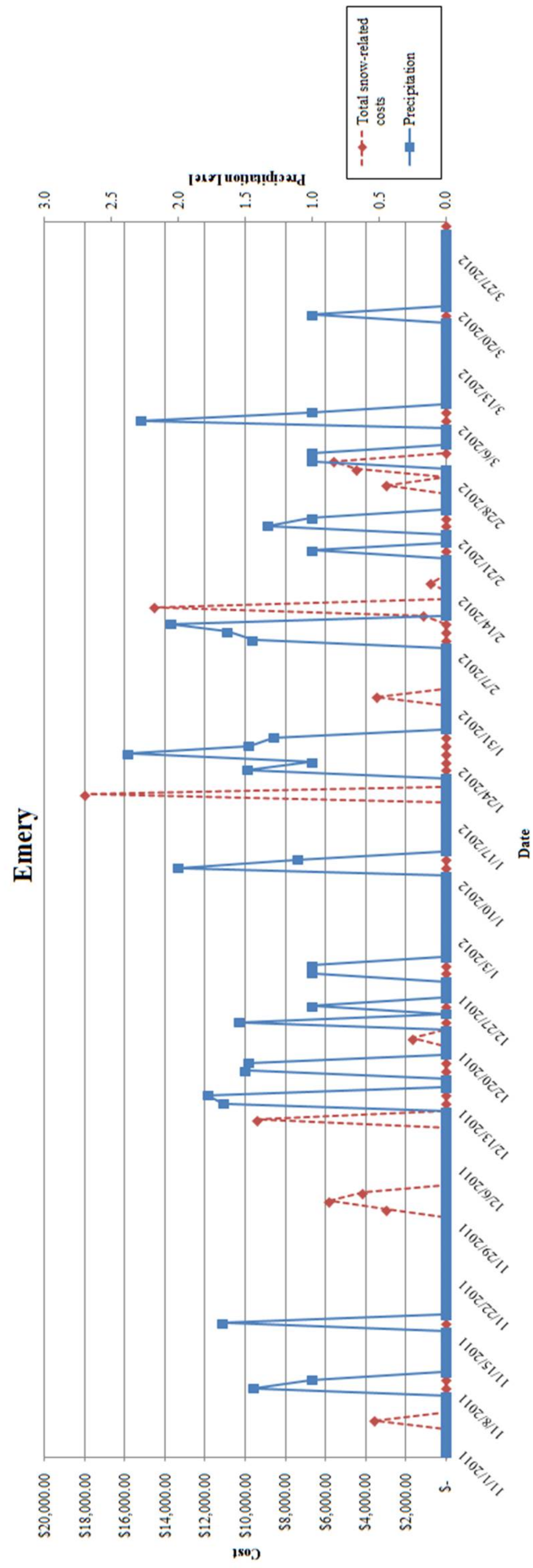
3/14/2011
3/21/2011
3/28/2011

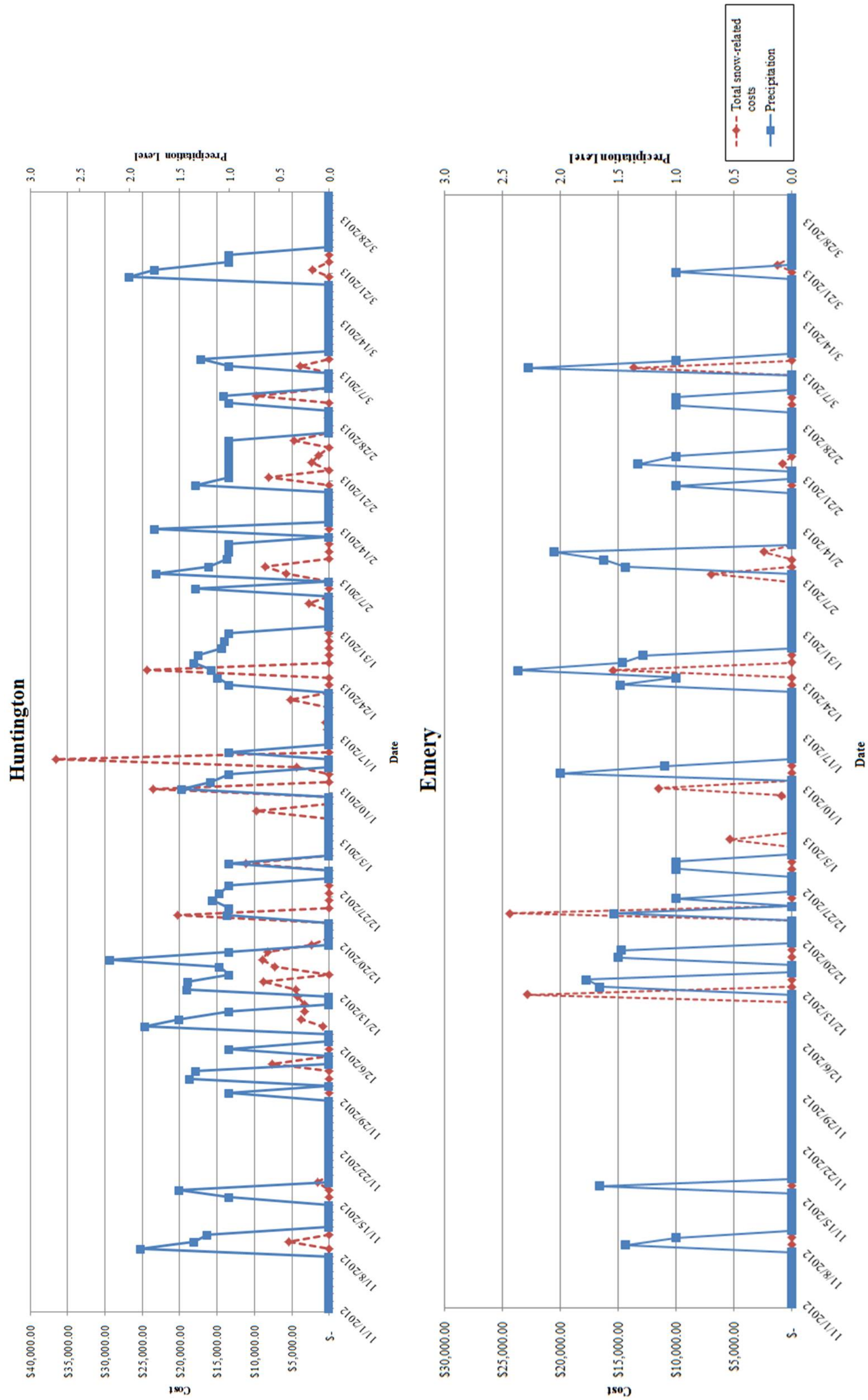

Emery
Cost
Precipitation Level
Date
$16,000.00
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
3.0
2.5
2.0
1.5
1.0
0.5
0.0
11/1/2010
11/8/2010
11/15/2010
11/22/2010
11/29/2010
12/6/2010
12/13/2010
12/20/2010
12/27/2010
1/3/2011
1/10/2011
1/17/2011
1/24/2011
1/31/2011
2/7/2011
2/14/2011
2/21/2011
2/28/2011
3/7/2011
3/14/2011
3/21/2011
3/28/2011
Total snow-related costs
Precipitation



Huntington
Cost
Date
Precipitation Level



Emery
Cost
Date
Precipitation Level
Total snow-related costs
Precipitation


Huntington
Cost
Precipitation Level
Date
Emery
Cost
Precipitation Level
Date
Total snow-related costs
Precipitation