Monitoring Stockpiles of Solid Winter Maintenance Materials

Synthesis Report

research for winter highway maintenance

CTC & Associates LLC

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Disclaimer

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16. Abstract

Finding the right method to take frequent, accurate measurements of stockpiles of solid winter maintenance materials can be challenging for transportation agencies. Measurement practices can be time-consuming or fail to produce measurements that are accurate enough for the agency to rely on. Without accurate measurements of the materials on hand, an agency can face shortages of the solid winter maintenance materials needed to see it through a winter season.

This synthesis sought best management practices for the accurate measurement of solid winter maintenance materials using technology and other measurement methods that are not technology-based. A national survey of state department of transportation winter maintenance experts was used to gather information about their stockpile measurement practices. Results of a literature search supplemented survey findings and provided information about other technologies and practices used to measure stockpiles of solid materials.

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This synthesis used a national survey of state department of transportation (DOT) winter maintenance experts to gather information about best management practices for the accurate measurement of solid winter maintenance materials using technology and other measurement methods that are not technology-based. Results of a literature search supplemented survey findings and provided information about commercial technologies used to measure stockpiles of solid materials.

Survey of Practice

Thirty-seven states provided 40 responses to the survey. Almost all of the responding states measure stockpiles, but most do not take measurements in real time. Seven states, or almost 19 percent of respondents, use technology to gather and process stockpile measurements. Almost three-quarters of respondents measure stockpiles without the use of technology. Only three of the responding states do not measure stockpiles.

A table on page 32 of this synthesis report brings together selected data about all respondents' measurement systems and practices—the number of staff required, the length of time required and frequency for taking measurements, and the accuracy of measurements—to allow for a limited comparison of measurement practices.

Using Technology to Measure Stockpiles

Of the seven states using technology to measure stockpiles, three employ a commercial system and four developed an in-house measurement system.

Commercial Systems

Respondents' use of commercial measurement systems is highlighted below. More information about these products appears in this synthesis report on page 10.

- **Differential GPS (Alaska)**. Alaska Department of Transportation and Public Facilities uses an unnamed differential Global Positioning System (GPS) to take several GPS points around the base of the stockpile and on top of the stockpile. A transit level is used to verify the accuracy of GPS measurements. (Differential GPS uses two cooperating receivers: a stationary receiver and another receiver that roves to make position measurements. One receiver measures timing errors and provides correction information to other roving receivers to eliminate virtually all errors in the system.)
- **Laser positioning system (Idaho)**. Three Idaho Transportation Department respondents described the use of similar laser positioning systems provided by Laser Technology Inc. These systems employ a laser rangefinder, field mapping software, a data collector and other surveying components to take distance and height measurements.

  To gather data, crew members set up control points and collect multiple shots by firing the laser at different points on the stockpile, for example, the bottom ("toe") and edges ("pile") of the stockpile. The crew member traverses to multiple control points to represent the entire surface. Stockpile volume is calculated using a computer image of triangulated points.

- **Handheld LiDAR sensor/scanner (Iowa)**. Iowa DOT uses the ZEB1 handheld LiDAR sensor/scanner provided by Qntfi Inc. to take stockpile measurements. (LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure distance.) A crew member moves on and around the stockpile waving the handheld LiDAR scanner to create a 3-D image of the stockpile. Measurements are uploaded to Quick Terrain Modeler, a software program provided by Applied Imagery, to convert the LiDAR points into stockpile tonnage.

Systems Developed In-House

The four in-house systems developed by respondents are described below. More information about the products used in these systems appears on page 13 of this synthesis report.

- **Track-mounted camera (Delaware)**. A robotic system employs a camera mounted on a track system to measure indoor stockpiles. For outdoor measurements, the camera is mounted on a tall rover pole or drone (an unmanned aerial vehicle). After taking pictures automatically around the stockpile, the agency uploads the pictures to the cloud and employs two Autodesk Inc. software programs to manipulate the data gathered:
    - ReCap 360 creates a surface file by “stitching together” the files created by the camera.
    - The surface file is brought into AutoCAD Civil 3D to calculate a volume.

  Delaware DOT has also used a secondary laser scanning system that performs a 3-D laser scan of indoor and outdoor stockpiles.
- **Survey instruments (Minnesota)**. Unspecified survey instruments are used to complete measurements. A handheld laser measuring device will be purchased and tested to supplement current surveying practices.
- **Laser distance measurer (New York)**. A Bosch off-the-shelf laser distance measurer takes measurements, and an Excel spreadsheet developed in-house is used to record and analyze data. Crew members take distance measurements on the structure covering the stockpile. Additional measurements are taken on the stockpile relative to known points from the structure. The data gathered is entered into an Excel spreadsheet to calculate stockpile volume.
- **Survey instruments (North Dakota)**. GPS survey instruments are used in conjunction with measuring tapes and a survey level to measure and calculate stockpile volume.

Taking Measurements and Processing Data

All respondents measure outdoor and uncovered stockpiles; fewer measure indoor and covered stockpiles. Most respondents take measurements annually or as needed, but none take frequent measurements (weekly or biweekly). Six of the nine respondents use their technology to measure other types of stockpiles of solid materials such as gravel, various types of aggregates and other paving materials.

- **Staff requirements**. All respondents require only one or two staff members to gather and process data. Four respondents—two from Idaho and the Minnesota and New York State DOT respondents—need two staff members for measurement. Three of the nine systems—Idaho’s laser positioning system, Iowa DOT’s handheld LiDAR scanner and New York State DOT’s laser distance measurer—can be used without any specialized expertise. Others require basic computer skills or more advanced surveying or computer-aided design (CAD) skills.

- **Gathering measurements**. Six of the nine respondents require 30 minutes to gather their measurements. The Idaho respondents using the same measurement system reported significantly different measurement times, with two reporting 30 minutes and the third requiring two hours to gather measurements. Only Delaware DOT takes less time—just 15 minutes—to gather measurements with its track-mounted camera system.

- **Processing data**. All respondents need just 15 to 30 minutes to process data. For most respondents, processing data takes the same or less time than the time needed to measure the stockpile. Only Delaware DOT requires more time—15 minutes more—to process data than to gather measurements. For one of the Idaho respondents, the time savings is significant, with data processing taking just 15 minutes after two hours of gathering measurements.

Measurement Accuracy

The survey asked respondents about the accuracy of their measurements as a percentage or range of percentages compared to the actual stockpile. For purposes of this analysis, a completely accurate measurement is 0 percent different than the actual stockpile.

Accuracy estimates ranged from an accuracy of within 1 percent of the actual stockpile in Alaska to within 10 percent of the actual stockpile, which was reported by more than half of respondents. Most respondents indicated that accuracies can vary. The Alaska respondent is an exception, reporting that the agency has consistently produced measurements that are within 1 percent of actual using differential GPS.

System Costs

Initial costs for respondents' systems varied widely, from a high of $40,000 for the GPS unit used statewide in Alaska to a low of $100 for New York State DOT's laser distance measurer. A majority of respondents do not pay ongoing maintenance fees. All respondents store data on agency computers, and none pay annual fees for data usage or storage. Only Delaware DOT pays a periodic fee for data usage—$5 for each volume calculation the agency makes. Iowa DOT paid $2,025 for a two-year warranty for its handheld LiDAR sensor/scanner.

Policies and Procedures

Among the technology users, only Iowa DOT has documented a standard operating procedure for its ZEB1 handheld LiDAR sensor/scanner (see Appendix C). In Alaska, the agency has developed its own best practices for use of differential GPS but has not formalized them.

Successes and Challenges

Most respondents have had success with their measurement systems. The Alaska, Idaho and New York respondents noted that their systems are accurate and efficient, and produce consistent measurements; the North Dakota respondent's GPS surveying method is simple to use. Among the respondents still determining the efficacy of their measurement practices are Delaware DOT, which has used its robotic track-mounted camera system for only one winter season in a single facility, and Iowa and New York State DOTs.

While other respondents cited the accuracy and consistency of the measurements their systems produce, the Iowa, Minnesota and North Dakota respondents voiced concerns about the same issues. Safety is also a concern for agencies that require staff to climb on stockpiles to gather measurements.

Measuring Stockpiles Without Technology

The measurement practices of the 27 states not employing technology to measure stockpiles fall into these categories:

- **Bills of lading or other delivery documents**. Monitoring of the solid winter maintenance material delivered is often used in conjunction with another measurement method to verify quantities.
- **Loader buckets/loader scales**. Loader buckets are counted or weighed to produce an estimate of the material used. One agency uses loader scales.
- **Mathematical calculation**. Applying basic math to the dimensions of the stockpile is one of the most commonly reported measurement practices.
- **Storage shed capacity**. Another common measurement practice is using storage shed capacities or markings to monitor stockpiles. Respondents who reported using this practice may use another method to verify the initial result.
- **Surveying**. Six states use traditional surveying methods to measure stockpiles.
- **Visual observation**. Only one state uses visual observation independent of other factors to assess stockpile volume.

Taking Measurements

All but one respondent measures indoor stockpiles, but only one-quarter of respondents measure uncovered stockpiles. Most respondents take frequent stockpile measurements, with almost 60 percent of respondents taking measurements either weekly or monthly. Several respondents measure stockpiles after every winter event as a matter of course or when storms are frequent. Forty percent of respondents take measurements annually; many of these respondents also take weekly or monthly measurements. Twelve respondents described the other types of stockpiles they measure, including aggregate and chip seal, millings, cold patch material, soil, rock, stone, gravel or riprap, and topsoil.

- **Staff requirements**. A majority of respondents (56 percent) require only one staff member to complete the measurement process; slightly more than one-quarter of respondents require two staff members. Three states—Nebraska, West Virginia and Wyoming—use three staff members to conduct measurements. Two states—New Hampshire and Ohio—use more than three.

  Almost 60 percent of respondents require no specialized expertise to measure stockpiles without the use of technology. For those requiring some level of expertise, math and surveying skills are most often needed.

- **Gathering measurements and completing calculations**. Measuring stockpiles without the use of technology takes little time for most respondents. Almost half of respondents need just 15 minutes; another 46 percent of respondents require 30 minutes to one hour. At two hours, Nebraska Department of Roads and Oregon DOT reported the longest time needed to gather measurements and complete calculations.

Measurement Accuracy

Accuracy estimates ranged widely, from West Virginia DOT's accuracy of within 1 percent of the actual stockpile using traditional survey methods, to Wisconsin DOT's accuracy of within 50 percent of actual, also produced using traditional survey methods. More than half of respondents estimated that their measurements were accurate to within 1 to 10 percent of the actual stockpile. Accuracy does not appear to be related to the measurement practice, with similar practices producing differing levels of accuracy.

Measurement Costs

Only Wyoming DOT reported a specific cost associated with its measurement practice—the agency pays $1,000 per hour for survey crews. Fifteen other respondents noted unspecified labor costs. One respondent noted that travel expenses may be incurred, while another commented on fuel costs for the loader tractor used to manage stockpiles. All other respondents noted that costs were minimal or limited to the labor costs for staff taking the measurements and reconciling inventories.

Policies and Procedures

Like their technology-using counterparts, respondents not using technology to measure stockpiles offered relatively little when asked about formal policies and procedures guiding their measurement practices. California DOT provided a chapter of the agency's maintenance manual that addresses sand and deicer storage but not measurement practices.

Successes and Challenges

Respondents reporting successes with their measurement practices most often cited the accuracy of the measurements. Illinois DOT's use of mathematical calculations in conjunction with storage shed capacity is "simple and fast." In Maryland, the use of loader buckets to monitor stockpiles "can be generally fairly accurate as long as the data of loads out and returned is right."

Most of the respondents' concerns about their nontechnology-based measurement practices are associated with inaccurate reporting and inconsistent practices used to report data. Washington State DOT's surveying practices can be time-consuming, and Pennsylvania DOT indicated that several back-to-back winter events can make it difficult to ensure measurements are taken as needed.

Future Plans

Eight agencies plan to transition to a new technology for stockpile measurement or have expressed interest in making such a change:

- **Drones**. Alaska Department of Transportation and Public Facilities is evaluating drones as a replacement for the agency's current use of differential GPS to measure stockpiles. The agency expects to use drones for stockpile measurement within the next two to three years. West Virginia DOT is considering the use of aerial drones to photograph stockpiles and conduct computer-based volume calculations.
- **Loader scales**. Maryland, Massachusetts and New Jersey DOTs are currently outfitting loaders with loader scales or plan to implement them soon. In Maryland, radio frequency identification (RFID) technology will be used to calculate tonnage; in New Jersey, portable scales will also be used.
- **Mobile application**. Oregon DOT is examining an unspecified stockpile calculator mobile application that can be used with an iPhone.
- **Unnamed technologies**. Colorado DOT will use an unnamed technology to monitor tank and stockpile volumes, beginning with tank monitoring. Washington State DOT is interested in increasing the accuracy of its surveying-based measurement method, following up on a successful but costly small-scale experiment that used LiDAR for stockpile measurement.

Literature Search

To supplement the information gathered from survey respondents, we conducted a literature search to identify similar products and other vendor solutions used to measure stockpiles of solid materials. Vendor solutions included drones, iPhone applications, laser technology, software used to manipulate data, stockpile calculators, and laser and acoustic scanners used as stockpile monitors.

Also highlighted in the literature search section of this synthesis report are publications that describe the commercial stockpile measurement products employed by Ohio and Texas DOTs, two agencies not responding to this project's survey:

- Research reports published in 2014 and 2015 describe the results of Ohio DOT's examination of fixed acoustic and laser scanning stockpile monitoring systems. Researchers recommended using an acoustic laser scanner "as a tool to determine the end-of-season balance and the amount of salt necessary for preseason ordering" rather than using it for daily inventory purposes.
- Stockpile Reports provides the technology used by Texas DOT to measure its stockpiles. This commercial measurement system includes a video capture and uploading application, stockpile volume calculation and web-based reporting. The agency uses an iPhone to take a video of the circumference of a stockpile and then synchronizes the video data with the Stockpile Reports software to produce the calculation.

Conclusion

Almost all of the states responding to this project's survey measure stockpiles of solid winter maintenance materials, and most of them measure without the use of technology. Several of the agencies using technology-based measurement methods are continuing to evaluate the effectiveness of these practices. Measurement takes relatively little time for both types of methods, though agencies measuring without technology tend to take more frequent measurements. Respondents in both groups appear to be relatively satisfied with their current practices, and both types of practices can produce measurements that are within 1 to 10 percent of the actual stockpile.

The survey responses indicate that a range of stockpile measurement practices can produce satisfactory results. This synthesis report gives agencies an opportunity to see how their measurement methods compare to other agencies' practices, and the experiences of early adopters of technology can help other agencies assess available options and the implications of incorporating technology into their stockpile measurement practices.

1 Introduction

Finding the right method to take frequent, accurate measurements of stockpiles of solid winter maintenance materials can be challenging for transportation agencies. Measurement practices can be time-consuming or fail to produce measurements that are accurate enough for the agency to rely on. Without accurate measurements of the materials on hand, an agency can face shortages of the solid winter maintenance materials needed to see it through a winter season.

This synthesis sought best management practices for the accurate measurement of solid winter maintenance materials using technology and other measurement methods that are not technology-based. A national survey of state department of transportation (DOT) winter maintenance experts was used to gather information about their stockpile measurement practices. The results of a literature search supplemented survey findings and provided information about other technologies and practices used to measure stockpiles of solid materials.

2 Survey of Practice

2.1 Overview

An online survey distributed to the primary winter maintenance contacts in all 50 state DOTs gathered information about the use of real-time measurement tools to monitor material usage and agency practices for measuring stockpiles of solid winter maintenance materials. After respondents addressed the use of real-time measurement tools, they were sorted into one of three categories: those that use technology to measure stockpiles, those that measure stockpiles without the use of technology and those that do not measure stockpiles. Respondents in the first two categories then answered questions tailored to their experiences; respondents in the third category completed the survey with no further questions.

Thirty-seven states provided 40 responses to the survey (four Idaho Transportation Department regions provided responses). Almost all of the responding states measure stockpiles. Almost three-quarters of respondents measure stockpiles without the use of technology, with seven states, or almost 19 percent of respondents, using technology to gather and process stockpile measurements. Only three states—Arizona, Kentucky and Mississippi—do not measure stockpiles.

The survey questions are listed in Appendix A; the full text of survey responses is in Appendix B.

The next subsection of this synthesis report addresses all respondents' use of real-time measurement tools. The remaining subsections present the survey responses for two categories of respondents—those that use technology to measure stockpiles and those that measure stockpiles without the use of technology—followed by a brief comparison of all respondents' measurement systems and practices.

2.2 Real-Time Measurement Tools

Respondents were asked about the real-time measurement tools they use to monitor material usage when loading and/or after applying solid winter maintenance materials. While the survey question asked respondents to identify real-time monitoring practices other than the use of readouts from material spreader controllers, several respondents did report on this monitoring practice. Other respondents could be using spreader controller data to monitor real-time material usage but did not report the practice given the way the survey question was phrased.

A majority of respondents do not use a real-time measurement tool. The most commonly reported tools are loader scales and spreader controller data; a few agencies use multiple measurement tools. An examination of all survey results indicated no connection between respondents' use of a real-time measurement tool and the likelihood that they will use technology to measure stockpiles. Table 2.1 presents survey responses.

Table 2.1 Real-Time Measurement Tools

Real-Time Measurement Tool	State
Automatic vehicle location (AVL) technology	Kentucky, Michigan, Minnesota, North Dakota, Wisconsin
Loader bucket counts	Nebraska, Wisconsin
Loader scales	Arizona, Delaware, Kentucky, Michigan, Nebraska, New York, Ohio, Pennsylvania, Wisconsin
Maintenance decision support system (MDSS) technology	Kentucky, Minnesota
Material management/work order systems	Colorado, Idaho, Pennsylvania
Spreader controller data	Idaho, Indiana, Kentucky, Michigan, New York, Pennsylvania, Utah
None	Alaska, California, Connecticut, Illinois, Iowa, Kansas, Maryland, Nebraska, Oklahoma, Oregon, Vermont, Virginia, Washington, Wyoming

2.3 Using Technology to Measure Stockpiles

Nine respondents from seven states use technology to measure stockpiles:

- Alaska
- Delaware
- Idaho 1, 2, 3
- Iowa
- Minnesota
- New York
- North Dakota

Five respondents use a commercial system; four developed an in-house measurement system.

Commercial Systems

The Alaska respondent reported the use of a differential Global Positioning System (GPS) but did not provide details of the system other than noting that a transit level is used to verify the accuracy of GPS measurements. A differential GPS is described in a Trimble Navigation Limited tutorial (see **Related Resources** below):

> Differential GPS involves the cooperation of two receivers, one that's stationary and another that's roving around making position measurements.
>
> The stationary receiver is the key. It ties all the satellite measurements into a solid local reference.

> ….
>
> That's the idea behind differential GPS: We have one receiver measure the timing errors and then provide correction information to the other receivers that are roving around. That way virtually all errors can be eliminated from the system, even the pesky Selective Availability error that the DoD [Department of Defense] puts in on purpose.

The three Idaho Transportation Department respondents use similar systems that employ a laser rangefinder and other surveying components to take distance and height measurements. Iowa DOT uses a handheld LiDAR sensor/scanner to take measurements that are processed using a separate software program to produce volume data. (LiDAR, which stands for *light detection and ranging*, is defined by the National Oceanic and Atmospheric Administration as "a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth"; see http://oceanservice.noaa.gov/facts/lidar.html.)

Table 2.2 provides general information about the commercial systems used by respondents. Additional information about the commercial products appears in **Related Resources** below.

Table 2.2 Commercial Systems Used to Measure Stockpiles

State	Product/Vendor	Additional Equipment Needed	Mobile (Yes/No)	Require Calibration (Yes/No)
Alaska	Differential GPS (product name and vendor not provided). AutoCAD/Autodesk Inc. or other software used to process data.	Traditional survey grade or field transit level to double-check accuracy of the GPS.	Yes	No
Idaho 1	MapStar laser positioning system/Laser Technology Inc.	Laser rangefinder, Bluetooth-enabled data collector and software.	Yes	Yes
Idaho 2	Laser positioning system package: • Trimble Nomad data collector. • MapSmart field mapping software. • MapStar TruAngle angle encoder. • TruPulse laser rangefinder. The last three components are provided by Laser Technology Inc.	Tripod, cones and a tribrach (leveling screws and footplate used to attach a surveying instrument) to improve efficiency and accuracy of equipment. General supplies include tape measures, lath and marking paint.	Yes	Yes
Idaho 3	MapSmart field mapping software/Laser Technology Inc.	Scale to measure unit weight.	Yes	Yes
Iowa	ZEB1 handheld LiDAR sensor/scanner/Qntfi Inc. Quick Terrain Modeler/Applied Imagery (converts salt tonnage using the LiDAR points collected with the ZEB1 scanner).	None.	Yes	Yes

Related Resources

The resources below provide more information about the commercial products used by respondents.

Alaska

"Differential GPS," Trimble GPS Tutorial, Trimble Navigation Limited, 2016.
http://www.trimble.com/gps_tutorial/dgps.aspx
This website describes how differential GPS works and also discusses advanced uses of the concept.

AutoCAD, Autodesk Inc., 2016.
http://www.autodesk.com/products/autocad/overview
This website provides information about the different AutoCAD products available for 2-D and 3-D computer-aided design (CAD). Alaska Department of Transportation and Public Facilities uses this type of software program to process measurements taken with its differential GPS.

Idaho

Stockpile Volumes, Laser Technology Inc., 2016.
http://www.lasertech.com/Stockpile-Volumes.aspx
This vendor website describes the measurement system used by Idaho Transportation Department. A single operator can use the vendor's TruPulse laser rangefinder in conjunction with its MapSmart + Volume software to gather and record data "from a safe distance," and produce volume calculation results in less than an hour. The website also describes the typical stockpile measurement procedure:

1. Walk around the pile, temporarily marking instrument points that will afford full coverage of the surface.
2. Choose a starting point, set up and configure the LTI [Laser Technology Inc.] MapStar system or TruPulse laser with the MapSmart software.
3. Aim and shoot all necessary points on the pile from the starting location.
4. After collecting your last data point, aim and shoot to the next instrument location and then occupy that point.
5. Continue shooting the pile from each new location until the entire surface has been measured.
6. Either transfer your field data to your PC for processing or perform volume calculations right in the field following a few steps found in MapSmart + Volume software.

TruPulse Laser Rangefinder, Laser Technology Inc., 2016.
http://www.lasertech.com/TruPulse-Laser-Rangefinder.aspx
As the vendor describes in this website, with this instrument "you can instantly measure slope distance, inclination and azimuth and calculate horizontal and vertical distance—all with a single push of a button."

MapSmart Field Mapping Software, Laser Technology Inc., 2016.
http://www.lasertech.com/MapSmart-Software.aspx
This product is used to "[c]ollect and store data points electronically and easily transfer them to your PC or view calculations, such as distances between points or the area of multiple points, right in the field."

MapStar TruAngle Angle Encoder, Laser Technology Inc., 2016.
http://www.lasertech.com/MapStar-TruAngle-Angle-Encoder.aspx
This product "precisely calculates a turned horizontal angle that can be referenced to any desired point or direction."

Nomad 900 Series Handheld Computer, Trimble Navigation Limited, 2016.
http://www.trimble.com/Mobile-Computing/Nomad-Product-Page.aspx
The Idaho respondent who reported using a Nomad data collector did not indicate the product series used. This website provides an overview of the Nomad's capabilities to save and transmit data, and to compute location with an integrated GPS receiver.

"How the Idaho Transportation Department Measures Stockpile Volumes," Chase Fly, Electronic Data Solutions, April 27, 2015.
http://www.elecdata.com/blog/how-the-idaho-transportation-department-measures-stockpile-volumes/
From the blog entry:

> Laser Technology has developed a one-man operated stockpile measurement system that won't require you to walk on piles, and you can have an accurate volume of your pile on the spot and on-site. This is the system that the Idaho Transportation Department (ITD) has found to be an effective and efficient tool for the job.
>
> ….
>
> Shooting a pile may take anywhere from 15-45 minutes depending on the size and complexity of the pile. Most salt piles are covered under large canopies which presented a challenge for other methods. These piles are often pushed up against walls and, being under shelter, GPS surveys and flyovers were not viable options. The Laser Technology system works even in these challenging environments.

<u>Iowa</u>

ZEB1 Handheld Laser Scanner, Qntfi Inc., undated. (Qntfi Inc. is an official distributor for GeoSLAM ZEB1 handheld scanner products and software in the eastern United States.)
https://www.qntfii.com/zeb1.html
This vendor website provides information about the ZEB1, a mobile, lightweight handheld laser scanner that automatically creates 3-D point clouds without the need for external positioning data.

Related Resource:

> **ZEB1**, GeoSLAM Ltd, 2016.
> http://geoslam.com/hardware-products/zeb1/
> This website for GeoSLAM, the developer of the ZEB1, provides specifications for the product and a brief description of its use for a variety of applications.

Iowa DOT Deploys GeoSLAM Survey Solutions to Monitor Salt Stockpiles and Improve Service Provision, GeoSLAM Ltd, 2015.
http://geoslam.flodev.co.uk/app/uploads/2015/11/59243-Iowa-lr.pdf
This vendor document includes a description of the ZEB1 tool:

> The ZEB1 is the first truly mobile lightweight hand-held laser scanner which is suitable for use in a number of applications including: mining, forensics, architecture, forestry, stock piles and for rapid visualisation.

> With ZEB1 in hand the user can simply walk through the target survey environment while rapidly recording more than 40,000 measurement points per second without the need for external positioning data such as GNSS [global navigation satellite system]. The ZEB1 works best in feature-rich environments while on the move, so there is typically no need for targets and absolutely no need for a tripod. Once the data has been collected, it can be uploaded to the GeoSLAM Cloud, where SLAM software transforms the survey measurements into a fully registered point cloud. Thereafter, the data can be downloaded (on a pay-as-you-go basis) for use inside all major CAD software. With this finance-friendly business model, the GeoSLAM solution eliminates the need for upfront software costs and annual maintenance charges.

A similar description of the Iowa DOT measuring process is available at http://www.3dlasermapping.com/wp-content/uploads/2015/02/IowaDOT-SuccessStory-19-6-2015-2.pdf.

Quick Terrain Modeler, Applied Imagery, 2015.
http://appliedimagery.com/
Iowa DOT uses this software package to calculate salt tonnage using the LiDAR points collected with the ZEB1 scanner. From the website:

> Quick Terrain Modeler is the world's premier 3D point cloud and terrain visualization software package. Designed for use with LiDAR, but flexible enough to accommodate other 3D data sources, Quick Terrain Modeler provides an easy to use software experience that allows users to work with significantly more data, render larger models, analyze data faster, and export a variety of products. These benefits enable very powerful, yet simple and intuitive, terrain exploitation.

Systems Developed In-House

The four measurement systems developed in-house use cameras, laser distance measurers and survey instruments to take measurements. All systems rely to some degree on commercial products. Table 2.3 describes respondents' in-house measuring systems. Information about the commercial products used by respondents appears in **Related Resources** below.

Table 2.3 In-House Systems Used to Measure Stockpiles

State	Measurement System Description	Mobile (Yes/No)	Require Calibration (Yes/No)
Delaware	**New system (to be expanded next year)**: A robotic system employs a camera mounted on a track system to measure indoor stockpiles. For outdoor measurements, the camera is mounted on a tall rover pole or drone. **Secondary system (used on a more limited basis)**: A laser scanning system (FARO X 330), which is set up at multiple points on a stockpile, performs a 3-D laser scan of indoor and outdoor stockpiles. **Software to process data**: ReCap 360 creates a surface file by "stitching together" the files created by both systems. The surface file is brought into AutoCAD Civil 3D to calculate a volume.	Partially (Camera system can be moved to another site if track or mounting pole is installed.)	No
Minnesota	Unspecified survey instruments are used to complete measurements.	Yes	Yes

State	Measurement System Description	Mobile (Yes/No)	Require Calibration (Yes/No)
	(The agency recently approved the purchase of a handheld laser measuring device—the ZEB1 handheld LiDAR sensor/scanner used by Iowa DOT—which will be tested as an alternative to current surveying practices.)		
New York	A Bosch off-the-shelf laser distance measurer takes measurements, and an Excel spreadsheet developed in-house is used to record and analyze data. (The survey respondent did not identify the specific product used. A publication cited in **Related Resources** below includes a photo of the agency's Bosch laser distance measurer.)	Yes	No
North Dakota	GPS survey instruments are used in conjunction with measuring tapes and a survey level to measure and calculate the volume of stockpiles.	Yes	Yes

Related Resources

The resources below provide more information about the commercial products used in respondents' in-house systems.

Delaware

FARO Focus3D, Laser Scanners X Series—Perfect Instruments for 3D Documentation and Surveying, FARO, undated.
http://www.faro.com/products/3d-surveying/laser-scanner-faro-focus-3d/overview
Delaware DOT uses this laser scanner as a supplemental measuring system.

ReCap 360, Autodesk Inc., 2016.
http://www.autodesk.com/products/recap-360/overview
As the website indicates, this software is used with laser scans and photos to "[c]reate accurate 3D models with reality capture." Delaware DOT uses this software to create a surface file.

AutoCAD Civil 3D, Autodesk Inc., 2016.
http://www.autodesk.com/products/autocad-civil-3d/overview
This website provides information about Civil 3D, a civil engineering design and documentation software used by Delaware DOT to calculate stockpile volumes.

New York

Salt Inventory Laser Measurement System, 2016 GreenLITES Operations Innovation Award, New York State Department of Transportation, 2016.
https://www.dot.ny.gov/programs/greenlites/repository/2016%20Operations%20Innovations%20Award%20Summaries.pdf
Page 1 of this innovation awards summary describes the laser distance measurer used by New York State DOT, including a screen shot of the Excel spreadsheet developed to calculate stockpile volumes and this summary:

Region 6 is utilizing inexpensive laser distance measuring devices to accurately measure bulk salt stockpiles. In the past salt piles were difficult to measure accurately. Rough measurements could result in large stockpile adjustments and a low confidence in the accuracy of stock pile inventory. The rough measurements could lead to locations receiving more salt than the barns could comfortably house. Residency staff is using an off the shelf laser distance measurer and a residency developed spreadsheet to generate very accurate stockpile quantities.

Laser Measuring, Robert Bosch Tool Corporation, undated.
https://www.boschtools.com/us/en/boschtools-ocs/laser-measuring-23502-c/
This website provides information about a range of Bosch laser measuring devices that are similar to the laser measuring device used by New York State DOT.

Measurement Process

Respondents provided varying degrees of detail about their measurement processes (the Minnesota respondent did not provide a description). Table 2.4 presents their responses.

Table 2.4 Description of the Measurement Process

State	Measurement System	Description of the Measurement Process
Alaska	Differential GPS	• Take GPS points around the base of the stockpile and several on top of the stockpile. Measurements are limited to the Northern Region and are not taken in the agency's Central and Southcoast regions.
Delaware	Track-mounted camera	• Take pictures automatically around the stockpile. • Upload pictures to the cloud where a surface file is built using ReCap 360. • Bring the surface file into AutoCAD Civil 3D where a volume is calculated.
Idaho 1	Laser positioning system	• Set up control points; collect multiple shots by firing the laser at different points on the stockpile, for example, the bottom ("toe") and edges ("pile") of the stockpile. • Traverse to multiple control points to represent the entire surface. • Calculate volume using a computer image of triangulated points.
Idaho 2	Laser positioning system	• Set foresight and backsight cones for control points. • Set the instrument to zero degrees on the backsight and begin measuring angles and distances. • Move the instrument to the next control point after measurements are taken on the part of the pile that is visible; backsight the previously occupied point and set the instrument to zero again to continue measuring. • Repeat this process until measurements have been taken of the entire stockpile. • Take a measurement on the original control point and close the survey. • Process data collected on-site and calculate material quantity using Trimble Nomad data collector and MapStar software. • Download data to a computer for storage and compilation.
Idaho 3	Laser positioning system	• Set up cones at points around the stockpile. • Shoot the laser at the toe of the stockpile and at breaks in the stockpile.

State	Measurement System	Description of the Measurement Process
Iowa	Handheld LiDAR sensor/scanner	• Gain access to all sides of the stockpile. • Move on and around the stockpile waving the handheld LiDAR scanner to create a 3-D image of the stockpile and determine the volume. • Upload measurements to Quick Terrain Modeler to convert LiDAR points into stockpile tonnage.
New York	Laser distance measurer	• Take distance measurements on the structure covering the stockpile. • Take measurements on the stockpile relative to known points from the structure. • Enter data into an Excel spreadsheet to calculate stockpile volume.
North Dakota	Survey instruments	• Use measuring tapes and survey level to calculate stockpile size. • Use GPS survey units to calculate stockpile quantity.

Types of Stockpiles Measured

All respondents measure outdoor and uncovered stockpiles; fewer measure indoor and covered stockpiles. Delaware DOT's camera system can be deployed indoors and also measures outdoor stockpiles when the typically track-mounted camera is mounted to a tall rover pole or drone (unmanned aerial vehicle). Table 2.5 presents survey responses.

Table 2.5 Types of Stockpiles Measured (With Technology)

State	Stockpile Type			
	Indoor	Outdoor	Covered	Uncovered
Alaska	X	X	X	X
Delaware	X	X	X	X
Idaho 1	X	X	X	X
Idaho 2	X	X	X	X
Idaho 3	X	X	X	X
Iowa	X	X		X
Minnesota	X	X		X
New York		X	X	X
North Dakota	X	X	X	X

Staff Needed for Measurement

Number of Staff

All respondents require only one or two staff members to gather and process data. Only four respondents—two from Idaho and the Minnesota and New York State DOT respondents—need two staff members for measurement. One of the Idaho respondents noted that it is possible to measure stockpiles with one person, but two people can greatly improve the efficiency and safety of the operation.

Specialized Expertise

Three of the nine systems can be used without any specialized expertise. Others require basic computer skills or more advanced surveying or CAD skills. In Alaska, while knowledge of GPS technology is required to take measurements, a nonsurveyor takes these measurements and feels comfortable with the process after two years of on-the-job practice. In Delaware, gathering data with the agency's in-house system "is something any employee can do. The processing requires very basic CAD knowledge." The Idaho respondents using similar systems reported different types of expertise needed to use those systems. Table 2.6 summarizes the type of expertise needed for respondents' stockpile measurement practices.

Table 2.6 Specialized Expertise Needed for Stockpile Measurement (With Technology)

State	Measurement System	Type of Expertise				
		No Specialized Expertise	Excel	CAD	GPS	Surveying
Commercial						
Alaska	Differential GPS				X	
Idaho 1	Laser positioning system		X			
Idaho 2	Laser positioning system			X		X
Idaho 3	Laser positioning system	X				
Iowa	Handheld LiDAR sensor/scanner	X				
In-House						
Delaware	Track-mounted camera			X		
Minnesota	Survey instruments					X
New York	Laser distance measurer	X				
North Dakota	Survey instruments					X

Taking Measurements and Processing Data

Time Required to Gather Measurements

Six of the nine respondents require 30 minutes to gather measurements. The three Idaho respondents using the same measurement system identified significantly different measurement times, with two respondents reporting 30 minutes and the third requiring two hours to gather measurements. Only Delaware DOT takes less time—just 15 minutes—to gather measurements with its track-mounted camera system.

One of the two Idaho respondents reporting relatively quick data gathering and processing times noted that the region is training multiple teams to use multiple sets of data collection hardware.

Time to Process Data

All respondents need just 15 to 30 minutes to process data. For most respondents, processing data takes the same or less time than the time needed to measure the stockpile. Only Delaware DOT requires more time—15 minutes more—to process data than to gather measurements. For one of the Idaho respondents, the time savings is significant, with data processing taking just 15 minutes after two hours of gathering measurements. Table 2.7 presents the time needed for respondents to gather measurements and process data.

Table 2.7 Time Needed to Complete Stockpile Measurements (With Technology)

State	Measurement System	Time Required to Gather Measurements	Time Required to Process Data
Commercial			
Alaska	Differential GPS	30 minutes	15 minutes
Idaho 1	Laser positioning system	30 minutes	30 minutes
Idaho 2	Laser positioning system	2 hours	15 minutes
Idaho 3	Laser positioning system	30 minutes	30 minutes
Iowa	Handheld LiDAR sensor/scanner	30 minutes	30 minutes
In-House			
Delaware	Track-mounted camera	15 minutes	30 minutes
Minnesota	Survey instruments	30 minutes	30 minutes
New York	Laser distance measurer	1 hour	30 minutes
North Dakota	Survey instruments	30 minutes	30 minutes

Measurement Frequency

Most respondents take measurements annually or as needed. None of the respondents take frequent measurements (weekly or biweekly). Table 2.8 presents survey responses.

Table 2.8 Measurement Frequency (With Technology)

State	Measurement Frequency			
	Monthly	Quarterly	Annually	As Needed
Alaska			X	
Delaware	X			X
Idaho 1			X	
Idaho 2			X	X
Idaho 3			X	
Iowa			X	X

State	Measurement Frequency			
	Monthly	Quarterly	Annually	As Needed
Minnesota				X
New York	X			X
North Dakota		X		

Measurement Accuracy

Respondents were asked about the accuracy of their measurements as a percentage or range of percentages compared to the actual stockpile. For purposes of this discussion, a completely accurate measurement is 0 percent different than the actual stockpile.

Accuracy estimates ranged from an accuracy of within 1 percent of the actual stockpile in Alaska to within 10 percent of the actual stockpile, which was reported by more than half of respondents. Most respondents indicated that accuracies can vary. The Alaska respondent is an exception, reporting that the agency has consistently produced measurements that are within 1 percent of actual. Delaware DOT's 2 percent accuracy was determined by comparing measurements from the agency's camera system with results from the agency's secondary 3-D laser scanning system. One of the Idaho respondents noted that their system is too new to have generated a track record; however, the vendor states that its product produces measurements that are within 10 percent of actual. The Minnesota respondent did not provide an estimate of accuracy. Table 2.9 presents survey responses.

Table 2.9 Measurement Accuracy (With Technology)

Accuracy Range (percent difference from actual)	State	Measurement System	Accuracy (percent difference from actual)
<5%	**Alaska**	Differential GPS	Within 1%
	Delaware	Track-mounted camera	Within 2%
	New York	Laser distance measurer	2 to 3%
	Iowa	Handheld LiDAR sensor/scanner	3 to 10%
5 to 10%	**North Dakota**	Survey instruments	5%
	Idaho 1	Laser positioning system	5 to 10%
	Idaho 3	Laser positioning system	5 to 10% (assumption)
	Idaho 2	Laser positioning system	10% (vendor claim)
	Iowa	Handheld LiDAR sensor/scanner	3 to 10%

System Costs

Initial costs for respondents' systems varied widely, from a high of $40,000 for the GPS used statewide in Alaska to a low of $100 for New York State DOT's laser distance measurer. In North Dakota, the GPS units used to measure stockpiles were purchased for surveying purposes, not specifically to measure stockpiles, and the respondent did not provide costs. The Minnesota respondent also did not provide costs for the agency's survey instruments.

A majority of respondents do not pay ongoing maintenance fees. All respondents store data on agency computers, and none pay annual fees for data usage or storage. Only Delaware DOT pays a periodic fee for data usage—$5 for each volume calculation the agency makes. Table 2.10 summarizes survey responses.

Table 2.10 System Costs (With Technology)

State	Measurement System	Initial Purchase of Hardware and Software	Annual Hardware Maintenance Fees	Annual Software Maintenance Fees	Other Fees
Alaska	Differential GPS	$30,000 to $40,000	$14,400 for both hardware and software*	$14,400 for both hardware and software*	None
Delaware	Track-mounted camera	$5,000 for hardware per site	0**	0	None
Idaho 1	Laser positioning system	$4,000	0	$200 (software license)	Staff time
Idaho 2	Laser positioning system	$4,797 $600 for tripod/tribrach	0	0	None
Idaho 3	Laser positioning system	$8,000	0	0	None
Iowa	Handheld LiDAR sensor/scanner	$23,000	$1,200 for both hardware and software	$1,200 for both hardware and software	$2,025 for two-year warranty
New York	Laser distance measurer	$100	0	0	None

* The State of Alaska pays for the GPS and departments can rent it out for approximately $1,200 per month. This covers all software and hardware maintenance fees.

** The only ongoing hardware cost noted by the respondent is the potential need for a new camera at a cost of $500.

Measuring Other Types of Stockpiles

Six of the nine respondents using technology to measure stockpiles of sand and salt also use that technology to measure other types of stockpiles. These agencies measure gravel, various types of aggregates and other paving materials.

Policies and Procedures

Respondents offered the following when asked about the policies and procedures guiding their stockpile measurement practices:

- In Alaska, the agency has developed its own best practices but has not formalized them. Staff follows industry standards for GPS and guidelines in the agency's survey manual. The 2010

Alaska Survey Manual: GPS Surveys is available here: http://ntl.bts.gov/lib/52000/52600/52608/fhwa_ak_rd_10_11.pdf.

- One of the Idaho respondents mentioned the agency's October 2015 Operations Manual, which includes Section 500.00, Stockpiling (available at http://apps.itd.idaho.gov/apps/manuals/OperationsManual/OperationsSection500.html). Instead of specifying a measurement method, the manual provides this guidance:

    > The District Operations Manager or Designee is responsible for establishing the most accurate method and procedure to determine the physical on-hand balance of a given stockpile.

- Iowa DOT developed a standard operating procedure for use of the ZEB1 handheld LiDAR sensor/scanner and Quick Terrain Modeler, which converts the LiDAR images collected with the ZEB1 scanner to salt tonnage; see Appendix C.

Measurement Successes

Most respondents have had success with their measurement system, as summarized below:

- Accurate (Alaska, Idaho 1, New York).
- More efficient (Idaho 1, Idaho 2).
- Reduced the need to make salt adjustments (Iowa).
- Repeatable (Alaska, Idaho 2).
- Simple to use (North Dakota).

A few respondents are continuing their assessment:

- Delaware DOT's robotic track-mounted camera system, in use for only one winter season in a single facility, is too new to assess. The agency expects to measure stockpiles in multiple installations next year.
- Iowa DOT is still analyzing its handheld LiDAR sensor/scanner.
- In New York, the surveying techniques used are relatively new and used at only a few locations.

Measurement Challenges

The measurement systems also present some challenges for respondents, including:

- Accuracy/consistent measurements (Iowa, Minnesota, North Dakota).
- Safety (Alaska, Delaware (related to the secondary 3-D laser scanning system)).
- Standardization (Idaho 1).

One of the Idaho respondents highlighted a potential challenge that the region has been able to address: Indoor stockpiles require the operator to use innovative methods to move around the pile and shoot backsights to complete the surveying circuit.

Future Plans

Alaska Department of Transportation and Public Facilities is evaluating drones as an alternative to the agency's current use of differential GPS to measure stockpiles. The agency expects to use drones for stockpile measurement within the next two to three years. Minnesota DOT will purchase and test the ZEB1 handheld LiDAR sensor/scanner now in use by Iowa DOT.

2.4 Measuring Stockpiles Without Technology

Twenty-seven states measure stockpiles without the use of technology:

- California
- Colorado
- Connecticut
- Illinois
- Indiana
- Kansas
- Maine
- Maryland
- Massachusetts
- Michigan
- Missouri
- Nebraska
- New Hampshire
- New Jersey
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Dakota
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

Note: Those respondents measuring stockpiles were further sorted into one of two subcategories: agencies using technology to measure stockpiles, and agencies using measurement methods not based on technology. Respondents answered different question sets based on those categories. Agencies using surveying equipment to measure stockpiles appear in this synthesis report in both categories:

- Respondents from Alaska, Minnesota and North Dakota identified their surveying practices as a use of technology to measure stockpiles, and their responses appear in the preceding subsections of this synthesis report.
- Respondents from six other states—Maine, Nebraska, Washington, West Virginia, Wisconsin and Wyoming—identified their use of traditional surveying methods as a nontechnology measurement practice. Their responses appear below.

Measurement Practices

Respondents reported a range of measurement practices that do not employ technology. Several agencies use more than one method, often using one method to verify the accuracy of another. Table 2.11 highlights respondents' measurement practices in these categories:

- **Bills of lading or other delivery documents**. Monitoring of the material delivered is often used in conjunction with another measurement method to verify quantities.
- **Loader buckets/loader scales**. Loader buckets are counted or weighed to produce an estimate of the material used. One agency uses loader scales.
- **Mathematical calculation**. Applying basic math to the dimensions of the stockpile is one of the most commonly reported practices among respondents.

- **Storage shed capacity**. Another common measurement practice is using storage shed capacities or markings to monitor stockpiles. Respondents who reported using this practice may use another method to verify the initial result.
- **Surveying**. Six states use traditional surveying methods to determine stockpile volume.
- **Visual observation**. Only one state uses visual observation independent of other factors to assess stockpile volume.

Table 2.11 Nontechnology Measurement Practices

Measurement Practice	State	Details of Practice	Equipment Used
Bills of lading or other delivery documents	California	Bill of lading used to estimate stockpile if storage shed is empty.	N/A
	Kansas	Inventory report maintained based on the receipts of material less the material used.	N/A
	Maine	All incoming and outgoing amounts tracked and check against measurements.	N/A
	Pennsylvania	Delivery slips used to know how much salt is added to the stockpile.	N/A
	South Dakota	Combination of bills of lading and loader buckets; usage is tracked through an in-house database.	N/A
	Utah	Amount of material in stockpiles estimated by station foremen and compared with amount ordered and amount applied to the roadway.	N/A
Loader buckets/loader scales	Kansas	Loader buckets counted as trucks are loaded.	Loader buckets
	Maryland	Weight measurement taken for each loader bucket at the beginning of the winter season. The agency tallies loads out and returned using loader sheets completed by loader operators.	Loader buckets
	New Jersey	Very rough estimation based on loader buckets sent out in trucks and returned to storage buildings.	Loader buckets
	Oklahoma	Stockpile measurements sometimes verified or checked against load counts.	Loader buckets
	Pennsylvania	Scales built into the loader help track salt loaded onto trucks.	Loader scales
	South Dakota	Combination of bills of lading and loader buckets; usage is tracked through an in-house database.	Loader buckets
Mathematical calculation	Colorado	Height and width measurements taken to calculate volume.	None described
	Connecticut	Unspecified measurements and calculations.	Tape measure
	Illinois	Footprint area and height of stockpile measured to calculate estimated volume/tonnage (if storage shed is not full).	Measuring wheel and tape measure

Measurement Practice	State	Details of Practice	Equipment Used
	Indiana	Unspecified measurements and calculations.	Measuring wheel and sometimes a transit
	Maine	Basic geometry (cylinders, cubes, rectangles and/or triangles) used to approximate volume.	Tape measure and calculator
	Massachusetts	Storage volume = length*width*wall height. Account for shape of pile by multiplying by 1.15 (15%). Multiply volume by 72 lb per cubic foot. Convert to tonnage by dividing by 2,000.	None described
	Missouri	Unspecified measurements and calculations.	None described
	Oregon	Unspecified measurements and calculations.	Tape measure
	Vermont	Tape measure and the dimensions and capacity of the shed used.	Tape measure
	Washington	The pile’s length, width and height measured with a measuring wheel to calculate the volume.	Tape measure, measuring wheel, calculator
Storage shed capacity	California	Graduated marks on the walls correspond to the number of feet from the back wall; material is stacked to a specific height. Calculation determines cubic yards.	100-foot tape measure when necessary
	Colorado	Lines painted on sand shed walls show quantities left in the shed.	None described
	Illinois	Design capacity of the dome used (if dome is full).	None described
	Michigan	Lines on shed walls used to approximate volume. (Some have tried simple distance calculation rangefinders to estimate volumes.)	Distance calculation rangefinder
	New Hampshire	The number of rafters in the storage shed occupied by the stockpile counted.	None described
	Oklahoma	Each stockpile shed/barn has a known capacity. An estimate of percentage is used to determine stockpile size.	Tape measure or rod
	Pennsylvania	Various ways of marking storage bins used to indicate the approximate amount of salt based on height of the stockpile.	Paint marks, sign paddles
	Rhode Island	Visual estimates based on capacity of the storage building.	Measuring wheel and tape measure
	Vermont	Tape measure used with knowledge of the dimensions and capacity of the shed.	Tape measure
	Virginia	Buildings filled to a set height and tonnage marked on walls.	None described
Surveying	Maine	Stockpile surveyed if a more accurate assessment is needed.	Surveying equipment

Measurement Practice	State	Details of Practice	Equipment Used
	Nebraska	Cross section of stockpile determined manually; survey data collector tied into satellite GPS also used.	Surveying equipment (Total Station, auto level and rodman tools)
	Washington	Traditional survey methods.	Surveying equipment (Total Station)
	West Virginia	Cross section of stockpiles taken to calculate volume.	Surveying equipment
	Wisconsin	Traditional survey methods.	Surveying equipment
	Wyoming	Traditional survey methods (engineering crew).	Surveying equipment
Visual observation	Ohio	Visual observations of the stockpile.	None

Types of Stockpiles Measured

While all but one respondent measures indoor stockpiles, only one-quarter of them measure uncovered stockpiles. Two-thirds of respondents measure more than one type of stockpile. Table 2.12 presents survey responses.

Table 2.12 Types of Stockpiles Measured (Other Methods)

State	Stockpile Type			
	Indoor	Outdoor	Covered	Uncovered
California	X			
Colorado	X	X		
Connecticut	X	X	X	
Illinois	X	X		
Indiana	X	X		
Kansas	X		X	
Maine	X	X	X	X
Maryland	X		X	
Massachusetts	X			
Michigan	X			
Missouri	X			
Nebraska	X	X	X	X
New Hampshire	X			
New Jersey	X			
Ohio	X		X	
Oklahoma	X	X	X	
Oregon	X	X	X	X

State	Stockpile Type			
	Indoor	Outdoor	Covered	Uncovered
Pennsylvania	X			
Rhode Island	X	X	X	
South Dakota			X	
Utah	X	X	X	X
Vermont	X			
Virginia	X	X		X
Washington	X	X	X	X
West Virginia	X	X		
Wisconsin	X	X	X	
Wyoming	X	X		X
Total Number of Respondents	**26**	**15**	**13**	**7**

Staff Needed for Measurement

Number of Staff

A majority of respondents (56 percent) require only one staff member to complete the measurement process; slightly more than one-quarter of respondents require two staff members. Three states—Nebraska, West Virginia and Wyoming—use three staff members to conduct measurements, and two states—New Hampshire and Ohio—use more than three.

Specialized Expertise

Almost 60 percent of respondents require no specialized expertise to measure stockpiles without the use of technology. For those requiring some level of expertise, math and surveying skills are most often needed. Table 2.13 summarizes the type of expertise needed to measure stockpiles without the use of technology.

Table 2.13 Specialized Expertise Needed for Stockpile Measurement (Other Methods)

Type of Expertise	State	Comment
Basic mathematics	Colorado, Connecticut, Maine, Michigan, Maryland, Wyoming	N/A
Higher-level mathematics	Connecticut, Vermont, Wyoming	*Connecticut*: Knowledge of basic math and trigonometry functions. *Vermont*: Some basic geometry and area calculation experience. *Wyoming*: Use of math and/or geometry.

Type of Expertise	State	Comment
Spatial skills	Maine, Ohio	Math and spatial skills.
Surveying equipment/ practices	Nebraska, Washington, West Virginia	*Washington*: Familiarity with survey equipment (hand surveys do not require specialized expertise).

Taking Measurements

Time to Gather Measurements

Measuring stockpiles without the use of technology takes little time for most respondents. Almost half of respondents need just 15 minutes; another 46 percent of respondents require 30 minutes to one hour. At two hours, Nebraska Department of Roads and Oregon DOT reported the longest time needed to gather measurements and complete calculations. Table 2.14 summarizes responses.

Table 2.14 Time Needed to Complete Stockpile Measurements (Other Methods)

Time Needed for Measurement	State
15 minutes	California, Connecticut, Illinois, Kansas, Maine, New Jersey, Oklahoma, Pennsylvania, Rhode Island, South Dakota, Vermont, Virginia
30 minutes	Massachusetts, Missouri, New Hampshire, Ohio, Washington, Wisconsin
1 hour	Colorado, Indiana, Maryland, Utah, West Virginia, Wyoming
2 hours	Nebraska, Oregon

Measurement Frequency

Most respondents take frequent stockpile measurements, with almost 60 percent of respondents taking measurements either weekly or monthly. Only 40 percent of respondents take measurements annually; many of these respondents also take weekly or monthly measurements. None take measurements quarterly.

Several respondents measure stockpiles after every winter event as a matter of course or when storms are frequent. Maryland "runs the numbers" and places orders to refill winter maintenance materials after every event. Missouri DOT measures more frequently when there are multiple winter events and when material quantities are running low. New Jersey, Ohio and Utah DOTs measure stockpiles after every winter event; Virginia DOT measures after every major event in addition to the agency's typical weekly measurement. Kansas DOT enters receipts for material delivery every day; usage is reported daily.
In Wisconsin, available materials are estimated through a visual assessment each month; end-of-season assessments can be visual or a more formal measurement. Table 2.15 summarizes the measurement frequency reported by respondents.

Table 2.15 Measurement Frequency (Other Methods)

State	Measurement Frequency			
	Weekly	Biweekly	Monthly	Annually
California			X	
Colorado			X	
Connecticut	X			
Illinois				X
Indiana				X
Maine			X	X
Massachusetts	X		X	X
Michigan		X		
Missouri	X			X
Nebraska				X
New Hampshire	X			
Oklahoma	X			
Oregon				X
Pennsylvania	X			
Rhode Island	X			
South Dakota			X	
Vermont	X			
Washington	X	X		X
West Virginia				X
Wisconsin			X	X
Wyoming				X
Total Number of Respondents	**9**	**2**	**6**	**11**

Measurement Accuracy

The respondents who estimated the accuracy of their measurements took varying approaches in describing that accuracy. To allow for comparison in the table below, some responses have been converted to reflect the difference of a measurement, as a percentage or range of percentages, from the actual stockpile. For purposes of this discussion, a completely accurate measurement is 0 percent different than the actual stockpile.

Accuracy estimates ranged widely, from West Virginia DOT's accuracy of within 1 percent of the actual stockpile using traditional survey methods, to Wisconsin DOT's accuracy of within 50 percent of actual, also produced through the use of traditional survey methods. More than half of respondents estimated that their measurements were accurate to within 1 to 10 percent of the actual stockpile. Accuracy does not appear to be related to the measurement practice, with similar practices producing differing levels of accuracy. Table 2.16 presents measurement practices and the reported and adjusted accuracies.

Table 2.16 Measurement Accuracy (Other Methods)

Accuracy Range (percent difference from actual)	State	Measurement Practice(s)	Reported Accuracy	Adjusted Accuracy (percent difference from actual)
<5%	**West Virginia**	Surveying	Within 1%	1%
5 to 10%	**Indiana**	Mathematical calculation	5%*	5%
	Oregon	Mathematical calculation	5 to 10%	5 to 10%
	Connecticut	Mathematical calculation	90 to 95%	5 to 10%
	Virginia	Storage shed capacity	85 to 95%	5 to 15%
	Kansas	Inventory report/loader buckets	10%	10%
	Maryland	Loader buckets	10%	10%
	South Dakota	Bill of lading/loader buckets	10% (average)	10%
	Massachusetts	Mathematical calculation	90%	10%
	California	Bill of lading/storage shed capacity	90%	10%
	Maine	Bill of lading/mathematical calculation/surveying	±10%	±10%
	Oklahoma	Loader buckets/storage shed capacity	±10%	±10%
15 to 20%	**Virginia**	Storage shed capacity	85 to 95%	5 to 15%
	Missouri	Mathematical calculation	±15%	±15%
	Illinois	Mathematical calculation/ storage shed capacity	85%	15%
	Ohio	Visual observation	15 to 20%	15 to 20%
	Washington	Mathematical calculation/surveying	±20% (at best)	±20%
	Wyoming	Surveying	80%	20%
	Michigan	Storage shed capacity	20% (up to)	20%
25% or more	**Utah**	Delivery document	75%	25%
	New Jersey	Loader buckets	75% (estimate)	25%
	Wisconsin	Surveying	<50% (estimate)	50%

* Measurements are within 5 percent of actual, but inventory can be off by 30 to 40 percent at times.

Measurement Costs

Only Wyoming DOT reported a specific cost associated with its measurement practice—the agency pays $1,000 per hour for survey crews. Fifteen other respondents noted unspecified labor costs. One respondent noted that travel expenses may be incurred, while another commented on fuel costs for the loader tractor used to manage stockpiles. All other respondents noted that costs were minimal or limited to the labor costs for staff taking the measurements and reconciling inventories.

Measuring Other Types of Stockpiles

Solid winter maintenance materials such as sand and salt are just one type of material that transportation agencies typically stockpile and could potentially measure. Twelve respondents described the other types of stockpiles they measure, including aggregate and chip seal, millings, cold patch material, soil, rock, stone, gravel or riprap, and topsoil. In Indiana, measurements may also be taken of dirt and debris accumulated from ditch cleaning, flood cleanup and debris removal.

Policies and Procedures

When asked about the policies and procedures that can guide their measurement practices, respondents offered the following:

- The California DOT respondent provided a chapter of the agency's 2016 Maintenance Manual (Chapter R, Snow and Ice Control) that addresses sand and deicer storage but not measurement practices (see http://www.dot.ca.gov/hq/maint/manual/2016/29_Chap-R_Jan_2016.pdf).
- Indiana DOT requires its winter maintenance managers to calibrate spreaders and download spreader controller usage data. Each season, maintenance areas measure a bucket of material to have a rough idea of the volume of material loaded into each truck. The agency reports actual application quantities and records any unused material returned to stockpiles.
- Oregon DOT has no formal policy, but the agency uses a specific equation to compute stockpile volume (see Appendix D).
- Vermont Agency of Transportation checks and balances salt use using snowplow drivers' estimations and verifies the amounts used in its maintenance management system.

Measurement Successes

Respondents reporting successes with their measurement practices most often cited the accuracy of the measurements. Their comments:

- Connecticut DOT's mathematical calculations provide "pretty consistent accuracy."
- Illinois DOT's use of mathematical calculations in conjunction with storage shed capacity is "simple and fast."
- In Maryland, the use of loader buckets to monitor stockpiles "can be generally fairly accurate as long as the data of loads out and returned is right."
- Virginia DOT's practice of examining storage shed capacity is "cheap and accurate enough for determining the need to reorder," and it is "easy to determine estimated tonnage and accurate enough to determine the quantity used in a storm."
- In Wyoming, stockpile measurements provide the data needed to prepare bid letting documents for the next year's sand and salt.

While the mathematical calculation now used by Oregon DOT appears to be working acceptably well, some in the agency are investigating use of a mobile application that will help calculate stockpile volume. Specifics of the application were not available at the time of publication.

Measurement Challenges

Most of the concerns respondents raised in connection with their measurement practices are associated with inaccurate reporting and inconsistent practices used to report data. Table 2.17 summarizes survey responses.

Table 2.17 Challenges in Measuring Stockpiles (Other Methods)

Challenge	State	Comment
Inaccurate reporting	Colorado, Illinois, Indiana, Kansas, Missouri, Nebraska, New Jersey, Oregon, Utah, Washington, Wisconsin, Wyoming	*Indiana*: Agency has "failed consistently on having an accurate account for what has been used." *Kansas*: Accuracy of loader buckets and differently sized loaders pose a challenge, as does the return of material to the stockpile. *Washington*: Practice "works, but is not accurate or efficient." *Wyoming*: Measurement errors have resulted in stockpiled materials running out during a snow season.
Inconsistency of staff reporting	Maine, Maryland, New Hampshire, Vermont	*Maine*: When staff is not careful with reporting, actual quantities can drift significantly from theoretical quantities. *Vermont*: Challenging to get districts to buy into the importance of validation of salt quantities.
Time-consuming	Washington	N/A
Timing	Pennsylvania	Difficult if there are several back-to-back winter events.
Safety	Michigan	Requiring staff to get on top of the stockpile is a safety concern.
Staffing	Nebraska, Ohio	*Nebraska*: Limited staff. *Ohio*: Determining stockpile volume using visual observation is a difficult skill to teach a new manager.
Stockpile management	California, Massachusetts, Michigan	*California*: Multiple measurements are required for nonuniform stockpiles. *Massachusetts*: Outdoor stockpiles under bridges are difficult to measure. *Michigan*: Irregularities on top of the stockpile are difficult to measure.

Future Plans

Respondents not currently using technology to measure stockpiles were almost evenly split among three options when asked about possible plans to transition to a technology-based measurement practice. Ten states are not contemplating a change (California, Illinois, Kansas, Maine, Oklahoma, Pennsylvania, South Dakota, Vermont, Wisconsin and Wyoming) and another nine states may possibly change (Connecticut, Indiana, Michigan, Missouri, Nebraska, New Hampshire, Ohio, Utah and Virginia). The Ohio respondent noted that if the agency "found an economical process that could accurately measure the volume of material in a covered structure, we would be interested." The agency would expect the measurement practice to produce an accuracy rate "better than 15 percent."

The remaining seven states reported plans or expectations to employ some type of technology in the stockpile measurement process. Table 2.18 summarizes these survey responses.

Table 2.18 Transition to Technology-Based Stockpile Measurement

Type of Technology	State	Plan/Expectation	Reason for Transition	Timing
Drone	**West Virginia**	Considering use of aerial drones to photograph stockpiles and conduct computer-based volume calculations; drone must be usable in enclosed storage shed.	Not provided.	In process
Loader Scales	**Maryland**	Currently outfitting five loaders with loader scales to calculate tonnage using radio frequency identification (RFID) technology.	Environmental and fiscal impacts are driving the change in practice.	Upcoming winter season
	Massachusetts	Planning to implement loader scales.	To increase efficiency.	By 2018
	New Jersey	Will install scales and use portable scales at designated locations; also use loaders with scales built into the bucket.	Need better controls of materials inventory.	Over the next five years
Mobile Application	**Oregon**	Examining a stockpile calculator mobile application that can be used with an iPhone; data sent to a vendor to calculate volume (a paid service).	Not provided.	Early stages of fact-finding
Unnamed Technology	**Colorado**	Using technology to monitor tank volumes and stockpiles, focusing first on tanks.	Real-time data needs.	Next year
	Washington	Interested in increasing accuracy; small-scale experiment with LiDAR successful but costly.	To reduce inaccuracies and provide better reports of inventory.	No timeline

2.5 Comparing Measurement Systems and Practices

Table 2.19 brings together selected data about all respondents' measurement systems and practices—how many staff are required, how long it takes to measure and how often measurements are taken, and the accuracy of measurements—to allow for a comparison among measurement practices that use technology and those that do not.

Table 2.19 Comparing Respondents' Measurement Systems and Practices

State	Measurement System/Practice	Staff Needed for Measurement	Total Time Needed for Measurement*	Measurement Frequency	Adjusted Accuracy (percent difference from actual)
Alaska	Differential GPS	1	45 minutes	Annually	1%
California	Bill of lading/storage shed capacity	1	15 minutes	Monthly	10%
Colorado	Mathematical calculation/storage shed capacity	1	1 hour	Monthly	Not provided
Connecticut	Mathematical calculation	2	15 minutes	Weekly	5 to 10%
Delaware	Track-mounted camera	1	45 minutes	Monthly, as needed	2%
Idaho 1	Laser positioning system	2	1 hour	Annually	5 to 10%
Idaho 2	Laser positioning system	1	2 hours, 15 minutes	Annually, as needed	10%
Idaho 3	Laser positioning system	2	1 hour	Annually	5 to 10%
Illinois	Mathematical calculation/storage shed capacity	2	15 minutes	Annually	15%
Indiana	Mathematical calculation	2	1 hour	Annually	5%**
Iowa	Handheld LiDAR sensor/scanner	1	1 hour	Annually, as needed	3 to 10%
Kansas	Inventory report/loader buckets	1	15 minutes	When receipts entered	10%
Maine	Bill of lading/mathematical calculation/surveying	1	15 minutes	Monthly, annually	±10%
Maryland	Loader buckets	2	1 hour	After every event	10%
Massachusetts	Mathematical calculation	2	30 minutes	Weekly, monthly, annually	10%
Michigan	Storage shed capacity	1	Not provided	Biweekly	20% (up to)
Minnesota	Survey instruments	2	1 hour	As needed	Not provided
Missouri	Mathematical calculation	1	30 minutes	Weekly, annually	±15%
Nebraska	Surveying	3	2 hours	Annually	Not provided
New Hampshire	Storage shed capacity	More than 3	30 minutes	Weekly	Not provided
New Jersey	Loader buckets	1	15 minutes	During and after events	25%
New York	Laser distance measurer	2	1 hour, 30 minutes	Monthly, as needed	2 to 3%

State	Measurement System/Practice	Staff Needed for Measurement	Total Time Needed for Measurement*	Measurement Frequency	Adjusted Accuracy (percent difference from actual)
North Dakota	Survey instruments	1	1 hour	Quarterly	5%
Ohio	Visual observation	More than 3	30 minutes	After events	15 to 20%
Oklahoma	Loader buckets/storage shed capacity	1	15 minutes	Weekly	±10%
Oregon	Mathematical calculation	1	2 hours	Annually	5 to 10%
Pennsylvania	Bill of lading/loader buckets/storage shed capacity	1	15 minutes	Weekly	Not provided
Rhode Island	Storage shed capacity	1	15 minutes	Weekly	Not provided
South Dakota	Bill of lading/loader buckets	1	15 minutes	Monthly	10%
Utah	Delivery document	1	1 hour	After every event	25%
Vermont	Mathematical calculation/ storage shed capacity	1	15 minutes	Weekly	Not provided
Virginia	Storage shed capacity	1	15 minutes	Weekly, after every event	5 to 15%
Washington	Mathematical calculation/surveying	2	30 minutes	Weekly, biweekly, annually	±20% (at best)
West Virginia	Surveying	3	1 hour	Annually	1%
Wisconsin	Surveying	2	30 minutes	Monthly, end of season	<50%
Wyoming	Surveying	3	1 hour	Annually	20%

* Combines data gathering and processing time for technology users.

** Measurements are within 5 percent of actual, but inventory can be off by 30 to 40 percent at times.

3 Literature Search

3.1 Overview

Citations that provide additional information about the products and practices used by respondents to measure stockpiles appear in the previous section of this synthesis report (see **Related Resources** on pages 10 and 13). A literature search identified a sampling of resources describing similar technologies and practices used to measure stockpiles of salt, sand and other solid materials. Results of the literature search are presented below in these topic areas:

- Measurement technologies
  - Drones
  - iPhone applications
  - Laser technology
  - Software
  - Stockpile monitors
- Related resources

3.2 Measurement Technologies

Drones

Alaska Department of Transportation and Public Facilities and West Virginia DOT are considering the use of drones to take stockpile measurements. Cited below are vendors providing drone systems and tools to process aerial data, as well as a vendor's comparison of aerial measurements with those gathered by land-based LiDAR surveys.

Stockpile Volume Measurement, Kespry Inc., 2016.
http://www.kespry.com/stockpile
This website describes how the vendor's drone system is used to measure stockpiles:

> 1. **Fly drone over stockpiles in minutes.** Kespry drones are completely automated, from takeoff to landing. No piloting experience needed. Automatically fly a 150 acre site with 100 stockpiles in less than 30 minutes.
> 2. **Aerial data is automatically uploaded and processed.** Kespry's Cloud Reporting automatically turns stockpile aerials into maps, contours, elevations and 3D models. The Kespry Cloud also makes it easy to share online images and models with teams.
> 3. **Measure stockpiles in less than a minute.** Measure an aggregate stockpile in less than one minute, including the perimeter, area and volume for each stockpile. Whether you're measuring sand stockpiles, rock stockpiles or wood stockpiles, all it takes is a few clicks.
>
> In addition, stockpile density and cost factors can be entered to calculate stockpile weight and value, ideal for stockpile inventory reports. Even odd-shaped stockpiles against walls can be accurately measured with the Kespry Drone System.

DataMapper: Professional Drone Based Mapping and Analytics, DataMapper, 2014.
https://www.datamapper.com/
Used in conjunction with aerial data, this software package "automatically converts aerial data into georeferenced orthomosaics, features a library of on-demand analysis tools, and makes aerial data easy to share."

"Putting Stock in Your Survey: How Accurate is UAV Surveying for Determining Stockpile Volumes?," Bernhard Draeyer and Christoph Strecha, *Geoconnexion International Magazine*, pages 32, 34, February 2014.
https://www.sensefly.com/fileadmin/user_upload/sensefly/releases/Article_UAV_surveying-for_stockpiles-GeoConnexion-Feb-2014.pdf
This article, written by employees of Pix4D, a vendor providing software that converts aerial images into 2-D maps and 3-D models, describes a vendor test that compared images from an unmanned aerial vehicle (UAV) with terrestrial LiDAR scan surveys. From the article's conclusion:

> With UAV photogrammetry, volume calculation based on the method of surface difference is achieved with the accuracy needed to comply with practical surveyor requirements. The overall mean elevation of these surfaces only deviate centimetres from the 'true' surface. This is mainly achieved through the high resolution of the surface models, despite the fact that the single point elevations actually show a variation/noise of up to three times the GSD [ground sample distance]. For the considered application, such an error is marginal but, if required, surveyors can obtain more precise results using either a more adapted camera or by reducing the flight altitude. While traditional surveying methods are still an interesting alternative for small surfaces, UAV photogrammetry is

unmatched in terms of efficiency for surfaces above several hectares all the while producing equivalent accuracy. In addition, using the UAV surveying method not only produces a DSM [digital surface model] but also a geo-referenced, highly detailed orthophoto—an important added-value for stockpile site documentation.

iPhone Applications

Presented below is information about Stockpile Reports, an application that can be used with an iPhone, and Texas DOT's use of this product. Oregon DOT is considering use of an unspecified iPhone application that may be similar to this product.

Stockpile Reports, Stockpile Reports, 2016.
https://www.stockpilereports.com/
This website describes Stockpile Reports as "an image-based stockpile inventory management system powered by a scalable, cloud-based platform. The company processes multiple sources of data including aerial, drone, and iPhone imagery, enabling the enterprise to measure multiple stockpiles, at all locations safely—from the ground or the air."

Related Resources:

"Stockpile Measurement Project: Improving Processes with Technology," Mark Bradshaw and Tim Wright, Texas Department of Transportation, *North Central Texas Council of Governments Regional GIS Meeting*, December 2015.
http://gis.dfwinfo.com/presentations/StockpileMeasurement.pdf
This presentation describes the Stockpile Reports technology Texas DOT uses to measure its stockpiles as providing "software as a service, video capture and uploading application, stockpile volume calculation, and web-based reporting." Phase 1 of the project, which began in the summer of 2014, produced ±2% accuracy on stockpiles of 100 cubic yards or less. The measurement practice was fully implemented in January 2015.

"Stockpile Measurement Pilot Project: Project Results and Expected Benefits," Texas Department of Transportation, *2015 Materials and Construction Spring Meeting*, Western Association of State Highway and Transportation Officials, March 2015.
http://www.washto.org/pdf/matcon/spring2015/20--MBradshaw--iphone-stockpile-volumeWASHTO%20presentation_03242015[2].pdf
This conference presentation provides details of the pilot project Texas DOT undertook to test the Stockpile Reports product. This presentation describes how the tool is used:

- Set cones in front of the stockpile at a known distance apart.
- Using an iPhone, take a video of the circumference of the stockpile, keeping the top and bottom of the stockpile in the viewfinder.
- Start at one traffic cone and slightly overlap with the starting point.
- Synchronize the video data with Stockpile Reports.

Among the benefits of the tool:

- Requires no additional equipment investment.
- Eliminates climbing on stockpiles.

- Provides same accuracy as GPS at greatly reduced cost.
- Provides management visibility of stockpiled inventory.
- Provides more accurate performance measurement data.

Nomination of Technology Ready for Implementation, Texas Department of Transportation, AASHTO Innovation Initiative, undated.
http://web.transportation.org/tig_solicitation/uploads/AII-nomination-form_Procurement_Div_Stockpile_Reports.docx
This application by Texas DOT for AASHTO's Innovation Initiative provides more detail about the agency's use of Stockpile Reports to measure stockpiles and its benefits, including cost savings.

Laser Technology

The vendors cited below provide tools and technology that are similar to the measuring systems used by Idaho Transportation Department.

Advantage Laser, MPH Industries, undated.
http://www.mphindustries.com/advantage-stockpile-system/
From the website:

> Typical stockpile measurement systems do not account for surface irregularities that occur in pile slumping. The Advantage Laser can complete an entire surface reading, mapping the shape of the stockpile accurately, resulting in accurate inventory valuations. Advantage enables one operator to gather full and precise measurements of your tailing or stock piles in much less time than conventional methods.

I-Site: Laser Scanning for Stockpiles, Case Study, Maptek Pty Ltd, 2009.
http://www.maptek.com/products/i-site/case_studies/stockpiles.html
Marketed as a tool to measure stockpiles of materials at mining sites, the I-Site generates 3-D models and volumes for both indoor and outdoor stockpiles. The benefits of this tool are described in this case study:

- Laser scanning gives a far more detailed model of the surface than other methods, providing greater accuracy.
- Safety benefits—remote measurement means no need to physically access the stockpile.
- Efficient processing produces final results with a rapid turnaround.
- Measure material samples of a known weight to accurately calculate material density.

"Measuring Stockpile Volumes…the Easy Way," Jon Aschenbach, Resource Supply, LLC, *Timber Measurement Society Meeting*, October 2008.
http://www.timbermeasure.com/Reno/jon-aschenbach2.pdf
This meeting presentation examines alternatives to measure timber-related stockpiles, compares two laser rangefinders and presents a procedure to measure stockpiles. The presentation also highlights key points to remember when taking measurements, and concludes that both products tested are cost-effective and superior to the use of LiDAR, flyovers and GPS.

Software

The software described below is used to convert images taken using a variety of tools, including drones. Respondents are using similar tools to determine stockpile volumes.

Pix4Dmapper Pro, Pix4D SA, undated.
https://pix4d.com/
From the website:

> Pix4Dmapper software automatically converts images taken by hand, by drone or by plane, and delivers highly precise, georeferenced 2D maps and 3D models. They're customizable, timely, and complement a wide range of applications and software.

Stockpile Monitors

The products cited below offer a fixed monitoring solution to measure stockpiles.

VM3D Volumetric Laser Scanner, ABB, 2016.
http://new.abb.com/products/measurement-products/level/laser-level-transmitters/vm3d
From the website:

> This 3D volumetric scanner system measures the volume of material stockpiles stored out in the open or in large structures like silos, bunkers, domes and sheds for the following applications:
>
> - Mining—for ore stockpiles, particularly for expensive metals like gold, silver and platinum.
> - Fertilizers—for granular type fertilizers; potash, urea...
> - Food and agriculture—sugar, grains...
> - Coal bunkers at power plants.
> - Other bulk chemicals.
>
> By integrating accurate laser technology into a network of scanning instruments, complex surfaces can be mapped accurately.
>
> The system makes use of remote monitoring and data processing services to guarantee data integrity to the level needed for confident stock management and precise auditing.

SiteMonitorSV, 3D Laser Mapping, 2016.
http://www.3dlasermapping.com/sitemonitor-sv/
From the website:

> **Stock control at your fingertips with SiteMonitorSV**
> SiteMonitorSV is a fully automated inventory management system. With rapidly communicating sensors working together to display information via automated reports in both graphical and Excel formats, decision making is made easy with the use of SiteMonitorSV.
>
> **How it works**
> SiteMonitorSV is a customisable solution, based on a system of laser scanners, control boxes and software packages. The number of laser scanners and their placement can vary from customer to customer in order to achieve the best results for each particular site.
>
> Stockpiles are scanned at customisable, regular intervals, gaining volume and tonnage data that can then be analysed and managed daily using the software packages installed.

3DLevelScanner: Bulk Solids Measurement, APM Automation Solutions, MeasureRite Inc., 2016.
http://www.measureriteinc.com/3d.htm
From the website:

> The 3DLevelScanner measures volume, while all other available technologies measure level at a single point.
>
> As a result, the best volume accuracy that can be hoped for with them is 10 to 15%, while the 3DLevelScanner provides a typical volume accuracy of 1 – 2%.
>
> Knowing the actual inventory enables more efficient plant operation than was not previously possible. This increased efficiency can save you money many different ways.
>
> Using revolutionary technology, the 3DLevelScanner measures and maps the entire surface area of the material, even surface irregularities that typically occur in large silos or open bins. Employing a low frequency pulse signal, it readily "penetrates" dust and moisture often encountered in industrial environments. The 3DLevelScanner accurately measures the volume, level and weight, enabling an unrivaled degree of process measurement and inventory control.

3.3 Related Resources

Cited below are a salt storage handbook offering information about space requirements for stockpiles, and publications associated with an Ohio DOT research study that examined fixed acoustic and laser scanning stockpile monitoring systems.

Salt Storage Handbook: Practical Recommendations for Storing and Handling Deicing Salt, Salt Institute, 2015.
http://www.saltinstitute.org/wp-content/uploads/2013/09/Salt-Storage-Handbook-2015.pdf
Page 6 of this handbook (page 10 of the PDF) offers information about storing salt and space requirements for stockpiles.

Optimization of Salt Storage for County Garage Facilities, Ken Walsh, Gayle Mitchell and Wallace Richardson, Ohio Department of Transportation, Interim Report, April 2014.
http://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Reports/InterimReports/134824_Phase%20I%20Interim%20Report.pdf
The goals for Phase 1 of this project were to identify practices and site modifications that can improve salt loading, storage and inventory at Ohio DOT salt storage facilities. Phase 2 will analyze results of the Phase 1 strategies implemented. As part of their Phase 1 analysis, researchers considered methods to measure stockpile volume, and noted that a "thorough search of the state-of-the practice in stockpile measurement concluded with two different volume-measuring technologies: laser and acoustic scanners." A discussion of these technologies begins on page 56 of the report (page 57 of the PDF).

Ohio DOT selected the BinMaster acoustic scanner system for Phase 2 evaluation. Reasons for selecting the acoustic system over a laser system include faster scanning time, reduced cost and reduced required maintenance. Total cost for the BinMaster system was $47,500.

Related Resources:

Optimization of Salt Storage for County Garage Facilities, Ken Walsh, Gayle Mitchell and Wallace Richardson, Ohio Department of Transportation, Final Report, May 2015.
http://www.bv.transports.gouv.qc.ca/mono/1173207.pdf
Researchers reported on limited success with the acoustic laser scanner tested in Phase 2 of this project. Page 63 of the report (page 65 of the PDF) describes results:

> In general, the system was shown to track the salt use at the Riveredge garage over the course of the data collection period. However, the natural fluctuations in the daily volume readings, combined with the measurement errors observed during frequent salt usage, should be considered when using the acoustic scanner system for daily inventory purposes where a high level of accuracy is desired for the purpose of predicting salt levels, and placing timely salt orders. As a result, it is recommended that the system be used in combination with some other inventory method, such as visual estimates.

Researchers also recommended use of the system "as a tool to determine the end-of-season balance and the amount of salt necessary for preseason ordering."

BinMaster RL: Acoustic Level Scanner, Garner Industries Inc., 2013.
http://www.binmaster.com/_resources/dyn/files/1110551z1241bb00/_fn/3DLevelScannner_RL_Oct2013.pdf
This brochure describes an acoustic scanning system that may be similar to the BinMaster system tested by Ohio DOT in the research study described above.

Appendix A
Survey Questions

The following survey was distributed to the primary winter maintenance contacts in all 50 state DOTs to gather information for this synthesis report. See Appendix B for the full text of survey responses.

Real-Time Measurement

Please describe any real-time measurement tools you're using to monitor material usage when loading and/or after applying solid winter maintenance materials. These could be snowplow truck add-ons (other than readouts from material spreader controls), scales or other equipment installed in winter maintenance facilities.

Measuring Stockpiles

Is your agency using a specific technology or device to measure stockpiles of solid winter maintenance materials?

- Yes.
- No, but we do measure stockpiles without the use of technology.
- No, we do not measure stockpiles.

Technology Used to Measure Stockpiles

1. What type of technology or device are you using?
2. What is the name of the product and vendor?

   Have you found that additional equipment beyond that provided by the vendor is needed to complete the measurement process?
3. Please describe the hardware and software used for stockpile measurement and processing of data. ("Processing of data" refers to converting data collected in the field into the volume of a stockpile.)
4. Is the hardware mobile so that it can be taken to different stockpile sites to take measurements?
5. Does the hardware require calibration?
6. What type of stockpiles can be measured with the technology or device you're using? Check all that apply.
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
   - Other (please describe).
7. How many staff members are required to gather and process data?
8. What type of expertise is needed to gather and process data? Check all that apply.
   - No specialized expertise.
   - CAD.
   - GIS.
   - Surveying.
   - Other (please describe).
9. Please describe the measurement process, including the processing of data collected in the field.
10. Approximately how long does it take to gather stockpile measurements in the field?

Appendix A
Survey Questions

11. Approximately how long does it take to complete processing of the data gathered in the field?
12. Have you identified any methods to expedite the processing of the data collected in the field?
13. How often do you take measurements? Check all that apply.
    - Weekly.
    - Biweekly.
    - Monthly.
    - Quarterly.
    - Annually.
    - Other (please describe).
14. How is measurement data stored?
15. How accurate are the measurements taken with your vendor product or in-house system as compared to actual inventories? Please provide a percentage or range of percentages. (For example, a vendor may state that a system, when properly used, can measure the volume of a stockpile to within 2-10% of actual.)
16. Please indicate your monitoring system's costs below, if applicable.
    - Initial purchase of hardware and software.
    - Annual fees for data usage and/or storage.
    - Periodic fees for data usage and/or storage.
    - Annual hardware maintenance fees.
    - Annual software maintenance fees.
    - Other costs (please describe and quantify the costs).
17. Are you using your stockpile measurement practice to measure stockpiles of other types of solid materials (for example, aggregate or gravel)?
18. Do you have any formal or informal policies or other documents that guide your stockpile measurement practices? Please provide a link below or send any file not available online to Chris Kline at chris.kline@ctcandassociates.com.
19. What successes have you experienced with the technology you use to monitor stockpiles of solid winter maintenance materials?
20. What challenges have you experienced with the technology you use to monitor stockpiles of solid winter maintenance materials?
21. Please use this space to provide any comments or additional information about your answers above.

Other Methods Used to Measure Stockpiles

1. Please describe the method you use to measure stockpiles of solid winter maintenance materials.

   Please describe any equipment you use to complete the measurement process.
2. What type of stockpiles do you measure with this method? Check all that apply.
    - Indoor.
    - Outdoor.
    - Covered.
    - Uncovered.

Appendix A
Survey Questions

- Other (please describe).

3. How many staff members are required to complete the measurement process?
4. Does your measurement process require any specialized expertise?
5. Approximately how long does it take to complete the measurement?
6. How often do you take measurements? Check all that apply.
    - Weekly.
    - Biweekly.
    - Monthly.
    - Quarterly.
    - Annually.
    - Other (please describe).
7. How accurate are the measurements taken with your method as compared to actual inventories? Please provide a percentage or range of percentages.
8. Please describe any costs associated with your measurement method.
9. Are you using your stockpile measurement practice to measure stockpiles of other types of solid materials (for example, aggregate or gravel)?
10. Do you have any formal or informal policies or other documents that guide your stockpile measurement practices? Please provide a link below or send any file not available online to Chris Kline at chris.kline@ctcandassociates.com.
11. What successes have you experienced with your practices to monitor stockpiles of solid winter maintenance materials?
12. What challenges have you experienced with your practices to monitor stockpiles of solid winter maintenance materials?
13. Do you have any plans to transition from your current method to the use of technology to measure stockpiles?
14. Please describe your plans to use technology to measure stockpiles, including the vendor(s) and product(s) you're considering.
15. What is prompting you to make this change in measurement practices?
16. When do you expect to implement the new measurement practice?
17. Please use this space to provide any comments or additional information about your answers above.

Appendix B
Survey Results

The full text of survey responses is provided below. For reference, an abbreviated version of each question is included before the response. The full question text appears in Appendix A. Sections of the survey and specific questions have been omitted if not relevant to the respondent or the respondent elected to skip that section or question.

For the most part, additional information about vendor products mentioned in survey responses appears in the body of this synthesis report; see **Related Resources** on pages 10 and 13.

Survey responses are organized in three categories:

- States using technology to measure stockpiles.
- States using other methods to measure stockpiles.
- States not measuring stockpiles.

States Using Technology to Measure Stockpiles

Alaska

Contact: Todd Hanley, Heavy Equipment Training Coordinator, Alaska Department of Transportation and Public Facilities, 907-269-5613, todd.hanley@alaska.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None at this time.

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Commercial product.
2. **Name of product/vendor:** GPS [Global Positioning System] differential. Not sure of the vendor at this time.

   Additional equipment needed? Yes. Just to double-check the accuracy of the GPS, we have used the traditional survey grade or field light transit level.
3. **Description of hardware and software:** AutoCAD or the GPS software.
4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** No.
6. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
7. **Number of staff members required to gather and process data:** 1.
8. **Expertise needed to gather and process data:** A nonsurveyor has been doing these measurements so he self-taught himself to use the GPS. He was comfortable after two years of

experience.

9. **Description of measurement process:** You have to take GPS points around the base of the stockpile as well as several up on the pile. This requires climbing up the stockpile to get the readings.
10. **Time required to gather stockpile measurements:** 30 minutes.
11. **Time required to process data:** 15 minutes.
12. **Method(s) to expedite data processing?** Yes. We are doing some research about using drones (UAVs) [unmanned aerial vehicles]. Probably within 2-3 years this will be our new method to measure stockpiles.
13. **Frequency of measurements:** Annually.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** This has been within 1%. Repeatable. It stays the same each time so pretty accurate.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** $30-$40,000.
    - **Annual fees for data usage and/or storage:** 0.
    - **Periodic fees for data usage and/or storage:** 0.
    - **Annual hardware maintenance fees:** $1,200 per month.
    - **Annual software maintenance fees:** 0.
    - **Other costs:** The state of Alaska pays for the GPS and then the specific department rents it out for around $1,200 a month. This would cover all the software and hardware maintenance fees also.
17. **Using measurement practice for other types of solid materials?** Yes; sand, salt, riprap, D-1 [aggregate], soil.
18. **Formal or informal policies or documents?** We have made our own best management practices but nothing is formalized. We follow the industry standard for GPS use along with survey maintenance manual guidelines. [The 2010 Alaska Survey Manual: GPS Surveys is available here: http://ntl.bts.gov/lib/52000/52600/52608/fhwa_ak_rd_10_11.pdf.] These measurements are only being used in the Northern Region and not in the Central or Southcoast regions.
19. **Successes:** This process has been very accurate for us and repeatable. We can do the measurements three different days and come up with the same results.
20. **Challenges:** Climbing up the stockpiles can be difficult and dangerous at times.
21. **Comments or additional information:** As I mentioned, we are leaning towards using drones and anticipate this being the new method within 2-3 years.

Appendix B
Survey Results

Delaware

Contact: Alastair Probert, District Engineer, Delaware Department of Transportation, 302-853-1305, alastair.probert@state.de.us.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Loader scales.

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Measurement system developed in-house.
3. **Description of hardware and software:** Use a camera mounted on a track system inside our salt buildings. Software used to process the images is ReCap and Civil 3D. Hardware is partially mobile in that the camera system can be moved site to site provided the track is already installed.
4. **Hardware mobile?** Partially (see above).
5. **Hardware require calibration?** No.
6. **Stockpile types that can be measured:**
    - Indoor.
    - Outdoor.
    - Covered.
    - Uncovered.

   The same camera system can be deployed outside; however, it wouldn't be track-mounted. It is mounted on either a tall rover pole or on a drone.
7. **Number of staff members required to gather and process data:** 1.
8. **Expertise needed to gather and process data:** CAD [computer-aided design]. The gathering of data is something any employee can do. The processing requires very basic CAD knowledge.
9. **Description of measurement process:** Pictures are taken automatically around the stockpile. Pictures are uploaded to the cloud where a surface file is built. The surface file is then brought into CAD where a volume is calculated.
10. **Time required to gather stockpile measurements:** 15 minutes.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Monthly, or when additional info is needed.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** When compared with a full 3-D laser scanning system, the error was within 2%.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** $5,000 for hardware per site.
    - **Periodic fees for data usage and/or storage:** $5/volume calculation.
    - **Annual hardware maintenance fees:** $500 (haven't had to change anything yet, but that

would be cost for a new camera).

17. **Using measurement practice for other types of solid materials?** Yes, sand, various types of stone.

19. **Successes:** Have only done i[t] for one winter so far and in one facility with the track system. There will be multiple installations next year. The laser system has been done in multiple facilities so far but has safety issues.

Follow-Up Contact:

The survey respondent provided the following in response to a follow-up contact to obtain information about the laser system referenced in his survey responses:

> The laser system is a FARO X 330, which we set up at multiple points on the salt stockpile and perform a 3-D laser scan of the stockpile inside [or] outside the building. We take all of the files that are created and stitch them together automatically using ReCap which creates a surface file.
>
> I then bring in the surface file into Civil 3D and calculate a volume.
>
> This is different than the robot I have which runs around on a track and takes pictures. Once the pictures are taken, it is the same process as the laser scanner as far as software and processing is concerned.

Idaho 1

Contact: Walter Burnside, District Operations Manager, Idaho Transportation Department, 208-886-7805, walter.burnside@itd.idaho.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None. We receive salt under contract delivered with weight ticket on invoice. We do complete an annual true-up of sanding materials stockpiles. Anti-skid materials, mixed salt and anti-skid and straight salt are measured annually for inventory at end of FY [fiscal year] using laser technology and computer triangulation to determine volume, which is converted to weight. We use Cirus controllers and WARS program [the agency's Winter Automated Reporting System] to determine what is coming out of the back of the trucks. [See http://www.ciruscontrols.com/ for information about Cirus controllers.]

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Commercial product.
2. **Name of product/vendor:** MapStar by Laser Technology.

   Additional equipment needed? Yes. Laser rangefinder and Bluetooth-enabled collector for a tablet and the software.
3. **Description of hardware and software:** MapSmart software [field mapping software].
4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** Yes.
6. **Stockpile types that can be measured:**

- Indoor.
- Outdoor.
- Covered.
- Uncovered.
- Material sources (pits).

7. **Number of staff members required to gather and process data:** 2.
8. **Expertise needed to gather and process data:** Computer knowledge like Excel.
9. **Description of measurement process:** Set up control points, take toe shoots, pile shoot and project base shots. Traverse to multiple control point[s] to get entire surface represented. Calculate volumes with computer program print image of triangulated points and volume output.
10. **Time required to gather stockpile measurements:** 30 minutes.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** Yes. Training multiple teams and having multiple set[s] of data collection hardware so many sites can be done quickly.
13. **Frequency of measurements:** Annually.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** 5-10%.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** $4,000.
    - **Annual fees for data usage and/or storage:** 0.
    - **Periodic fees for data usage and/or storage:** 0.
    - **Annual hardware maintenance fees:** 0.
    - **Annual software maintenance fees:** $200 software license.
    - **Other costs:** Staff time.
17. **Using measurement practice for other types of solid materials?** Yes, anti-skid, mixed piles, salt, aggregates.
18. **Formal or informal policies or documents?** ITD operations manual—minimal. [Section 500.00, Stockpiling, of the October 2015 Operations Manual is available at http://apps.itd.idaho.gov/apps/manuals/OperationsManual/OperationsSection500.html.]
19. **Successes:** Adopted for system of choice, savings in labor cost and increase in accuracy.
20. **Challenges:** Standardization statewide.

Idaho 2

Contact: Jeremy Gough, Materials Source Manager, Idaho Transportation Department, 208-239-3318, jeremy.gough@itd.idaho.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Truck-mounted Cirus controller monitors amount of materials distributed per mile.

Appendix B
Survey Results

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Commercial product.
2. **Name of product/vendor:** Stockpile measurement package from Resource Supply in Tigard, Oregon. Uses a Trimble Nomad data collector, MapSmart software, MapStar TruAngle angle encoder and a TruPulse laser rangefinder.

   Additional equipment needed? Yes. We had to buy a tripod, cones and a tribrach [an attachment plate used to affix a surveying instrument] to improve the efficiency and accuracy of this equipment. We also used general supplies like tape measures, lath and marking paint.
3. **Description of hardware and software:** The Trimble Nomad data collector and MapStar software process all of the data collected on site. I will download the data to a computer for storage and compilation.
4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** Yes.
6. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
7. **Number of staff members required to gather and process data:** 1.
8. **Expertise needed to gather and process data:** CAD and surveying. Survey methods need to be employed in the use of this equipment.
9. **Description of measurement process:** Set foresight and backsight cones for control points. Set the machine to zero degrees on the backsight and begin measuring angles and distances. Once you have measurements on the part of the pile that is visible, you move the machine to the next control point and backsight the previously occupied point and set the machine to zero again, then continue measuring. Repeat this process until you have covered the entire pile with measurements, and then you take a measurement on your original control point and close the survey. Then while on site the data collector is capable [of] process[ing] the data and calculat[ing] the quantity of material.
10. **Time required to gather stockpile measurements:** Two hours.
11. **Time required to process data:** 15 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Annually and as requested.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** The vendor states a 10% accuracy when used properly. This is the first year in use so we don’t have any history to compare it to.
16. **Monitoring system’s costs:**
    - **Initial purchase of hardware and software:** $4,797.00 plus about $600 for the tripod and tribrach.

- **Annual fees for data usage and/or storage:** None.
- **Periodic fees for data usage and/or storage:** None.
- **Annual hardware maintenance fees:** None.
- **Annual software maintenance fees:** None.
- **Other costs:** None.

17. **Using measurement practice for other types of solid materials?** Yes, gravels.
18. **Formal or informal policies or documents?** I will email a document.
19. **Successes:** We measured all stockpiles in a timely and consistent method.
20. **Challenges:** Piles inside buildings require the operator to use innovative methods to move around the pile and shoot backsights to complete the circuit. However, I have been able to measure each pile that our district has outdoors, under shelters or in sheds. We haven't encountered any stockpiles that we haven't been able to measure.
21. **Comments or additional information:** While it is possible to measure piles with one person, two people can greatly improve the efficiency and safety of the operation.

Idaho 3

Contact: Michael Garz, Operations Manager, Idaho Transportation Department, 208-334-8347, michael.garz@itd.idaho.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: ITD uses the controller to measure the usage. The trucks are calibrated about monthly.

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Commercial product.
2. **Name of product/vendor:** MapSmart v3.X by Laser Technology.

   Additional equipment needed? Yes. In the survey process we take a scale to measure unit weight.
3. **Description of hardware and software:** The unit does the calc[ulation].
6. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
7. **Number of staff members required to gather and process data:** 2.
8. **Expertise needed to gather and process data:** No specialized expertise.
9. **Description of measurement process:** Cones are set up at points around the stockpile and then

the laser is shot at the toe of the stockpile and the breaks in the stockpile.

10. **Time required to gather stockpile measurements:** 30 minutes.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Annually.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** Unknown, but would assume it is in the 5-10 percent range.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** $8,000.
    - **Annual fees for data usage and/or storage:** 0.
    - **Periodic fees for data usage and/or storage:** 0.
    - **Annual hardware maintenance fees:** 0.
    - **Annual software maintenance fees:** 0.
    - **Other costs:** 0.
18. **Formal or informal policies or documents?** ITD has a formal policy.

Iowa

Contact: Craig Bargfrede, Winter Operations Administrator, Iowa Department of Transportation, 515-290-2713, craig.bargfrede@dot.iowa.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None at this time.

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Commercial product.
2. **Name of product/vendor:** We are using a handheld LiDAR system called the ZEB1 from Qntfi Inc.

   Additional equipment needed? No.
3. **Description of hardware and software:** The LiDAR system creates a 3-D image of the stockpile and gives us a volume. The vendor provided a software package that is loaded on a couple of our computers here that we then upload the measurements to. This is what we then use to convert the volume into stockpile tonnage.
4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** Yes.
6. **Stockpile types that can be measured:**
    - Indoor.
    - Outdoor.

- Uncovered.

7. **Number of staff members required to gather and process data:** 1.
8. **Expertise needed to gather and process data:** No specialized expertise.
9. **Description of measurement process:** The person gathering the data must have access to all sides of the pile. They then move on/around the pile waving the handheld LiDAR which then creates a 3-D image of the stockpile. This information is then used to convert from a volume to tonnage.
10. **Time required to gather stockpile measurements:** 30 minutes.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Annually. We have been testing this method for measuring stockpiles for one year now. At this time we have done this annually but could potentially do this on an as-needed basis.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** We have seen a range of 3-10%.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** $23,000.
    - **Annual hardware maintenance fees:** $1,200 for both HW [hardware] and SW [software].
    - **Other costs:** We purchased a two-year warranty at a total cost of $2,025.
17. **Using measurement practice for other types of solid materials?** No.
18. **Formal or informal policies or documents?** I have attached an SOP [standard operating procedure] that we developed that walks the operator through the process [see **Related Document** below].
19. **Successes:** We seem to have reduced the salt of salt adjustments in storage sheds that were made last year.
20. **Challenges:** Getting consistent measurements.
21. **Comments or additional information:** We are still in the analysis phase of this project.

Related Document:

Salt Volume Calculations with LiDAR, Rough Draft, Version 4, Iowa Department of Transportation, August 2015.
See Appendix C.
This is a standard operating procedure for "scanning salt sheds/domes with the ZEB1 LiDAR wand and using Quick Terrain Modeler (QTM) to calculate the volume in tons."

Minnesota

Contact: Tom Peters, Maintenance Research Engineer, Minnesota Department of Transportation, 651-366-4346, tom.peters@state.mn.us.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Using MDSS [maintenance decision support system]/AVL [automatic vehicle location] technologies in snowplow trucks.

Appendix B
Survey Results

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Commercial product.
2. **Name of product/vendor:** Miscellaneous survey equipment.

   Additional equipment needed? Yes. We are purchasing and testing a handheld laser measuring device.
4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** Yes.
6. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Uncovered.
7. **Number of staff members required to gather and process data:** 2.
8. **Expertise needed to gather and process data:** Surveying.
10. **Time required to gather stockpile measurements:** 30 minutes.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Varies depending on salt usage.
14. **Storage of measurement data:** On agency computers.
17. **Using measurement practice for other types of solid materials?** Yes; aggregate.
20. **Challenges:** Accuracy.

New York

Contact: Michael Lashmet, Snow and Ice Program Engineer, New York State Department of Transportation, 518-457-5796, michael.lashmet@dot.ny.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Loader scales; automated spreader controllers; off-the-shelf laser distance measurer.

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Measurement system developed in-house.
3. **Description of hardware and software:** An off-the-shelf laser distance measurer and an Excel spreadsheet developed in-house.

4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** No.
6. **Stockpile types that can be measured:**
    - Outdoor.
    - Covered.
    - Uncovered.
7. **Number of staff members required to gather and process data:** 2.
8. **Expertise needed to gather and process data:** No specialized expertise.
9. **Description of measurement process:** Distance measurements are taken on the structure covering the salt pile. Then measurements are taken on the salt pile relative to known points from the structure. Data entered into spreadsheet calculates the volume of salt.
10. **Time required to gather stockpile measurements:** One hour.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Monthly, or as needed.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** Within 2-3% accurate.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** $100.
17. **Using measurement practice for other types of solid materials?** No.
18. **Formal or informal policies or documents?** No.
19. **Successes:** Results in very accurate calculations of salt stockpile quantities.
21. **Comments or additional information:** The technology described is relatively new and used only at a few locations.

North Dakota

Contact: Larry Gangl, District Engineer, North Dakota Department of Transportation, 701-227-6510, lgangl@ndsupernet.com.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We are using AVL/GPS units in some of our trucks to measure the amount of material we put down.

Measuring Stockpiles

Using technology or device to measure stockpiles? Yes.

Technology Used to Measure Stockpiles

1. **Type of technology or device:** Measurement system developed in-house.
3. **Description of hardware and software:** We block measure our piles and calculate the quantity from those physical measurements. We also use survey instruments to measure our stockpile quantities.

4. **Hardware mobile?** Yes.
5. **Hardware require calibration?** Yes.
6. **Stockpile types that can be measured:**
    - Indoor.
    - Outdoor.
    - Covered.
    - Uncovered.
7. **Number of staff members required to gather and process data:** 1.
8. **Expertise needed to gather and process data:** Surveying.
9. **Description of measurement process:** We use measuring tapes and a survey level to calculate the size of the piles. We also use GPS survey units to calculate the quantity in the stockpile.
10. **Time required to gather stockpile measurements:** 30 minutes.
11. **Time required to process data:** 30 minutes.
12. **Method(s) to expedite data processing?** No.
13. **Frequency of measurements:** Quarterly.
14. **Storage of measurement data:** On agency computers.
15. **Accuracy of measurements:** 5% range.
16. **Monitoring system's costs:**
    - **Initial purchase of hardware and software:** The GPS [units] are not specifically purchased for measuring stockpiles. They were purchased for surveying.
17. **Using measurement practice for other types of solid materials?** Yes; gravel, sand, processed HBP [hot bituminous pavement**]**.
18. **Formal or informal policies or documents?** N/A.
19. **Successes:** Relatively simple process, but the accuracy i[s] very dependent on the operator of the equipment.
20. **Challenges:** Accuracy of the information is the most challenging.

States Using Other Methods to Measure Stockpiles

California

Contact: Chris Smith, Winter Operations Chief, California Department of Transportation, 916-653-8782, chris.smith@dot.ca.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Our stockpiles are indoors. We have graduated marks on the walls that correspond to the number of feet from the back wall. Material is stacked to a specific height. From there it is just a mathematical calculation to determine cubic yards. If the shed is empty, we just use the bills of lad[ing].

   Equipment used to complete measurement process: 100' tape measure when necessary.
2. **Stockpile types that can be measured:**
   - Indoor.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Monthly.
7. **Accuracy of measurements:** I would guess that we are within 90%.
8. **Measurement method's costs:** No real costs. We do use spray paint and stencils, but that cost is minimal.
10. **Formal or informal policies or documents?** Snow and Ice Control [January 2016]. Storage is specifically mentioned in R.14. [See http://www.dot.ca.gov/hq/maint/manual/2016/29_Chap-R_Jan_2016.pdf.]
11. **Successes:** N/A.
12. **Challenges:** Not everyone stacks the piles uniformly. Sometimes it is necessary to take measurement in sections (all the same height) then add them together.
13. **Plans to transition to use of technology?** No.

Colorado

Contact: Kyle Lester, Director of Highway Maintenance, Colorado Department of Transportation, 303-512-5218, kyle.lester@state.co.us.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Reporting quantities through the work order system.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Height and width measurements, calculating volumes mathematically. Also in all sand sheds, physical lines are painted on the walls that show the quantities left in the shed.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.

3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** Yes. If we have to mathematically calculate the pile, the employee normally has to be trained on how to do that.
5. **Time required to complete measurement:** One hour.
6. **Frequency of measurements:** Monthly.
7. **Accuracy of measurements:** Actual inventories through invoices are the standard.
8. **Measurement method's costs:** None.
10. **Formal or informal policies or documents?** No.
11. **Successes:** None.
12. **Challenges:** Accurate data that is real time.
13. **Plans to transition to use of technology?** Yes.
14. **Transition plan:** Use technology to monitor tank volumes and stockpiles. We are focused on tanks first and then we will work on piles in next year.
15. **What is prompting change?** Real-time data needs.

Connecticut

Contact: John DeCastro, Transportation Maintenance Manager, Connecticut Department of Transportation, 860-594-2614, john.decastro@ct.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Tape measure and shed capacities.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** Yes. Knowledge of basic math and trig[onometry] functions to compute volume.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Weekly during the winter or after each storm.
7. **Accuracy of measurements:** 90 to 95 percent.
9. **Using measurement practice for other types of solid materials?** Yes. Topsoil, gravel, sand, stone, cold patch.

11. **Successes:** Pretty consistent accuracy.

12. **Challenges:** No real challenges.

13. **Plans to transition to use of technology?** I don't know/maybe.

17. **Comments or additional information:** Since we are a relatively small state we visually monitor [our] piles after every storm event and replenish supply. We have adequate capacity within our sheds to store materials for multiple storm events.

Idaho 4

Contact: Steve Spoor, Maintenance Services Manager, Idaho Transportation Department, 208-334-8413, steve.spoor@itd.idaho.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We use AVL and on-board data recording from our spreader controllers to capture real-time application totals of both granular and liquid materials based on either a conveyor sensor for granular, or a flow meter for liquid. This data is then interfaced directly to our maintenance management system (MMS) with operator input of the specific stockpile site. The data is then interfaced from our MMS directly to our financial system, which [is] also our inventory system. As such, all material data that is dispensed automatically update[s] the inventory of the stockpile.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Varies by district. Each district was requested to respond to this survey regarding their specific measurement methods.

10. **Formal or informal policies or documents?** The only policy requirement states when the measurement must be completed. The measurement process cannot begin before April 15 of each year and must be completed by June 1.

Illinois

Contact: Ruben Boehler, Winter Operations Engineer, Illinois Department of Transportation, 217-782-8419, ruben.boehler@illinois.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: N/A.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** If dome is full, we use the design capacity of the dome. If not, we measure the footprint area and height of salt pile to calculate an estimate of volume/tonnage.

Equipment used to complete measurement process: Measuring wheel and tape measure.

2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Annually.
7. **Accuracy of measurements:** 85%
8. **Measurement method's costs:** N/A.
9. **Using measurement practice for other types of solid materials?** Yes. Crushed aggregate, sand and patch mix.
10. **Formal or informal policies or documents?** No.
11. **Successes:** It's simple and fast.
12. **Challenges:** Lack of accuracy.
13. **Plans to transition to use of technology?** No.

Indiana

Contact: Phillip Anderle, Deputy General Manager, WVB East End Partners, 970-381-4104, panderle@wvb-partners.com. (Phillip Anderle is a former employee of Indiana DOT.)

Real-Time Measurement

Real-time measurement tools to monitor material usage: The only near-time measurement we would have is from the truck's spreader controller.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Measurement calculations.

   Equipment used to complete measurement process: Measuring wheel and sometimes a transit.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** One hour.
6. **Frequency of measurements:** Annually.
7. **Accuracy of measurements:** Measurements are within 5% of what is there but the inventory is off by 30 to 40% at times.

8. **Measurement method's costs:** Labor only.

9. **Using measurement practice for other types of solid materials?** Yes. Predominantly stockpiles of chip seal material or sand (grit) for winter applications and sometimes dirt and debris from ditch cleaning or cleanup from floods and debris removal. Just the measurement aspect of measuring the pile at the base, the height and the angle.

10. **Formal or informal policies or documents?** Yes, we are supposed to calibrate all of our spreaders, we are to download the usage from the controller. We are to measure a bucket of material prior to season so we have a rough idea of what is being loaded in each truck each time. We are supposed to report actual application quantities. We are supposed to record what unused material we dump back into the pile.

11. **Successes:** Varies, but generally speaking we have failed consistently on having an accurate account for what has been used.

12. **Challenges:** Inaccurate reporting, misuse of material. Waste. Poor cleanup habits, where material gets washed down the drain.

14. **Transition plan:** Waiting to see what the Clear Roads program comes up with.

15. **What is prompting change?** Frustration of either running out of material when we should have tons left or reordering material and not having room to store what we should be able to take.

16. **When new practice will be implemented:** Unknown.

Kansas

Contact: Clay Adams, Bureau Chief of Maintenance, Kansas Department of Transportation, 785-296-3233, clay.adams@ks.gov.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** We count loader buckets as the trucks are loaded. We maintain an inventory report based on the receipts of material less the material used.

   Equipment used to complete measurement process: Loader buckets.

2. **Stockpile types that can be measured:**
   - Indoor.
   - Covered.

3. **Number of staff members required to complete measurement process:** 1.

4. **Expertise needed for measurement?** Yes. You just need to know how much the material in a loader bucket weighs, and have an inventory system to keep track of the information.

5. **Time required to complete measurement:** 15 minutes.

6. **Frequency of measurements:** Every day receipts are entered and usage is reported daily.

7. **Accuracy of measurements:** 10%.

8. **Measurement method's costs:** None.

9. **Using measurement practice for other types of solid materials?** Yes. Same inventory process;

record material as it is delivered and as it is used.

12. **Challenges:** The accuracy of loader buckets, various sized loaders, and when you have to return material back to the stockpile.
13. **Plans to transition to use of technology?** No.

Maine

Contact: Brian Burne, Highway Maintenance Engineer, Maine Department of Transportation, 207-624-3571, brian.burne@maine.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Most of the time, we use basic geometry to approximate the quantities. When we really need to be more precise, we'll survey it.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** We track all incoming and outgoing amounts, then cross-check the pile using cylinders, cubes, rectangles and/or triangles to approximate the volume against the stockpile calculated amounts.

   Equipment used to complete measurement process: Usually a tape measure and a calculator, but survey equipment if we're trying to be really accurate.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** Yes. Math and spatial skills.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Monthly; annually.
7. **Accuracy of measurements:** I would say +/- 10%. I have not done a study to determine exactly.
8. **Measurement method's costs:** Personnel hours. Travel expenses in some cases.

10. **Formal or informal policies or documents?** No.
11. **Successes:** Our maintenance management system tracks our stockpiles and they are integrated into our work and accomplishment reporting.
12. **Challenges:** When people aren't careful about their reporting, actual quantities can drift significantly from theoretical quantities.
13. **Plans to transition to use of technology?** No.

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Maryland

Contact: Scott Simons, Transportation Engineer V, Maryland State Highway Administration, 410-582-5566, ssimons@sha.state.md.us.

Real-Time Measurement

Real-time measurement tools to monitor material usage: N/A.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** At the beginning of the winter season we take a weight measurement of each loader bucket we intend to use for loading our trucks and facilities. We then tally the loads out and returned for each truck, each facility, [and] each storm using loader sheets filled out by the loader operators.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Covered.

   We have no outdoor or uncovered stockpiles.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** Yes. Simple math skills are all that is needed.
5. **Time required to complete measurement:** 1 hour.
6. **Frequency of measurements:** After every event we run the numbers and place orders to refill prior to the next event.
7. **Accuracy of measurements:** 10%.
8. **Measurement method's costs:** Just labor hours are associated with this process.
9. **Using measurement practice for other types of solid materials?** No.

11. **Successes:** It can be generally fairly accurate as long as the data of loads out and returned is right.
12. **Challenges:** It can be generally fairly accurate as long as the data of loads out and returned is right.
13. **Plans to transition to use of technology?** Yes.
14. **Transition plan:** We are currently outfitting five of our loaders with loader scales, which will calculate tonnage for each truck using RFID [radio frequency identification] technology.
15. **What is prompting change?** Environmental and fiscal impacts are driving the change in practice.
16. **When new practice will be implemented:** This upcoming winter season.

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Massachusetts

Contact: Bassam (Sam) Salfity, State Snow and Ice Engineer, Massachusetts Department of Transportation, 857-368-9671, bassam.salfity@state.ma.us.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Storage volume = Length*Width*Wall Height. We account 15% for shape of pile *1.15. We multiply the volume by 72 lbs per cubic foot, then we convert to tonnage/2,000. Each salt bay could hold up to 150 tons.
2. **Stockpile types that can be measured:**
   - Indoor.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 30 minutes.
6. **Frequency of measurements:** Weekly, monthly and annually.
7. **Accuracy of measurements:** 90%.
9. **Using measurement practice for other types of solid materials?** No.
11. **Successes:** 75%.
12. **Challenges:** Outdoor stockpile under bridges.
13. **Plans to transition to use of technology?** Yes.
14. **Transition plan:** Loader scales.
15. **What is prompting change?** More efficient.
16. **When new practice will be implemented:** By 2018.

Michigan

Contact: Justin Droste, Asset Management Engineer, Michigan Department of Transportation, 517-636-0518, drostej@michigan.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Use AVL equipment on our direct force trucks to capture spreader controller info. Some garages also have scale loaders.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Lines on shed walls are used to approximate.

Equipment used to complete measurement process: Some have tried simple distance calculation rangefinders to estimate volumes.

2. **Stockpile types that can be measured:**
   - Indoor.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** Yes. Familiarity [with] rangefinder plus equations to estimate volume.
6. **Frequency of measurements:** Biweekly.
7. **Accuracy of measurements:** There can be up to 20% difference in reported salt use, AVL and stockpile calculations.
9. **Using measurement practice for other types of solid materials?** I don't think we measure other stockpiles. We don't use as much [of other types of solid materials] like we do with salt. We do also stock ice-control sand and coarse aggregate.
12. **Challenges:** Measuring irregularities in top of pile. Getting on top of pile is safety concern.
13. **Plans to transition to use of technology?** Yes.
14. **Transition plan:** Upon outcome of synthesis, will look into options.
15. **What is prompting change?** Want better confidence in salt stock and use.

Missouri

Contact: Tim Chojnacki, Maintenance Liaison Engineer, Missouri Department of Transportation, 573-751-1040, tim.chojnacki@modot.mo.gov.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Estimated quantity based on dimensions of the pile.
2. **Stockpile types that can be measured:**
   - Indoor.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 30 minutes.
6. **Frequency of measurements:** Weekly, annually and more frequently if many storms or low quantities.
7. **Accuracy of measurements:** +/- 15%.
8. **Measurement method's costs:** Time and labor.
9. **Using measurement practice for other types of solid materials?** Yes. Other road maintenance aggregates.
11. **Successes:** We get a general idea of our on-hand quantity.
12. **Challenges:** Our method is not precise.
13. **Plans to transition to use of technology?** I don't know/maybe.

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Nebraska

Contact: Tom Renninger, Assistant Operations Division Manager, Nebraska Department of Roads, 402-479-4787, tom.renninger@nebraska.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We do weigh loader buckets and use those results as average weight when figuring usage. Some of the newer loaders are being purchased [with] scales to allow the measurement of products used for winter maintenance.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Nebraska cross-sections stockpiles done manually; another method that is being used is the use of survey data collectors tied into the satellite GPS.

   Equipment used to complete measurement process: Total Station (data collector); [equipment needed for] cross-section is auto-level and rodman tools.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
3. **Number of staff members required to complete measurement process:** 3.
4. **Expertise needed for measurement?** Yes. Basic surveying techniques.
5. **Time required to complete measurement:** Two hours.
6. **Frequency of measurements:** Annually. [For] [s]olid materials we are looking at different techniques, but do have a process for liquid product.
7. **Accuracy of measurements:** Nebraska doesn’t actually use official inventories.
8. **Measurement method’s costs:** Equipment and labor.
9. **Using measurement practice for other types of solid materials?** Yes. Millings, gravel, etc.
10. **Formal or informal policies or documents?** No.
11. **Successes:** We know where we are at with products on hand versus product used.
12. **Challenges:** Limited staff and accurate reporting.
13. **Plans to transition to use of technology?** I don’t know/maybe.

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New Hampshire

Contact: David Gray, Winter Maintenance Program Specialist, New Hampshire Department of Transportation, 603-419-9017, dgray@dot.state.nh.us.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Looking at the pile in the barn and counting the number of rafters that it is taking up for space.
2. **Stockpile types that can be measured:**
    - Indoor.
3. **Number of staff members required to complete measurement process:** More than 3.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 30 minutes.
6. **Frequency of measurements:** Weekly.
7. **Accuracy of measurements:** Unsure at this time.
8. **Measurement method's costs:** Just personnel cost.
9. **Using measurement practice for other types of solid materials?** Yes; sand.
10. **Formal or informal policies or documents?** No.
11. **Successes:** None.
12. **Challenges:** Different employees can give different amounts of materials.
13. **Plans to transition to use of technology?** I don't know/maybe.
17. **Comments or additional information:** Depending on the outcome of this project we might try some of the methods that other states are using.

New Jersey

Contact: Douglas Campbell, Buyer/Winter Operations Coordinator, New Jersey Department of Transportation, 609-530-3786, douglas.campbell@dot.nj.gov.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Very rough estimation based on loader buckets placed in trucks and returned to storage buildings.
2. **Stockpile types that can be measured:**
    - Indoor.
3. **Number of staff members required to complete measurement process:** 1.

4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** During and after winter events.
7. **Accuracy of measurements:** We achieve approximately 75% accuracy with this method.
9. **Using measurement practice for other types of solid materials?** No.
12. **Challenges:** We do not have a specific, accurate record of the materials used during a winter event.
13. **Plans to transition to use of technology?** Yes.
14. **Transition plan:** We intend to install scales, as well as use portable scales, at designated locations. We also intend to use loaders with scales built into the bucket.
15. **What is prompting change?** Our materials represent a large capital investment and we need better controls of this inventory.
16. **When new practice will be implemented:** Realistically, over the next five years.

Ohio

Contact: Scott Lucas, Administrative Officer III, Ohio Department of Transportation, 614-644-6603, scott.lucas@dot.ohio.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We use loader scales in some of our garages.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** We use visual observations.

   Equipment used to complete measurement process: Nothing in particular.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Covered.

   All of our stockpiles are covered.
3. **Number of staff members required to complete measurement process:** More than 3.
4. **Expertise needed for measurement?** Yes. It takes a number of times for a manager to be able to look at a pile of salt and determine the size of a salt pile.
5. **Time required to complete measurement:** 30 minutes.
6. **Frequency of measurements:** After every storm event.
7. **Accuracy of measurements:** It is between 15% and 20% after adjustments.
8. **Measurement method's costs:** Labor of the people.
9. **Using measurement practice for other types of solid materials?** Yes. RAP [reclaimed asphalt

pavement], soil and aggregate.

10. **Formal or informal policies or documents?** No, we do not.
11. **Successes:** We compare our estimates against our actual inventory numbers.
12. **Challenges:** It is a difficult skill to teach a new manager.
13. **Plans to transition to use of technology?** I don't know/maybe.
17. **Comments or additional information:** If we found an economical process that could accurately measure the volume of material in a covered structure we would be interested. We would need to be better than 15%.

Oklahoma

Contact: D. Bradley Mirth, State Maintenance Engineer, Oklahoma Department of Transportation, 405-521-2557, bmirth@odot.org.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Each stockpile shed/barn has a known capacity. An estimate of percentage is used to determine stockpile size. Sometimes verified/checked against load counts.

   Equipment used to complete measurement process: Measuring tape or rod.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Weekly.
7. **Accuracy of measurements:** Plus or minus 10%.
8. **Measurement method's costs:** Labor.
9. **Using measurement practice for other types of solid materials?** Yes. Rock, aggregate, sand.
10. **Formal or informal policies or documents?** No.
11. **Successes:** N/A.
12. **Challenges:** N/A.
13. **Plans to transition to use of technology?** No.

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Oregon

Contact: Patti Caswell, Maintenance Environmental Program Manager, Oregon Department of Transportation, 503-986-3008, patti.caswell@odot.state.or.us.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We do not use this technology.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** ODOT uses basic math to determine the volume of solid stockpiled materials.

   Equipment used to complete measurement process: Tape measure.

2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** Two hours.
6. **Frequency of measurements:** Annually.
7. **Accuracy of measurements:** 5-10%.
8. **Measurement method's costs:** Labor (staff time).
9. **Using measurement practice for other types of solid materials?** Yes. We use the method to measure winter abrasive stockpiles.
10. **Formal or informal policies or documents?** No policies, but I will send you a .pdf of the math/equation to compute the volume [see **Related Document** below]. Some folks use online calculators like this: http://www.arthon.com/calculators/stockpile.shtml. [This link was no longer active at the time of publication of this report.]
11. **Successes:** N/A. The practice seems to work OK for ODOT. Some folks apparently are looking into an 'app' that will help calculate the volume. Not sure how much that will cost and whether it's worth it.
12. **Challenges:** Just around accuracy and balancing the books.
13. **Plans to transition to use of technology?** I don't know/maybe.

17. **Comments or additional information:** Apparently someone in one of ODOT's regions is looking into some sort of stockpile calculator/app that can be downloaded to your phone, and the info sent to a company that will calculate the volume for you. We would have to pay for this service. We are in the early stages of fact-finding at this writing.

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Related Document:

Computing Stockpile Volume, Oregon Department of Transportation, undated.
See Appendix D.
This document provides a series of calculations that guide Oregon DOT staff in computing the volume of simple and irregularly shaped stockpiles.

Pennsylvania

Contact: Jason Norville, Winter Operations Section Chief, Pennsylvania Department of Transportation, 717-787-7004, janorville@pa.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We utilize a combination of scales built into some of our loaders, our material management system and downloads of our spreader controller data.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Using various ways of marking the storage bins to indicate the approximate amount of salt in the storage bin based on height of the pile.

   Equipment used to complete measurement process: Paint marks, sign paddles or estimation based on height and diameter of the pile. We also know how much salt we have added to the pile based on the delivery slips we get from the drivers delivering salt. At some stockpiles we also have scales built into the loader to help track how much salt we have loaded on to the trucks.

2. **Stockpile types that can be measured:**
   - Indoor.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Weekly.
7. **Accuracy of measurements:** Fairly accurate if weekly inspections are performed.
8. **Measurement method's costs:** Just the time and labor necessary to inspect the piles and reconcile the inventory.
9. **Using measurement practice for other types of solid materials?** Yes. Stone and anti-skid.
10. **Formal or informal policies or documents?** None.

12. **Challenges:** Can be difficult to stay on top of if there are several back-to-back events.
13. **Plans to transition to use of technology?** No.

17. **Comments or additional information:** N/A.

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Rhode Island

Contact: Joe Bucci, Acting Administrator, Rhode Island Department of Transportation, 401-734-4800, joseph.bucci@dot.ri.gov.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Visual estimates only based upon capacity of the storage building.

   Equipment used to complete measurement process: Tape measures or measuring wheels.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Weekly.
7. **Accuracy of measurements:** Not sure.
8. **Measurement method's costs:** Minimal.
9. **Using measurement practice for other types of solid materials?** Our method is basically a visual estimate, and yes, we use it for other stockpiles. Winter sand, gravel, riprap, etc.
10. **Formal or informal policies or documents?** No.

South Dakota

Contact: Danny Varilek, Winter Maintenance Specialist, South Dakota Department of Transportation, 605-773-3571, daniel.varilek@state.sd.us.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** SDDOT uses a collaboration of bill of ladings and loader buckets. We track usage through our in-house database.

   Equipment used to complete measurement process: Loader buckets.
2. **Stockpile types that can be measured:**
   - Covered.
3. **Number of staff members required to complete measurement process:** 1.

4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Monthly.
7. **Accuracy of measurements:** SDDOT on average is within 10%.
8. **Measurement method's costs:** Fuel for the loader tractor.
9. **Using measurement practice for other types of solid materials?** Yes. Our aggregate is measured by the bill of ladings.
10. **Formal or informal policies or documents?** None.
11. **Successes:** Very successful.
12. **Challenges:** Have not noticed any.
13. **Plans to transition to use of technology?** No.

Utah

Contact: Brandon Klenk, Methods Engineer, Utah Department of Transportation, 801-965-4094, bklenk@utah.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: We only use the spreader controls.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Station foremen estimate the amount of material in the stockpiles and compare with the amount ordered and the amount applied to the roadway to make sure the totals match.

   Equipment used to complete measurement process: None.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 1 hour.
6. **Frequency of measurements:** The estimates are supposed to be done after every storm event.
7. **Accuracy of measurements:** 75%.
8. **Measurement method's costs:** One hour of labor.
9. **Using measurement practice for other types of solid materials?** No.

10. **Formal or informal policies or documents?** No.
12. **Challenges:** There can be a high level of inaccuracy that is only discovered at the end of season.
13. **Plans to transition to use of technology?** I don't know/maybe.
17. **Comments or additional information:** I've heard we are going to test other ways to measure, but I haven't seen anything official.

Vermont

Contact: Todd Law, Maintenance Engineer, Vermont Agency of Transportation, 802-839-0274, todd.law@vermont.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: N/A.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Our technical staff goes to the sites and measures our stockpiles.

   Equipment used to complete measurement process: The typical measurement process is a tape measure and the knowledge of the dimensions and capacity of the shed.
2. **Stockpile types that can be measured:**
   - Indoor.
3. **Number of staff members required to complete measurement process:** 1.
4. **Expertise needed for measurement?** Yes. Some basic geometry and area calculation experience.
5. **Time required to complete measurement:** 15 minutes.
6. **Frequency of measurements:** Weekly.
7. **Accuracy of measurements:** These are actual inventories.
8. **Measurement method's costs:** There is time for travel to the sites, but the time is covered in work hours.
9. **Using measurement practice for other types of solid materials?** No.
11. **Successes:** We have checked and balanced the salt use from the drivers' estimations and verified the amounts use[d] in our Managing Assets for Transportation Systems, which tracks inventories and activities.
12. **Challenges:** Getting districts to buy into the importance of validation of salt.
13. **Plans to transition to use of technology?** No.

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Virginia

Contact: Allen Williams, District Maintenance Engineer, Virginia Department of Transportation, 540-387-5346, allen.williams@vdot.virginia.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Buildings are filled to a set height and the tonnage is marked on the walls. Anyone can drive by and get an estimated tonnage remaining.

   Equipment used to complete measurement process: None.

2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Uncovered.

3. **Number of staff members required to complete measurement process:** 1.

4. **Expertise needed for measurement?** No.

5. **Time required to complete measurement:** 15 minutes.

6. **Frequency of measurements:** Weekly during the winter season and after every major event.

7. **Accuracy of measurements:** 85 to 95%.

10. **Formal or informal policies or documents?** No.

13. **Plans to transition to use of technology?** I don’t know/maybe.

17. **Comments or additional information:** Cheap and accurate enough for determining the need to reorder. Easy to determine estimated tonnage and accurate enough to determine the quantity used in a storm.

Washington

Contact: James Morin, Maintenance Operations Manager, Washington State Department of Transportation, 360-705-7803, morinj@wsdot.wa.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Typical survey methods at best, often measuring the pile’s length, width and height with a measuring wheel and calculating the volume.

Equipment used to complete measurement process: Total Station. Measuring tape, measuring wheel, calculator.

2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
   - Uncovered.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** Yes. Familiarity with survey equipment. Hand surveys do not require specialized expertise.
5. **Time required to complete measurement:** 30 minutes.
6. **Frequency of measurements:** Biweekly and annually. During winter months, survey grade measurement yearly.
7. **Accuracy of measurements:** 20% +/- at best.
8. **Measurement method's costs:** There are costs in terms of labor to do the physical measurement but there are also costs in reconciling inventory issues.
10. **Formal or informal policies or documents?** Procurement requires a measurement each May. Maintenance Areas typically do a weekly or biweekly physical inventory during winter months.
11. **Successes:** It works but is not accurate or efficient. Particularly since the time when we need to be the most accurate is also the time when we have the least amount of time to spend measuring the piles. This results in the need for creative math after a storm and certainly after the season.
12. **Challenges:** Inaccuracies, time consuming.
13. **Plans to transition to use of technology?** Yes.
14. **Transition plan:** We have no concrete plans. We want/need to increase accuracy but do not have a plan yet. We have on a very small scale experimented with LiDAR with some success but cost was the issue.
15. **What is prompting change?** Cost of material, inaccuracies and need to better report inventory.
16. **When new practice will be implemented:** We have no timeline.

West Virginia

Contact: Jeff Pifer, Maintenance Operations Section Head, West Virginia Department of Highways, 304-677-9839, jeff.m.pifer@wv.gov.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Cross-section stockpiles and calculate volume.

   Equipment used to complete measurement process: Surveying equipment.
2. **Stockpile types that can be measured:**

- Indoor.
- Outdoor.

3. **Number of staff members required to complete measurement process:** 3.
4. **Expertise needed for measurement?** Yes, surveying.
5. **Time required to complete measurement:** One hour.
6. **Frequency of measurements:** Annually.
7. **Accuracy of measurements:** Within 1%.
9. **Using measurement practice for other types of solid materials?** Yes; salt, aggregates, cold mix asphalt.
12. **Challenges:** Our inventory is held annually at the end of the fiscal year. During winter we are operating on estimates of salt used and estimates of material still in the shed or on the ground.
13. **Plans to transition to use of technology?** I don't know/maybe.
17. **Comments or additional information:** Currently looking into the feasibility of utilizing aerial drones to photograph stockpiles and break down the volume calculations using a PC. Need to determine if it can be accomplished in an enclosed salt storage shed.

Wisconsin

Contact: Michael D. Sproul, Winter Maintenance Engineer, Wisconsin Department of Transportation, 608-266-8680, michael.sproul@dot.wi.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Some of our counties use scales to load and unload. Some counties count loader buckets of salt. Some take the output from their AVL/GPS equipment. Some use loader scales.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Visual. Surveyors.

   Equipment used to complete measurement process: Surveying equipment.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Covered.
3. **Number of staff members required to complete measurement process:** 2.
4. **Expertise needed for measurement?** No.
5. **Time required to complete measurement:** 30 minutes.
6. **Frequency of measurements:** Monthly are visual. End of season can be visual or measured.
7. **Accuracy of measurements:** Not accurate, I'd guess < 50%.

8. **Measurement method's costs:** The people who take these measurements are professionals and just do the inventories as part of their typical hours.
9. **Using measurement practice for other types of solid materials?** No.
10. **Formal or informal policies or documents?** No.
12. **Challenges:** We're not very accurate. Then when we fill the sheds in the summer some of the salt won't fit because the inventories were off.
13. **Plans to transition to use of technology?** No.
17. **Comments or additional information:** Getting accurate inventories is a big problem for us especially in domes. 100% of state salt is covered and in a building.

Wyoming

Contact: Clifford Spoonemore, Maintenance Staff Engineer, Wyoming Department of Transportation, 307-777-6377, cliff.spoonemore@wyo.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: None, WYDOT keeps talking about this with no real steps forward.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, but we do measure stockpiles without the use of technology.

Other Methods Used to Measure Stockpiles

1. **Method used to measure stockpiles:** Ask the engineering crew to survey the pile.

   Equipment used to complete measurement process: Normal surveying equipment.
2. **Stockpile types that can be measured:**
   - Indoor.
   - Outdoor.
   - Uncovered.
3. **Number of staff members required to complete measurement process:** 3.
4. **Expertise needed for measurement?** Yes. Use of math and/or geometry.
5. **Time required to complete measurement:** One hour.
6. **Frequency of measurements:** Annually.
7. **Accuracy of measurements:** 80%.
8. **Measurement method's costs:** Man-hours that are worked into the crew's regular hours. $1,000 per hour for the survey crew.
9. **Using measurement practice for other types of solid materials?** Yes. We have our engineering crew measure the stockpile before and after the season. Then again if the stockpile is used up we don't need to measure, we take the quantity delivered and say it is all gone. Then start over with new delivery quantities.
10. **Formal or informal policies or documents?** No.

11. **Successes:** Able to prepare plans for bid letting for the next year's sand/salt pile project.

12. **Challenges:** The 20% error in measurement as compared to reported usage has caused stockpile to run out during a snow season.

13. **Plans to transition to use of technology?** No.

17. **Comments or additional information:** Now that our budget is really tight, there may be a need to track the stockpiles more. To this point there has not been a need for tracking. If we run out, we buy more.

States Not Measuring Stockpiles

Arizona

Contact: Mark Trennepohl, Winter Operations Support Manager, Arizona Department of Transportation, 602-712-8277, mtrennepohl@azdot.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Plow trucks are equipped with scales.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, we do not measure stockpiles.

Kentucky

Contact: David Cornett, Assistant Director, Division of Maintenance, Kentucky Transportation Cabinet, 502-782-5578, davidp.cornett@ky.gov.

Real-Time Measurement

Real-time measurement tools to monitor material usage: Loader-mounted scale on the bucket, AVL equipment, spreader control readouts, MDSS reporting.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, we do not measure stockpiles.

Mississippi

Contact: Heath Patterson, State Maintenance Engineer, Mississippi Department of Transportation, 601-359-7111, hpatterson@mdot.ms.gov.

Measuring Stockpiles

Using technology or device to measure stockpiles? No, we do not measure stockpiles.

Salt Volume Calculations with LiDAR

A Standard Operating Procedure (SOP) for scanning salt sheds/domes with the ZEB1 LiDAR Wand and using Quick Terrain Modeler (QTM) to calculate the volume in tons

Iowa Department of Transportation

Highway Division

Office of Maintenance

Winter Operations

Rough Draft, Version 4

August 6, 2015

Contact Information:

Winter Ops Administrator: Craig Bargfrede | craig.bargfrede@dot.iowa.gov | 515-239-1355

ZEB1 LiDAR Wand Coordinator: Tina Greenfield | Tina.Greenfield@dot.iowa.gov | 515-233-7746

Important Notes:

1. *Salt density differs – therefore it is important to measure the density of each respective pile, each and every time a scan occurs*
2. *5-gallon Walmart bucket at the DOT HQ in Ames was used in this SOP to test salt density – empty weight is 775.2 grams (1.7090235 lbs.)*
3. *From http://www.cargill.com/products/salt/winter/bulk-deicing-salt/faq/index.jsp -* ***Generally speaking, bulk deicing salt weighs about 80 lbs. per cubic foot translating to 2,160 lbs. per cubic yard or roughly 1 ton***
4. *Generic Stats:*
    a. *Types of 'tons'*
        i. *Short Ton: 2,000 lbs. (U.S. standard – 100lbs per hundredweight x 20)*
        ii. *Long Ton: 2,240 lbs. (British standard – 112lbs per hundredweight x 20)*
        iii. *Metric Ton: 2,204 lbs. (officially 'Tonne' – 1,000 kilograms)*
    b. *1 pound = 0.0005 short ton*
    c. *1 short ton = 2,000 lbs.*
5. *Links:*
    a. *3D Laser Mapping Official Website - http://www.3dlasermapping.com/*
    b. *ZEB1 LiDAR Wand Official Page - http://www.3dlasermapping.com/zeb1-indoor-mapping/*
6. *Reference Manuals: The ZEB1 LiDAR Wand comes with two PDF reference manuals. If you do not currently have these or are unaware of them please get in touch with the aforementioned contacts*
    a. *ZEB1 - Quickstart guide v1.0.2.pdf*
        i. *2-page guide on how to prepare for a scan and an explanation of the different light colors*
    b. *ZEB1 - User's Guide v2.0.0.pdf*
        i. *25-page operation manual*

Step 1: Data Collection with the ZEB1 LiDAR Wand

- ‘Operation’ and ‘Usage Guidelines’ tutorial videos by 3D Laser Mapping (creators of the ZEB1 LiDAR Wand) can be viewed here:
    - Operation - https://www.youtube.com/watch?v=xjBwBiCbv_c
    - Usage Guidelines - https://www.youtube.com/watch?v=GP2nKoiMA_4
- These videos must be viewed in order to learn the proper operating procedures prior to beginning your first scan. If you are currently unable to access the internet or are experiencing a slow connection, the video files themselves can be supplied via the shared ‘W:\’ drive upon request. A brief explanation relevant to the specific process of scanning Salt Sheds/Domes is available below:

1. **Setting up to Scan**: The first step in readying the LiDAR Wand prior to scanning is to set the backpack (with everything inside of it) on the ground directly in front of the salt shed/dome that is to be scanned **(1)**. Unzip the backpack so that everything is easily accessible, while removing the LiDAR Wand and leaving everything else in place. Inside the backpack, plug the attached cord into the battery (Deben Tracer Lithium-Polymer 12V 8Ah) in order to provide power to the ZEB-DL2600 Data Logger **(2)**. Press the ‘ON/POWER’ button **(3)**, following which the ‘ZEB1’ and ‘AUX’ input lights will glow orange for a few seconds **(4)**. Next, insert the ZEB1 cable into the LiDAR Wand **(5)**, matching up the red rectangle and circle **(6)** and connect the other end of the cable to the ‘ZEB1’ input **(7)**. Once the cable is inserted there will be a series of flashes/lights that you will need to wait for. Take notice that the amount of time it takes for this to happen is not always the same and sometimes the wait for any lights to come on might be a bit longer than others, so don’t worry if nothing is happening immediately. Only if it has been longer than a few minutes is it advised to try again by disconnecting and starting from the initial steps. The first flashing lights are a series of ‘Green-Orange-Red’ while the Data Logger boots up and is connecting to the LiDAR Wand. This is followed by a solid ‘Red’ light, then a flashing ‘Orange’ light (initialization mode) and lastly a solid ‘Green’ light (scanning mode) that indicates the LiDAR Wand is ready to scan, which will also show up on the LiDAR Wand itself **(8)**.

2. **Salt Density**: It is extremely important to note that salt density will of course vary from one pile to another. Even the density in a single pile alone will differ, as some of the salt may be older, more or less compacted and in varying degrees of condition (courser/finer). Therefore it is important to take a salt density sample that best represents the pile as a whole. It is recommended, as well as mandatory for this SOP, that a 5-gallon bucket be used in order to measure the salt density of a salt shed/dome prior to performing any LiDAR scan. ***Important to Note***: It is also highly encouraged that a very reliable and accurate scale be used if at all possible, and to always use the same scale in order to help ensure consistency with future scans. The more accurate the scale (i.e. weight in grams instead of every ½ pound), the more accurate the final salt calculations will be, as when dealing with hundreds to thousands of tons of salt, any slight change, inaccuracy or discrepancy in measurement will cause the

margin of error to grow exponentially with regards to the final tonnage. It cannot be overstated enough that although creating a nearly perfect model in QTM is very important, the initial salt density weight of a 5-gallon bucket has the ability to most greatly impact the outcome of the final tonnage calculations.

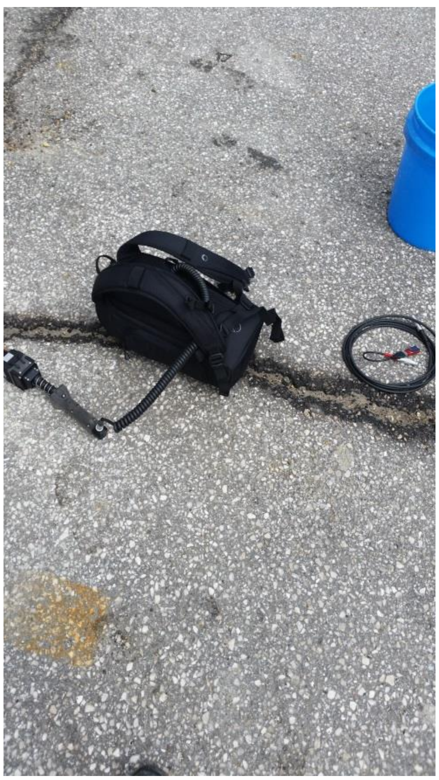
3. **Weighing 5-Gallon Bucket**: First, weigh your 5-gallon bucket empty and record this for all future usage (this will be explained further on in the SOP). Secondly, take a shovel and fill the bucket until it is slightly overflowing. Proceed to strike off the top with a straight edge, board or any other method that can produce a consistent and standardized level of salt. Then, pick up the bucket and let it slam down against the ground in order to help compact the salt, allowing the bucket to hold a little more. Repeat this process as needed until you are confident in weighing the bucket. Again, this is in order to be as consistent as possible and eliminate any errors in the process of determining the final tonnage calculation. It goes without saying that any foreseeable way in which to reduce or eliminate the possibility for human error should be highly sought after. Image **(9)** illustrates an example bucket filled with salt during a density weighing prior to a scan. Be sure to take a picture of what the filled bucket looks like, as well as an image of the scale with the weight showing in the off-chance that you forget it **(10)**.

4. **Taking Detailed Pictures**: Prior to beginning your scan, be sure to take detailed pictures of the inside and outside of the salt shed/dome. Taking all of these will help provide a context for when you are editing your LiDAR points, as well as for posterity. When using QTM, the pictures will help to provide information as to where the baseline of the salt starts, as well as help to remedy any anomalies or unique situations that may be inherent in the data. As a best practice, it is a good idea to take pictures of any odd contours inside of a salt shed/dome, as well as any areas where the salt meets the walls, so that irrelevant LiDAR points can be quickly identified within QTM and deleted as needed. Images **(11-16)** are examples of the different pictures that should be taken prior to/during scanning.

5. **Ensuring Complete Capture**: The most important thing to remember when scanning is that if the LiDAR Wand is oscillating too quickly the light on the handle will begin to flash ‘Orange’, which means that nothing is being collected. To remedy this, simply pause and stay still for a second until the light on the handle returns to solid ‘Green’. It may take some time and practice in order to get the oscillation of the LiDAR Wand to a workable consistency. Lastly, merely walking around the side of the salt inside of a salt shed/dome will not always capture the top/full height of a pile. When conducting a scan you can hold the LiDAR Wand about chest high straight in front of you, allowing it to rhythmically move horizontally back and forth. However, also be sure to hold the LiDAR Wand slanted above your head towards the top to capture everything as you go along. If the pile is high enough, attempt (if safely possible) to climb to/near the top to ensure complete collection. As a quick foreshadow, it is important to know that capturing the roof is not necessary (as it generally happens without trying anyways), because all irrelevant points will be cut out in QTM regardless. As you are nearing the completion of your scan, be sure to end it where you started and do so facing the salt shed/dome that you scanned. Once you are in the

approximate position of where you started, proceed to take off the backpack and lay down the wand (facing the salt), just as was shown in image **(1)**.

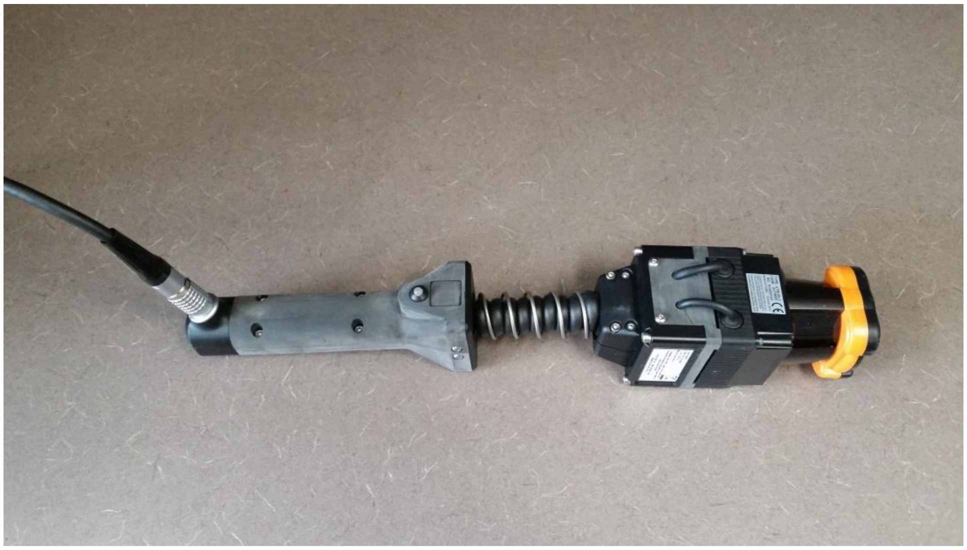
6. **Finishing a Scan**: Now that the scan is complete and the backpack and LiDAR Wand are on the ground, it is time to transfer the points collected via the scan to the 'USB Thumb Drive' **(17)**. The first step is to unplug the LiDAR Wand cord from the ZEB1 input, then wait a few seconds (possibly more), until the light flashes red. Take the 'USB Thumb Drive' and insert it into the USB end of the 'ZEB-DL2600 Download Cable' **(18)**. Now, go ahead and insert the other end of the 'ZEB-DL2600 Download Cable' into the 'AUX' input **(19-20)**. The light will turn Green, indicating that the LiDAR data is being transferred. When the Green light turns off, this means that the transfer has been completed. **Very Important to Note**: DO NOT, under any circumstance, remove the cable from the 'AUX' input or the 'USB Thumb Drive' from the cable before the transfer is finished. If either ends of the download cable are removed or interrupted, the transfer will not be successfully completed and all of the data collected will have been rendered corrupted and non-salvageable. There is unfortunately only one-shot at doing this, so avoid prematurely interrupting the transfer.


(1)

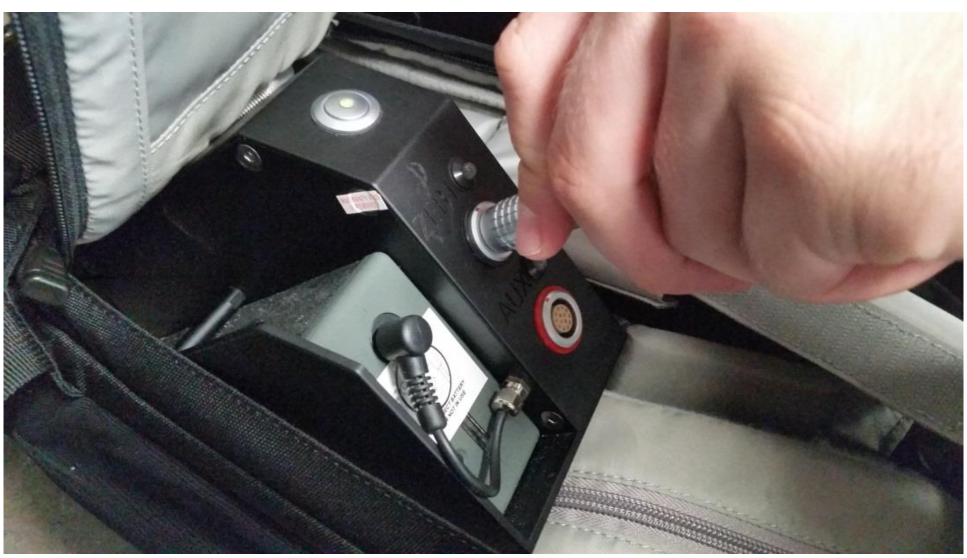
(2)

(3)

(4)


(5)


(6)



(7)


(8)


(9)


MODEL 4040 - CAPACITY 400 lb. / 180 kg
pelouze®
56.0
lb.
Hold
kg
lb./kg
ZERO HOLD
ON
OFF
(10)


(11)


(12)


(13)


(14)


(15)


(16)

(17)

(18)

(19)

(20)

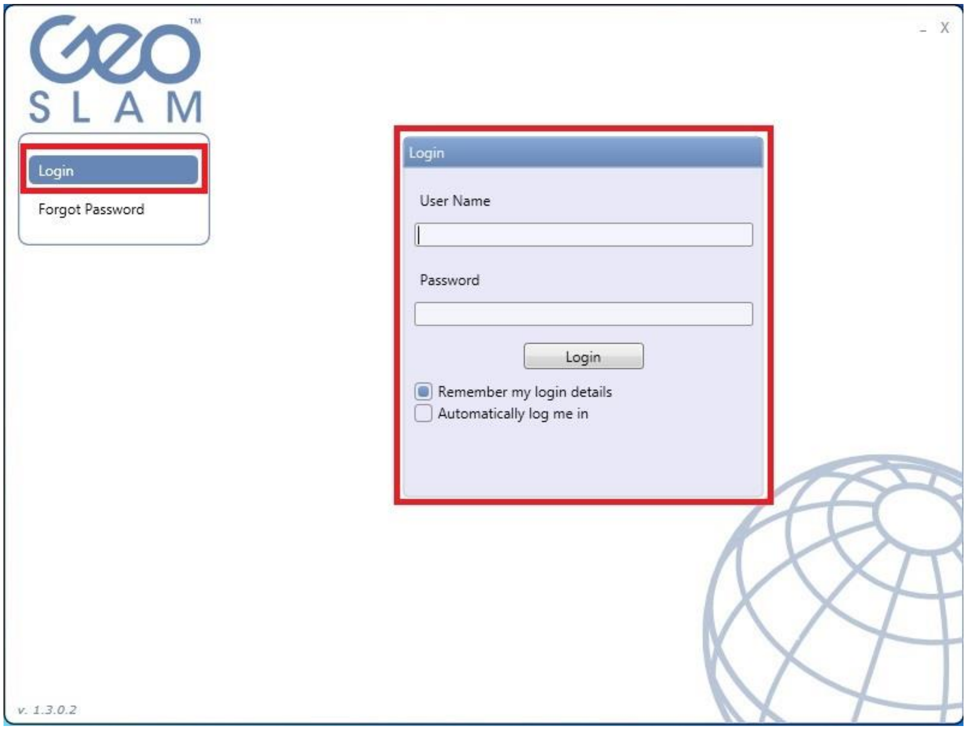
Step 2: Uploading and Conversion of Collected Data to Useable Format

- An 'Uploader Tutorial Video' created by 3D Laser Mapping can be viewed here: https://www.youtube.com/watch?v=MvjHO559BPQ
    - If you are currently unable to access the internet or are experiencing a slow connection, the video files themselves can be supplied via the shared 'W:\' drive upon request
- A brief explanation of the uploading and conversion process is available below:

1. The ZEB1 LiDAR Wand collects data in a proprietary format; therefore after collection is completed the data cannot simply be taken and immediately worked with. The LiDAR has to be uploaded, processed (converted) and then downloaded via an 'Uploader' program. It is important to note that this is not free and that 'Credits' must be purchased, which are redeemable to pay for collected LiDAR points. The amount of 'Credits' that a scan costs is relative to the amount of distance traversed per meter. The first step is to download and Install the ZEB1 Uploader Program.

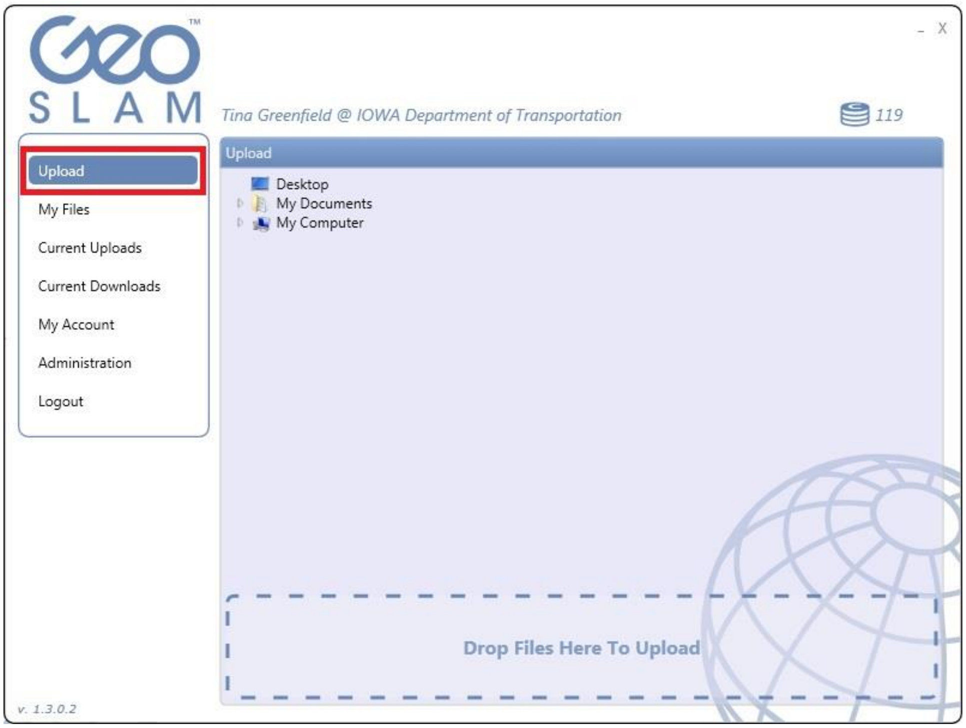
   a. Click Here

2. Open the ZEB1 Uploader Program. Image **(21)** shows what the main screen will look like after the program has been opened.

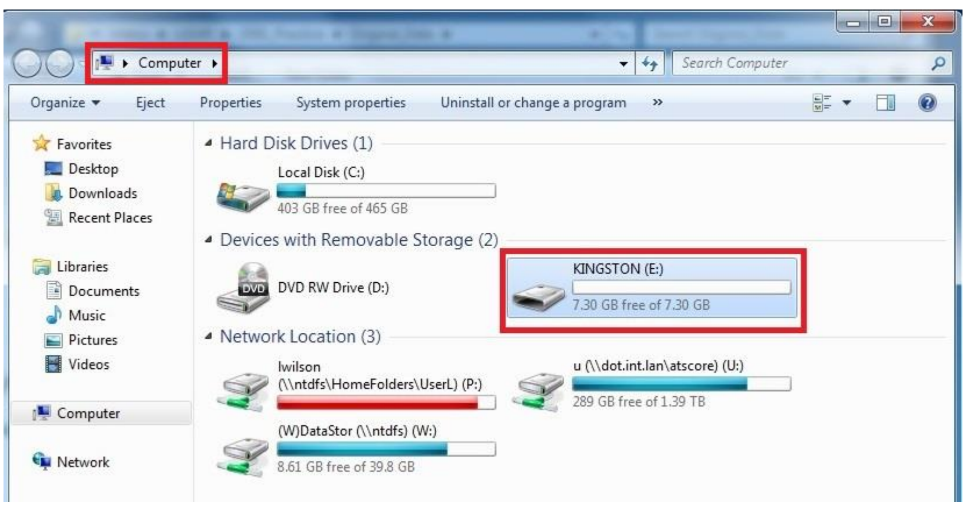
 **(21)**

3. Once the program is open you will have to log in using a User Name and Password. If you do not currently have your own login information or have not been given access to an organizational account, please contact Tina Greenfield, Office of Maintenance, Winter Operations, at Tina.Greenfield@dot.iowa.gov (515-233-7746).

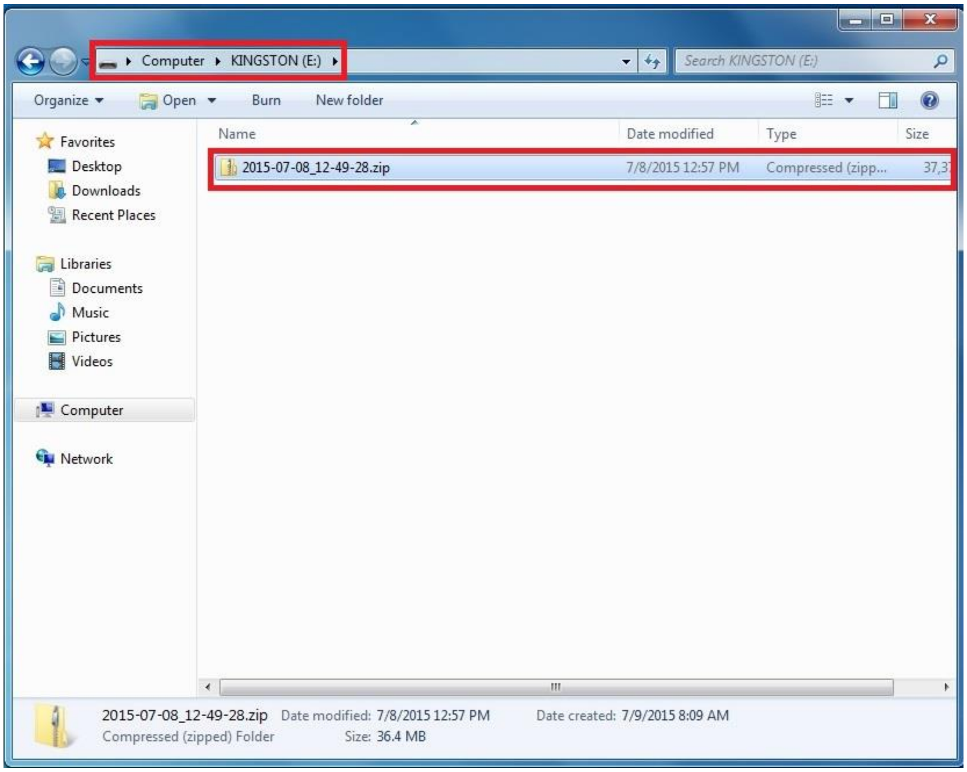
4. Once logged in you will be brought to a new screen that starts out on the ‘Upload’ tab **(22)**. Dragging and dropping is the easiest way to start the upload process. After inserting the USB Flash Drive that contains the collected LiDAR points, navigate to it **(23)**. Open the USB Flash Drive and find the file(s) that you want to drag and drop **(24)**. Now, drag and drop it into the specified area of the ‘Uploader’ program **(25)**. After doing this a progress bar under the ‘Current Uploads’ tab can be seen for the selected file(s) **(26)**. After the upload is complete the file’s status will change to ‘Processing’ under the ‘My Files’ tab **(27)**. Once the processing (converting) has been finished, the option to ‘Pay’ for the data using existing credits will be made available **(28)**. After the transaction is complete, the next step is to download the converted data to your computer (or shared drive) **(29)**. After clicking the ‘Download’ button, navigate to where you want to save the data and then click ‘save’ **(30)**. Once the data has been saved the last step is to right-click on it and select ‘Extract All’ **(31)**, followed by clicking the ‘Browse’ button to choose where to extract the files and then selecting ‘Extract’ **(32)**.


GEO SLAM
Tina Greenfield @ IOWA Department of Transportation
119
Upload
My Files
Current Uploads
Current Downloads
My Account
Administration
Logout
Upload
Desktop
My Documents
My Computer
Drop Files Here To Upload
v. 1.3.0.2

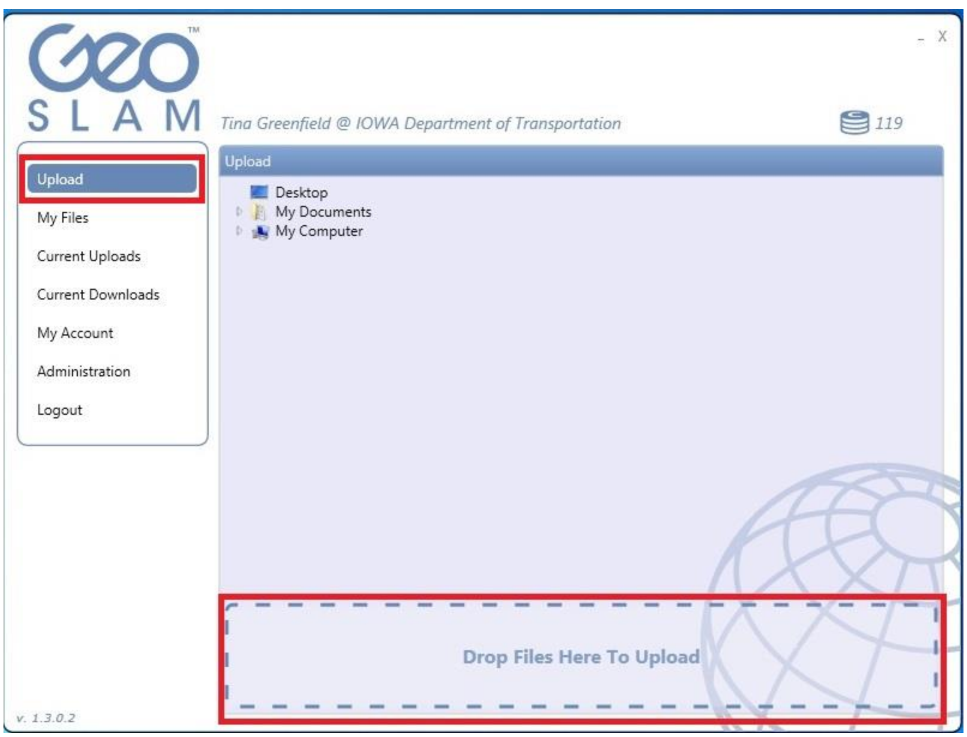
(22)


Computer
Search Computer
Organize
Eject
Properties
System properties
Uninstall or change a program
Favorites
Desktop
Downloads
Recent Places
Libraries
Documents
Music
Pictures
Videos
Computer
Network
Hard Disk Drives (1)
Local Disk (C:)
403 GB free of 465 GB
Devices with Removable Storage (2)
DVD RW Drive (D:)
KINGSTON (E:)
7.30 GB free of 7.30 GB
Network Location (3)
lwilson (\\ntdfs\HomeFolders\UserL) (P:)
u (\\dot.int.lan\atscore) (U:)
289 GB free of 1.39 TB
(W)DataStor (\\ntdfs) (W:)
8.61 GB free of 39.8 GB

(23)


Computer ▸ KINGSTON (E:) ▸
Search KINGSTON (E:)
Organize
Open
Burn
New folder
Favorites
Desktop
Downloads
Recent Places
Libraries
Documents
Music
Pictures
Videos
Computer
Network
Name
Date modified
Type
Size
2015-07-08_12-49-28.zip
7/8/2015 12:57 PM
Compressed (zipp...
2015-07-08_12-49-28.zip Date modified: 7/8/2015 12:57 PM Date created: 7/9/2015 8:09 AM
Compressed (zipped) Folder Size: 36.4 MB

(24)


GEO SLAM
Tina Greenfield @ IOWA Department of Transportation
119
Upload
My Files
Current Uploads
Current Downloads
My Account
Administration
Logout
Upload
Desktop
My Documents
My Computer
Drop Files Here To Upload
v. 1.3.0.2

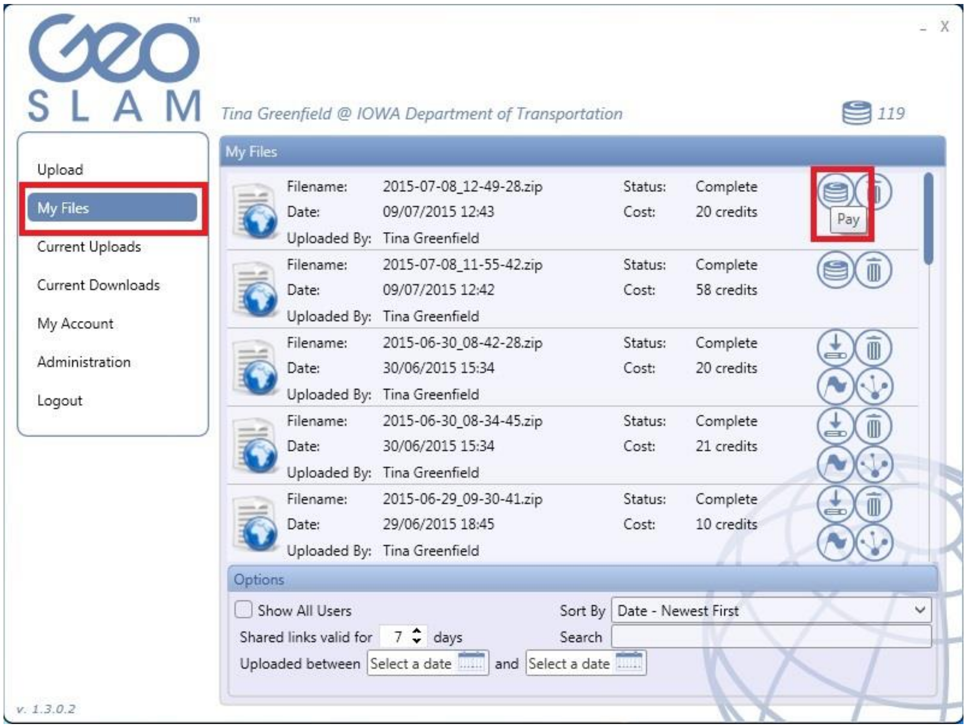
(25)

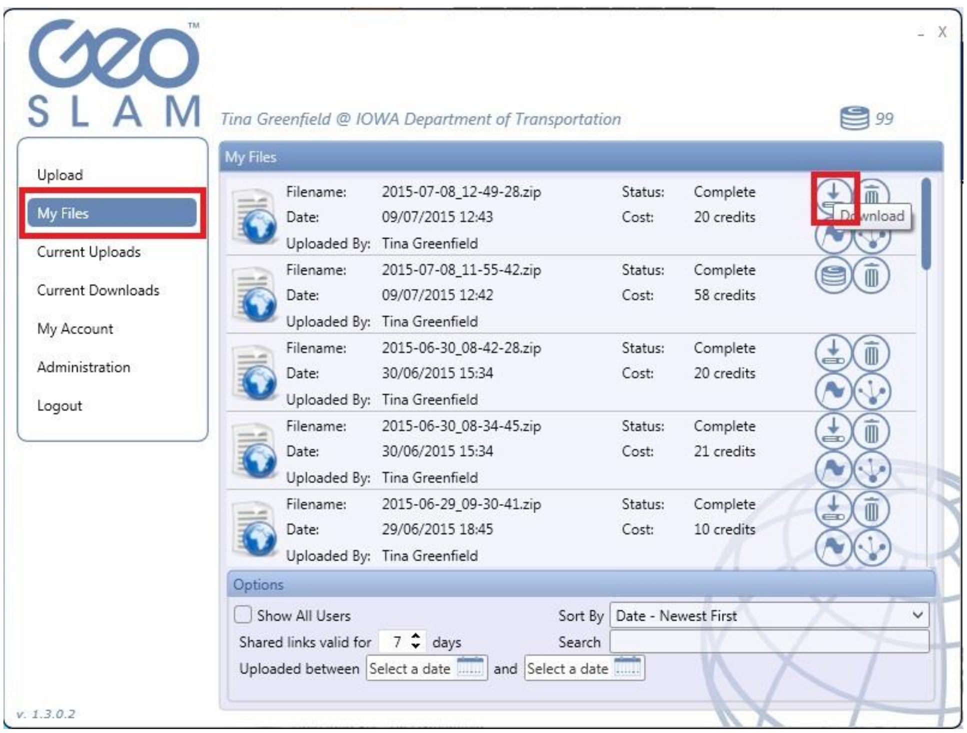
GeoSLAM
Tina Greenfield @ IOWA Department of Transportation
41
Upload
My Files
Current Uploads
Current Downloads
My Account
Administration
Logout
Current Uploads
W:\Highway\Maintenance\GIS\Intern\Lance_Wilson\Data_Structure\Matrix\LiDAR\ZEB1_Practice\Origir
6% - 4.5MB /64.8MB (1.02 MB/s)
v. 1.3.0.2

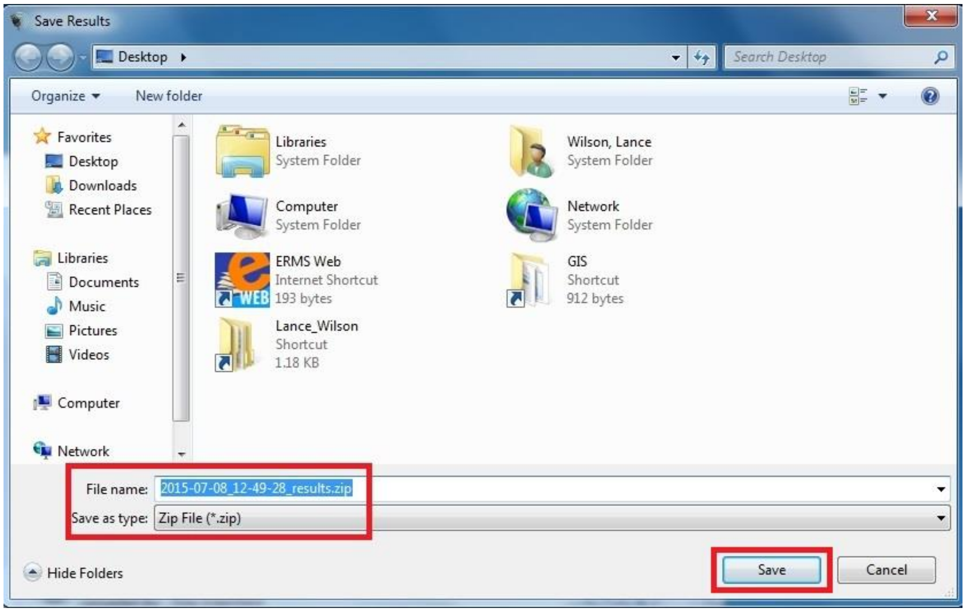
(26)

GeoSLAM
Tina Greenfield @ IOWA Department of Transportation
119
Upload
My Files
Current Uploads
Current Downloads
My Account
Administration
Logout
My Files
Filename: 2015-07-08_11-35-33.zip Status: Processing
Date: 09/07/2015 13:02 Cost: 0 credits
Uploaded By: Tina Greenfield
Filename: 2015-07-08_12-49-28.zip Status: Complete
Date: 09/07/2015 12:43 Cost: 20 credits
Uploaded By: Tina Greenfield
Filename: 2015-07-08_11-55-42.zip Status: Complete
Date: 09/07/2015 12:42 Cost: 58 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-30_08-42-28.zip Status: Complete
Date: 30/06/2015 15:34 Cost: 20 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-30_08-34-45.zip Status: Complete
Date: 30/06/2015 15:34 Cost: 21 credits
Uploaded By: Tina Greenfield
Options
Show All Users
Sort By Date - Newest First
Shared links valid for 7 days
Search
Uploaded between Select a date and Select a date
v. 1.3.0.2

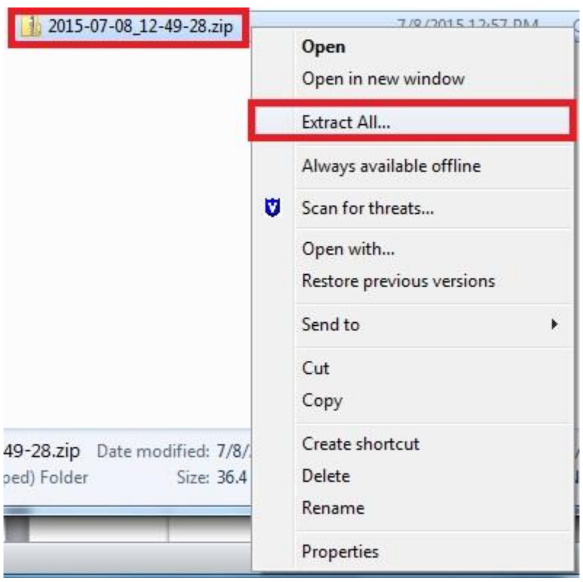
(27)


Tina Greenfield @ IOWA Department of Transportation
119
Upload
My Files
Current Uploads
Current Downloads
My Account
Administration
Logout
My Files
Filename: 2015-07-08_12-49-28.zip Status: Complete
Date: 09/07/2015 12:43 Cost: 20 credits
Uploaded By: Tina Greenfield
Pay
Filename: 2015-07-08_11-55-42.zip Status: Complete
Date: 09/07/2015 12:42 Cost: 58 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-30_08-42-28.zip Status: Complete
Date: 30/06/2015 15:34 Cost: 20 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-30_08-34-45.zip Status: Complete
Date: 30/06/2015 15:34 Cost: 21 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-29_09-30-41.zip Status: Complete
Date: 29/06/2015 18:45 Cost: 10 credits
Uploaded By: Tina Greenfield
Options
Show All Users
Sort By Date - Newest First
Shared links valid for 7 days
Search
Uploaded between Select a date and Select a date
v. 1.3.0.2
(28)

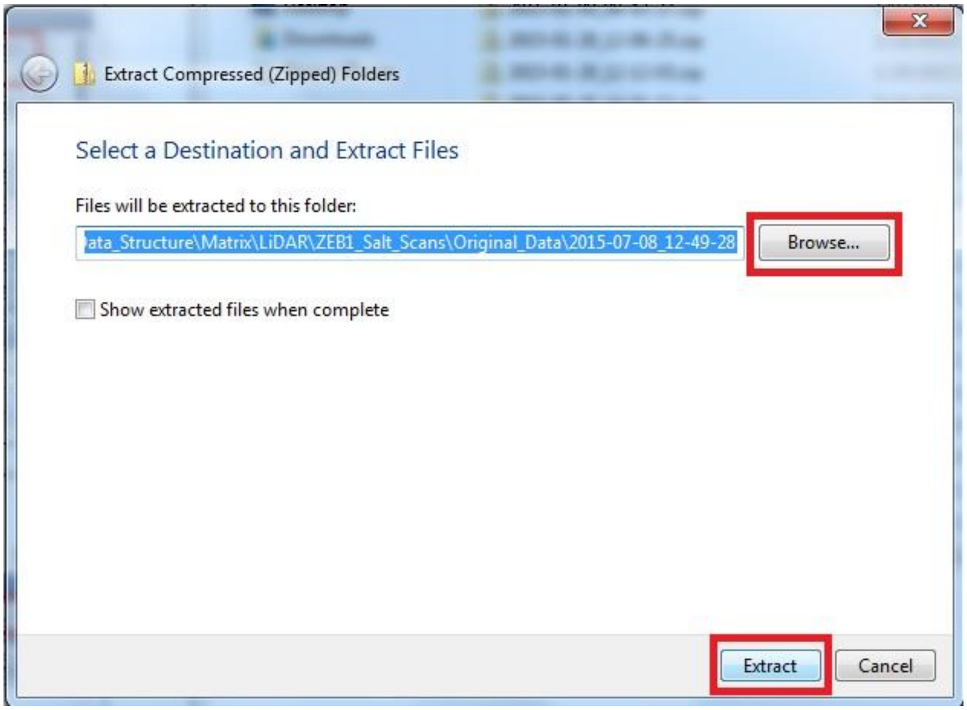

Tina Greenfield @ IOWA Department of Transportation
99
Upload
My Files
Current Uploads
Current Downloads
My Account
Administration
Logout
My Files
Filename: 2015-07-08_12-49-28.zip Status: Complete
Date: 09/07/2015 12:43 Cost: 20 credits
Uploaded By: Tina Greenfield
Download
Filename: 2015-07-08_11-55-42.zip Status: Complete
Date: 09/07/2015 12:42 Cost: 58 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-30_08-42-28.zip Status: Complete
Date: 30/06/2015 15:34 Cost: 20 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-30_08-34-45.zip Status: Complete
Date: 30/06/2015 15:34 Cost: 21 credits
Uploaded By: Tina Greenfield
Filename: 2015-06-29_09-30-41.zip Status: Complete
Date: 29/06/2015 18:45 Cost: 10 credits
Uploaded By: Tina Greenfield
Options
Show All Users
Sort By Date - Newest First
Shared links valid for 7 days
Search
Uploaded between Select a date and Select a date
v. 1.3.0.2
(29)


Save Results
Desktop
Search Desktop
Organize
New folder
Favorites
Desktop
Downloads
Recent Places
Libraries
Documents
Music
Pictures
Videos
Computer
Network
Libraries
System Folder
Wilson, Lance
System Folder
Computer
System Folder
Network
System Folder
ERMS Web
Internet Shortcut
193 bytes
GIS
Shortcut
912 bytes
Lance_Wilson
Shortcut
1.18 KB
File name: 2015-07-08_12-49-28_results.zip
Save as type: Zip File (*.zip)
Hide Folders
Save
Cancel

(30)


2015-07-08_12-49-28.zip
Open
Open in new window
Extract All...
Always available offline
Scan for threats...
Open with...
Restore previous versions
Send to
Cut
Copy
Create shortcut
Delete
Rename
Properties

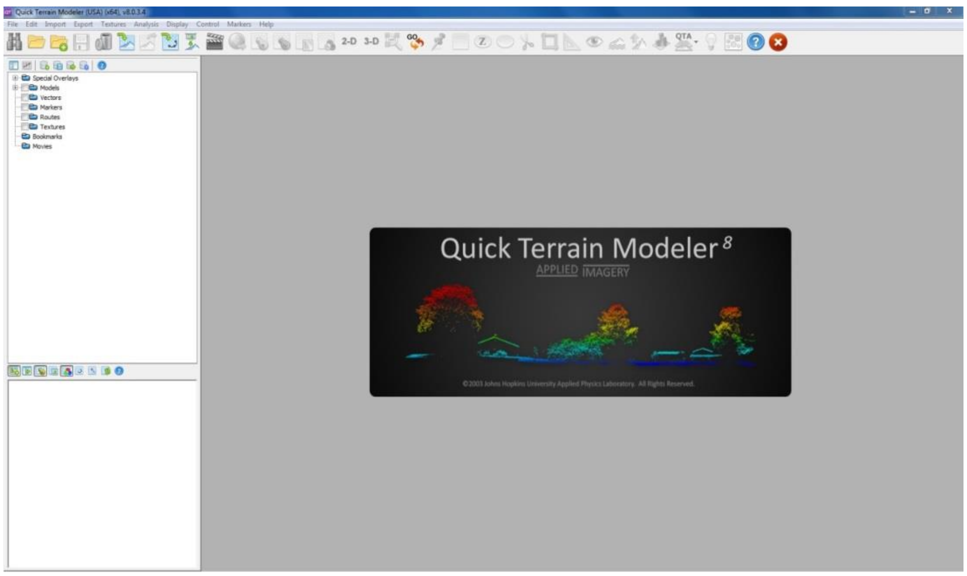
(31)


Extract Compressed (Zipped) Folders
Select a Destination and Extract Files
Files will be extracted to this folder:
ata_Structure\Matrix\LiDAR\ZEB1_Salt_Scans\Original_Data\2015-07-08_12-49-28
Browse...
Show extracted files when complete
Extract
Cancel

(32)

<u>Step 3</u>: Using Quick Terrain Modeler (QTM) to Calculate Salt Tonnage with Collected LiDAR Points

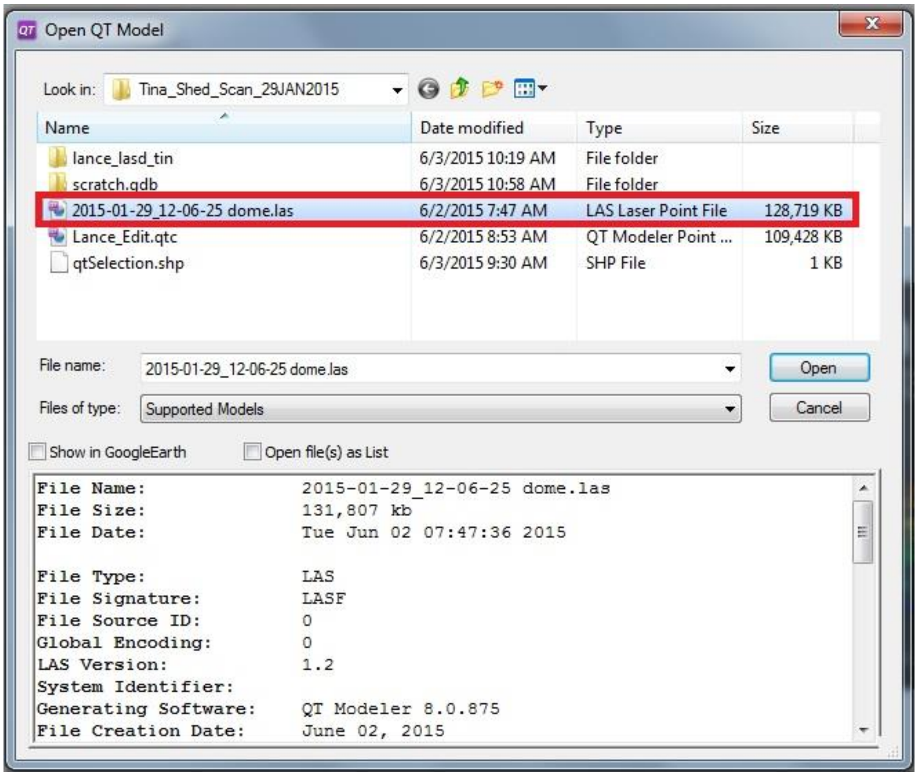
1. Open the QTM program. Image **<u>(33)</u>** shows what the default screen will look like.



<u>(33)</u>

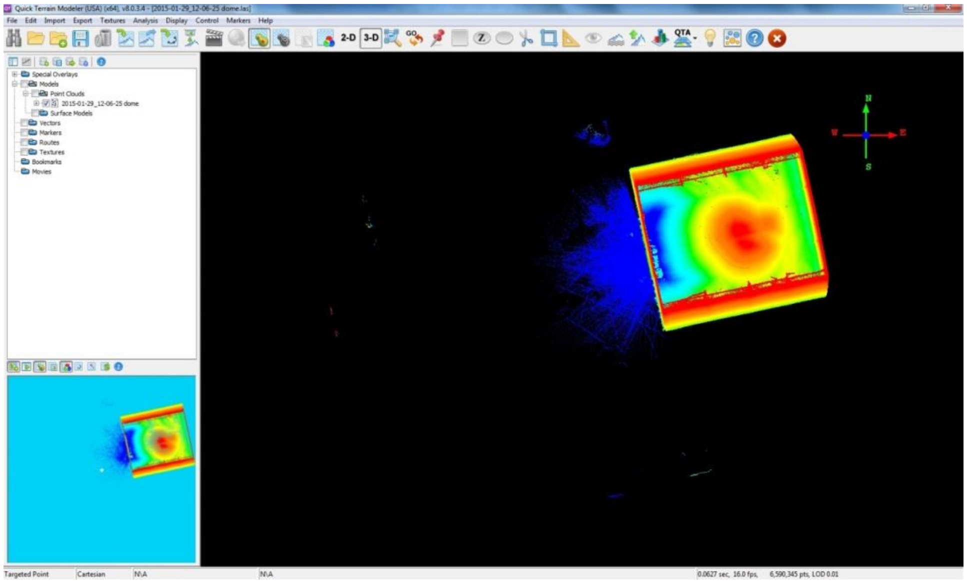
2. Open the successfully converted and extracted ZEB1 LiDAR data – should be in a '.LAS' format (Laser Point File) **<u>(34-35).</u>**

<u>(34)</u>

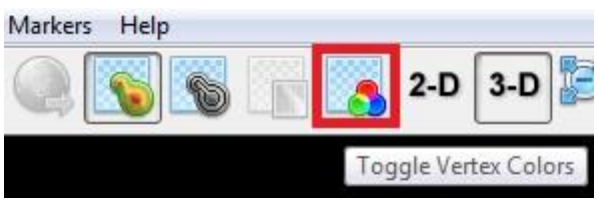


(35)

3. After opening the .LAS LiDAR data file that was created, QTM will default to a 'Top-Down' view of the entire extent of the collection of points. As can be seen in the example **(36)**, if any points were collected outside of your immediate Area of Interest (AOI), they will still be factored in to all future data analysis/calculations. The first thing that will need to be done is to delete all obvious irrelevant points (i.e. anything outside of the salt shed). ***Important to Note***: However, if you are having trouble seeing any data at all, there are a couple things to check. Sometimes the program is defaulted in such a way that the data does not show up instantly by itself. The first thing to do is to make sure that the 'Toggle Height Colors' and 'Toggle 3D Mode' buttons are pressed 'IN' **(37)**. Even if they are, uncheck and check them again. Lastly, check and uncheck the 'Toggle Vertex Colors' button as needed **(38)**. This should take care of any issue of a blank (black) QTM screen where the data is not visible.


(36)

(37)



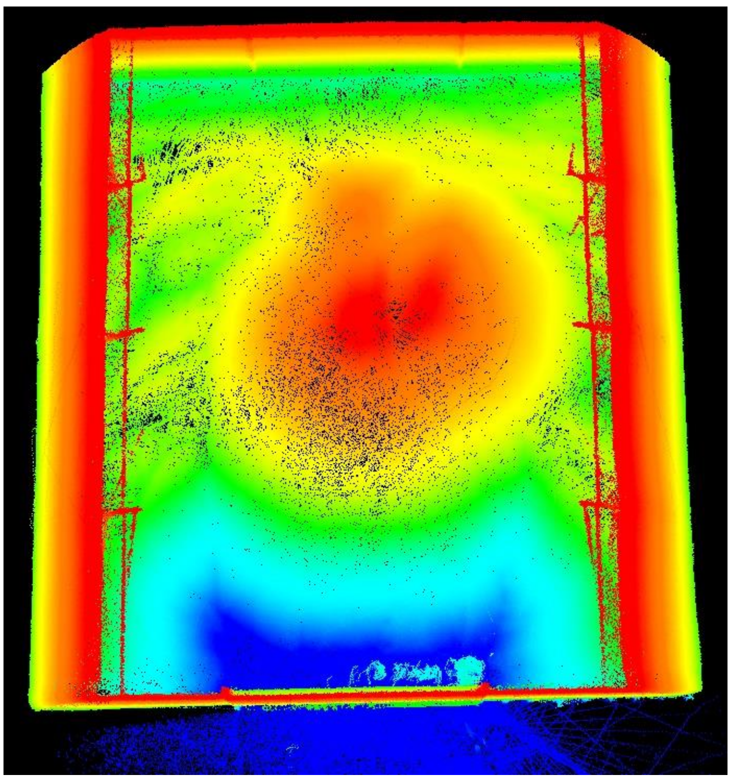
(38)

4. **Data Navigation**: Before beginning to edit the points, there are a few easy ways in which to navigate the data. Firstly, in order to 'zoom in' or 'zoom out', move the mouse scroll either forward (zoom in) or backward (zoom out). To rotate the data in any direction, hold down the left-click button on the mouse and move it as desired. To move the location of the data on the screen without changing the angle or zoom, hold down the right-click button on the mouse and move as needed. The quickest way to automatically go to the fullest extent and 'Top-Down' view of your data is to select the 'Zoom Out' tool shown **(39)**.

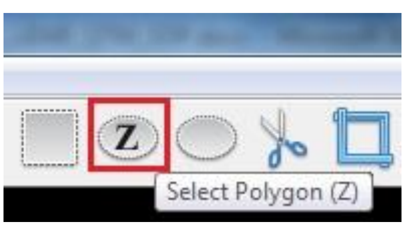
(39)

5. **Initial Cropping**: Now onto 'Crop' the desired data. As shown **(40)**, the LiDAR data that (for the most part) needs to be kept is zoomed in on. After zooming in, click on the 'Select

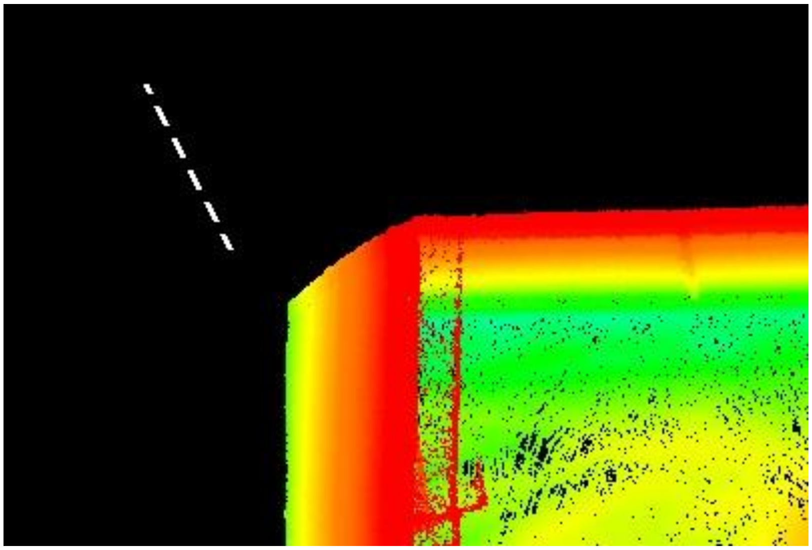
Polygon (Z)' tool **(41)** in order to select your AOI. Once you have chosen the tool, left-click at the point in which you want to start your AOI polygon **(42)**. Then move your mouse to continue making the polygon shape that fits your AOI **(43)**. After you have completed making the required shape, right-click on the mouse in order to finalize the polygon **(44)**. Be sure to notice that the AOI will only include the area shaded in white, not the entire reach of the dotted polygon lines. Lastly, there are two ways to crop the desired data. The first way shown **(45)** is achieved by clicking and holding the 'Ctrl' key and the right-click on the mouse and then selecting 'Crop to Selection' from the menu that pops up – the exact opposite can be accomplished by selecting 'Cut in Selection', which will remove everything within the AOI instead of deleting everything outside of it. The other way to crop your AOI is by clicking on the 'Crop' tool on the menu bar **(46)**. If at any point during an editing session something is mistakenly cut or cropped, go to 'Edit'-> 'Undo to last Cut/Crop' in order to revert the change(s) **(47)**.



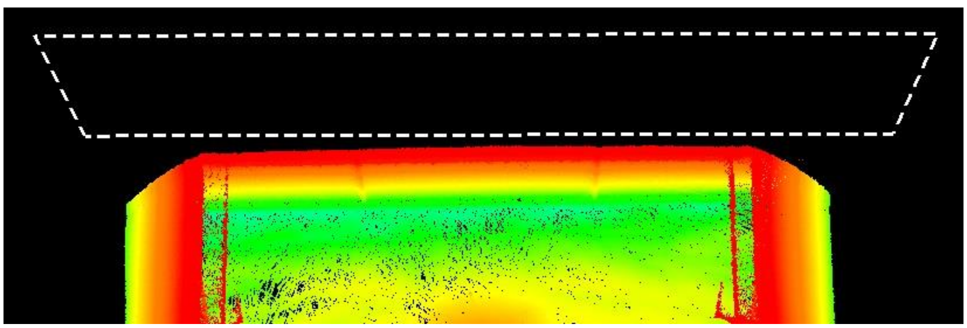
(40)



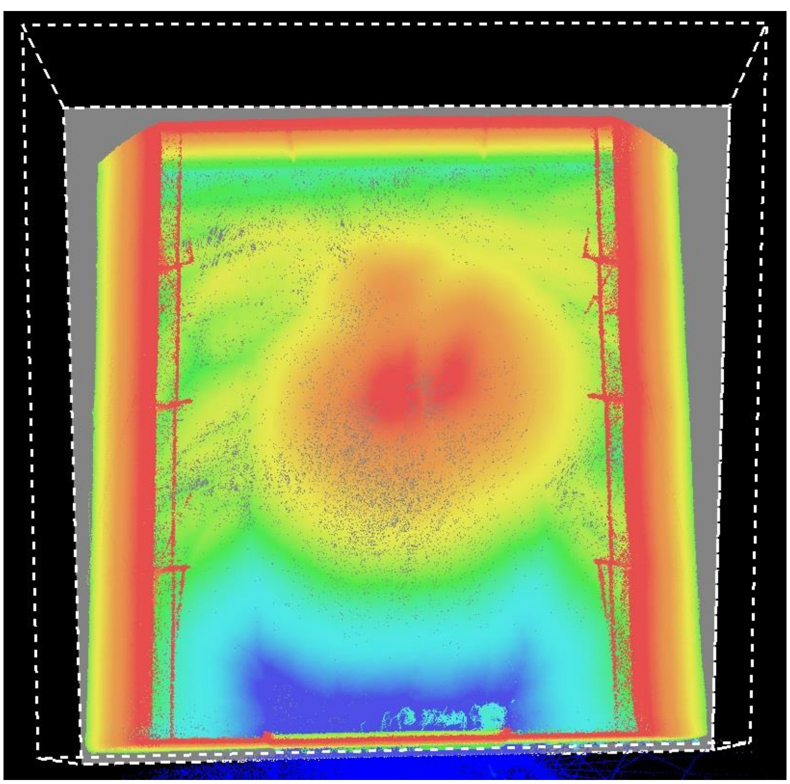
(41)



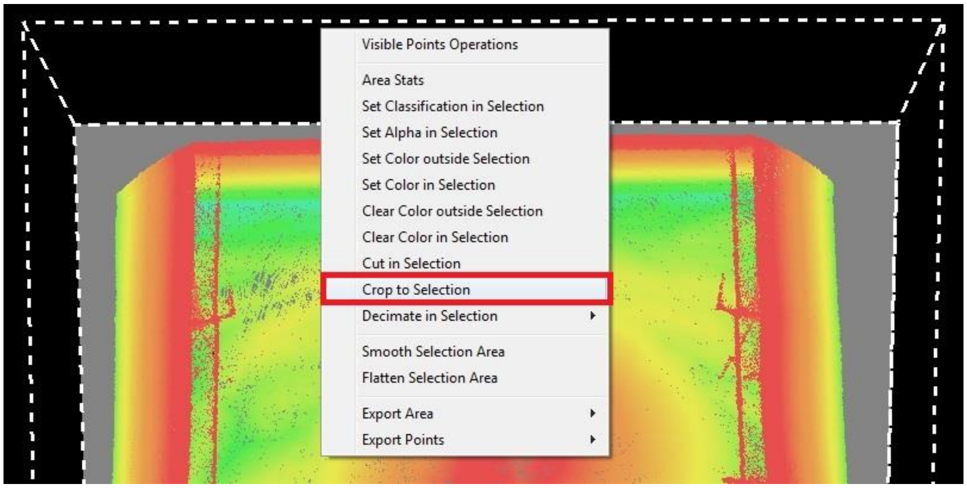
(42)



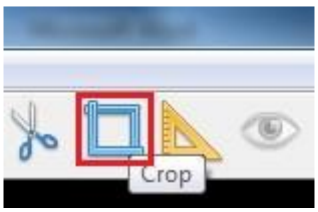
(43)



(44)



(45)

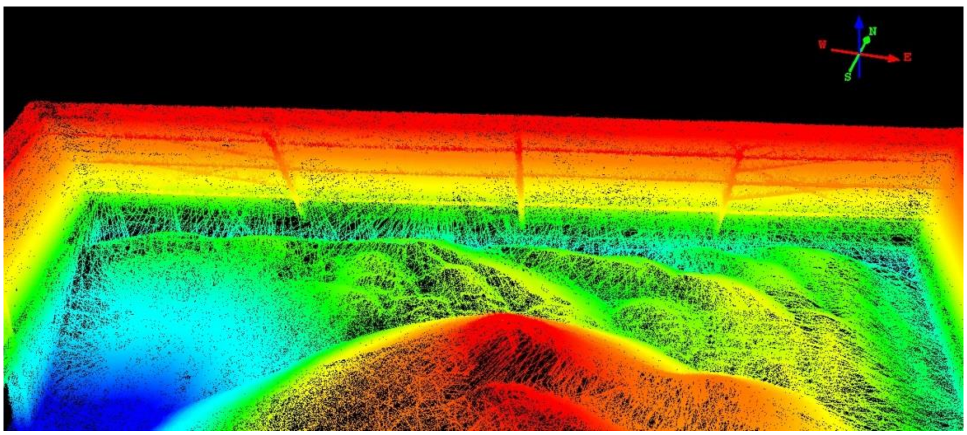


(46)

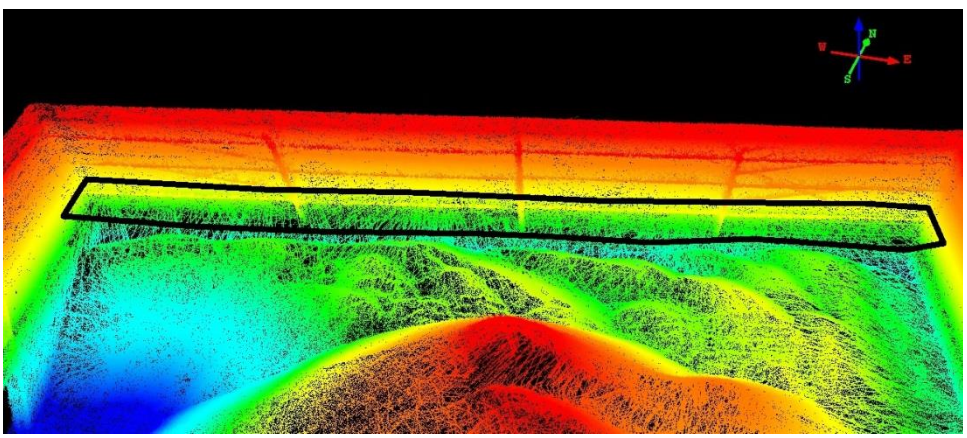
(47)

6. **Detailed Cropping**: After cropping your AOI, it is time to get into much more detail and eliminate as many points as possible that are not either salt or bare floor (which is needed as a base for the volume calculations). Cropping your AOI is the quickest way to delete all immediate outside points, but now to continue forward a little finesse and practice will be needed with the ‘Select Polygon (Screen)’ and ‘Cut’ tools. First, the sides of the walls will need to be removed (at least to where there is no salt against it), as they are the largest and easiest to get rid of. Once you are comfortable with navigating around your data to get the perfect angle/zoom that you want, position the data in such a way that the entirety of one inside wall is exposed to you **(48)**. As you can see in the image **(49)**, there is a black outline that has been drawn to illustrate the green layer of elevation that can be said to safely contain no salt, as the visible salt piles slope downward prior to that part of the wall. Unfortunately, there were no photos taken of this salt shed at the time of data collection, so editing will take a little bit of ‘guess work’. In order to avoid this, it is strongly advised that detailed pictures are taken alongside the LiDAR data for accurate future editing and

processing of points. Once you have zoomed in to the inside of a wall, click on the 'Select Polygon (Screen)' tool **(50)**. Now use this tool by left-clicking part of the wall/area that you want to get rid of. Continue to left-click until you are satisfied with your selection, it should look similar to image **(51)**. After you are done, right-click to finalize your selection. Then choose the 'Cut' tool to remove the points from the rest of the salt shed **(52)**. After doing this, unselect the 'Select Polygon (Screen)' tool by left-clicking on it again, which will remove the area selected and reveal the newly cut space **(53)**. ***Important to Note:*** Do not cut away from a wall looking at it from the outside **(54)**, as the 'Select Polygon (Screen)' tool cuts anything that is in the spatial area selected and is not stopped by the boundary of the wall. By doing this, you will be cutting away salt and other points that are on the inside of the shed **(55-56)**. Once you have finished with removing the major points (e.g. walls), you should have something that looks similar to image **(57)**.

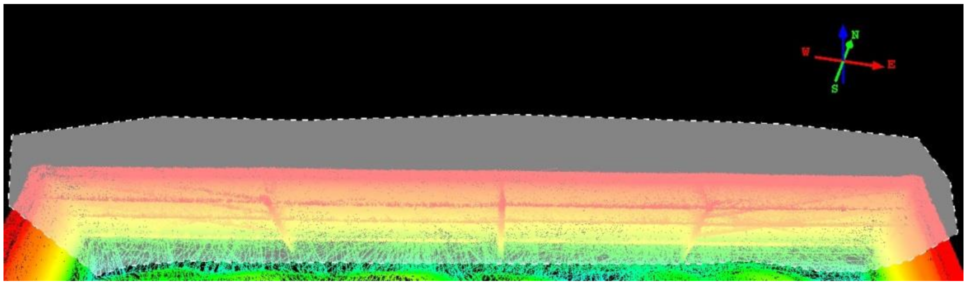


(48)

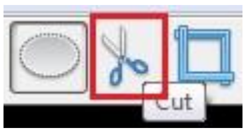


(49)

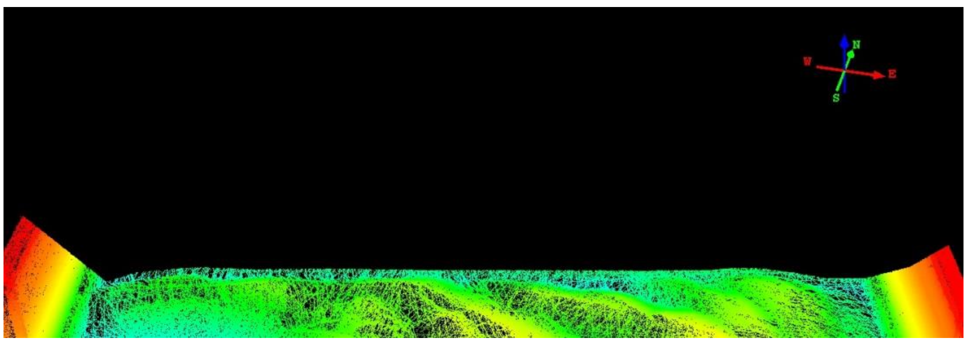
(50)



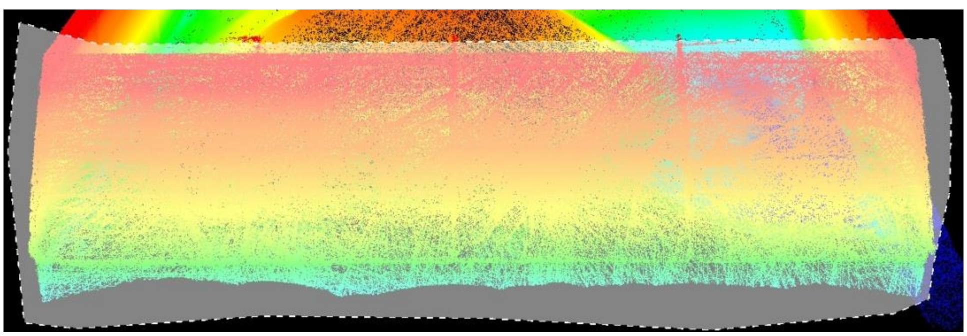
(51)

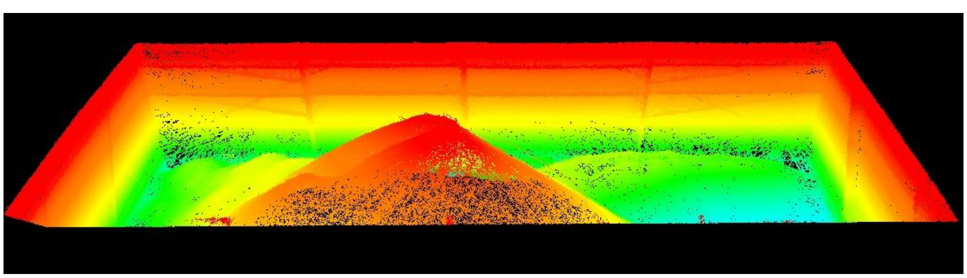


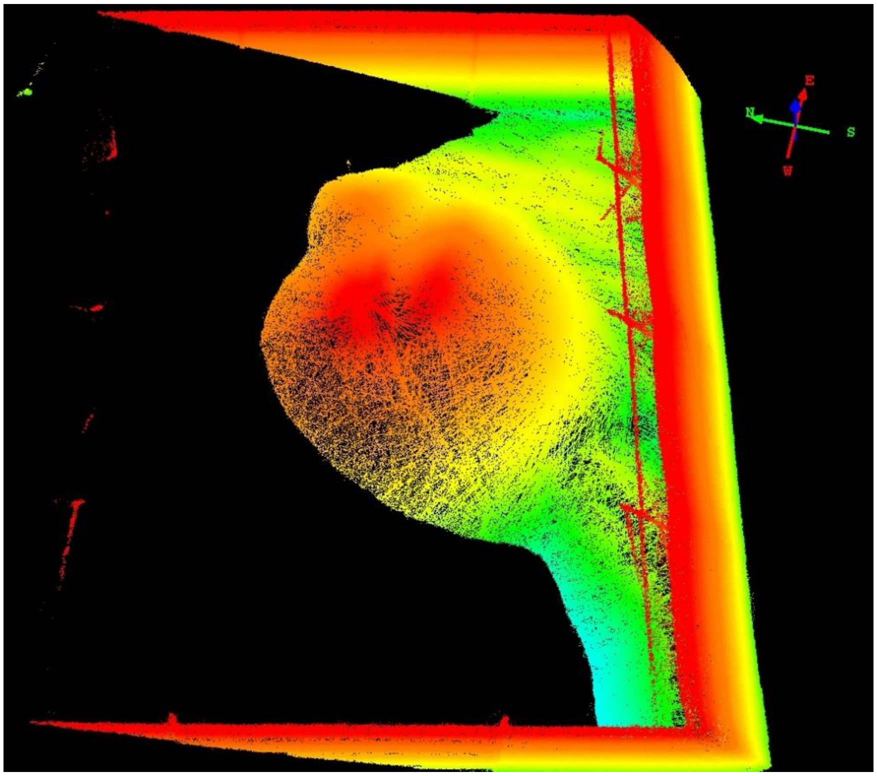
(52)

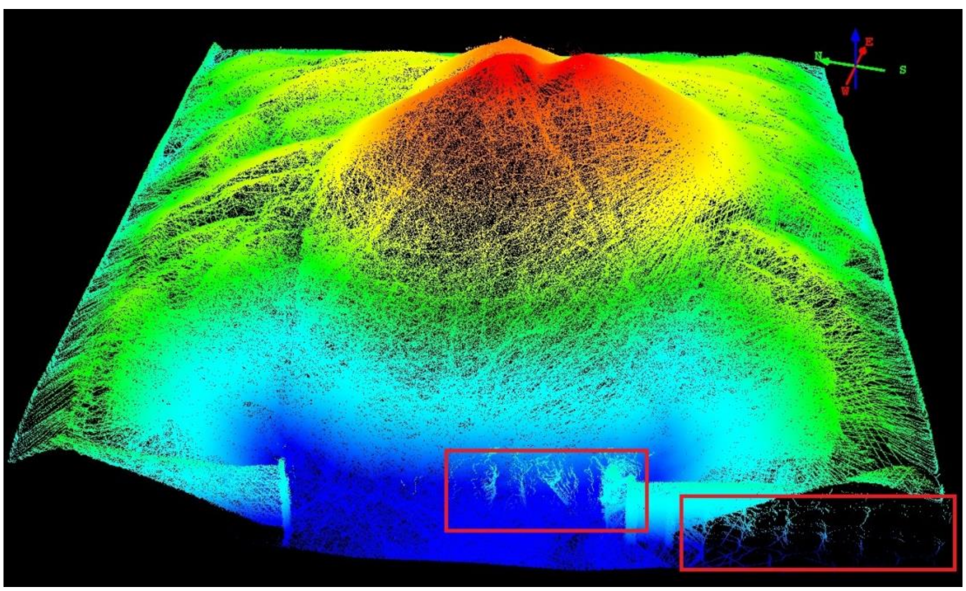


(53)


(54)

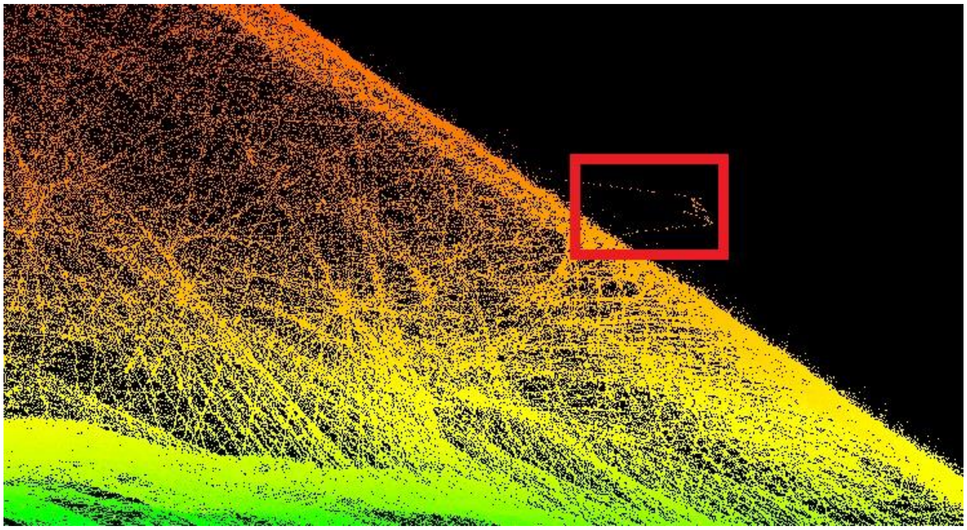

(55)

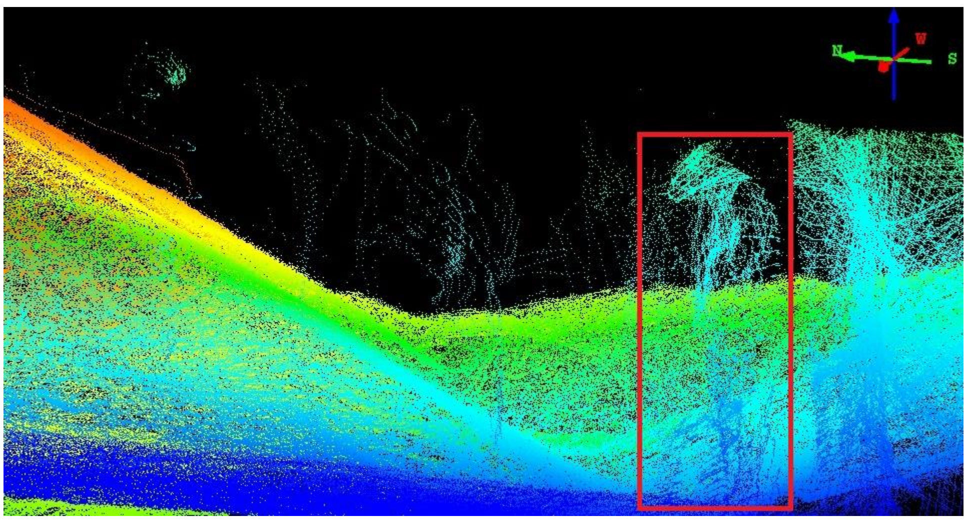

(56)


(57)

7. **Outliers:** Now that the majority of points have been removed that are not either salt or bare floor, it is time to delete any remaining points that are clearly outliers. For example, there are several outliers remaining in image **(57)**, to include the obvious ones at the entrance of the salt shed (which happen to be points of a person captured while taking the scan). There are also a few random salt outliers that have an exaggerated height and should be removed as well **(58)**. The reason for going into such great detail is that the more outliers (non-salt/bare floor points) that exist, the more inaccurate the calculated model will be. In the case of the person who was inadvertently captured via the LiDAR Wand, one will quickly notice that the

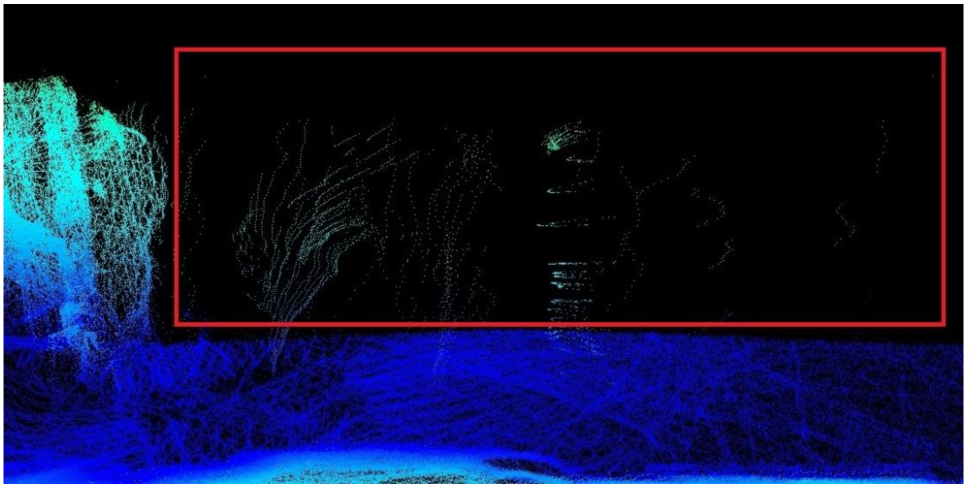
entirety of these points cannot be very easily removed (if at all) via the ‘Select Polygon (Screen)’ tool without deleting other salt points **(59)**. In this situation and any others where a suitable view cannot be achieved to delete outliers without harming any of the desired data, the ‘Start Mensuration’ tool can be used **(60)**. It is strongly advised however to attempt to remove all outliers using the previously aforementioned methods prior to ‘Start Mensuration’, as it is more time consuming and difficult to use. Firstly, move to an angle in which the most amount of outlier points can be removed without the use of the ‘Mensuration’ tool and remove what is possible via the ‘Select Polygon (Screen)’ tool **(61-62)**. In order to clearly show the use of the ‘Mensuration’ tool, the following images are without removing any excess points via the ‘Select Polygon (Screen)’ tool. Once you have selected the ‘Mensuration’ tool a crosshairs mouse icon will appear, left-click at the start of the area with the points you wish to remove **(63)**, creating a red vertical bar. You can choose to continue left-clicking in order to create an area around the points you wish to remove, or you can choose to make a straight line path (either will work). Now, right-click and select the ‘Profile Analysis Tool’ **(64)**. A screen will pop up showing the points you selected **(65)**. It is important to remember that this tool is showing you LiDAR Points from a profile view; i.e. what the points would look like if you were standing there looking straight at them. Therefore, there is naturally a limit to the amount of points that will show up; based upon how much “in front of you” you want to see the definition of. In order to adjust the amount of points, change the value of the ‘width’ **(66)** and then click the ‘Get Buffer Points’ button **(66)**. The easiest way to immediately see all of the points that you are viewing is to first left-click the ‘Select All Points’ button **(67)**, and then left-click ‘Highlight Selected Points in 3D’ **(68)**. This will highlight all of the currently viewed points in red **(69)** outside of the ‘Profile Analysis Tool’, so that you can determine whether or not you have the correct points in view before editing any of them. Alternatively, you can select only the points you want. First, left-click ‘Unselect All Points’ **(70)**, then left-click the ‘Select Area’ tool **(71)**, left-click and drag to draw a red rectangle **(72)** and then choose ‘Select Points in Selection Area’ **(73)**. The points that fall within the rectangle are now the only selected points **(74)**. Once you have selected which points you want to remove, left-click the ‘Operate on Selected Points’ **(75)** button and then select ‘Cut Active Points from Models’ **(76)**. Your desired points have now been deleted and all that is left to do is repeat this process as needed until all unwanted outliers are removed.


(58)

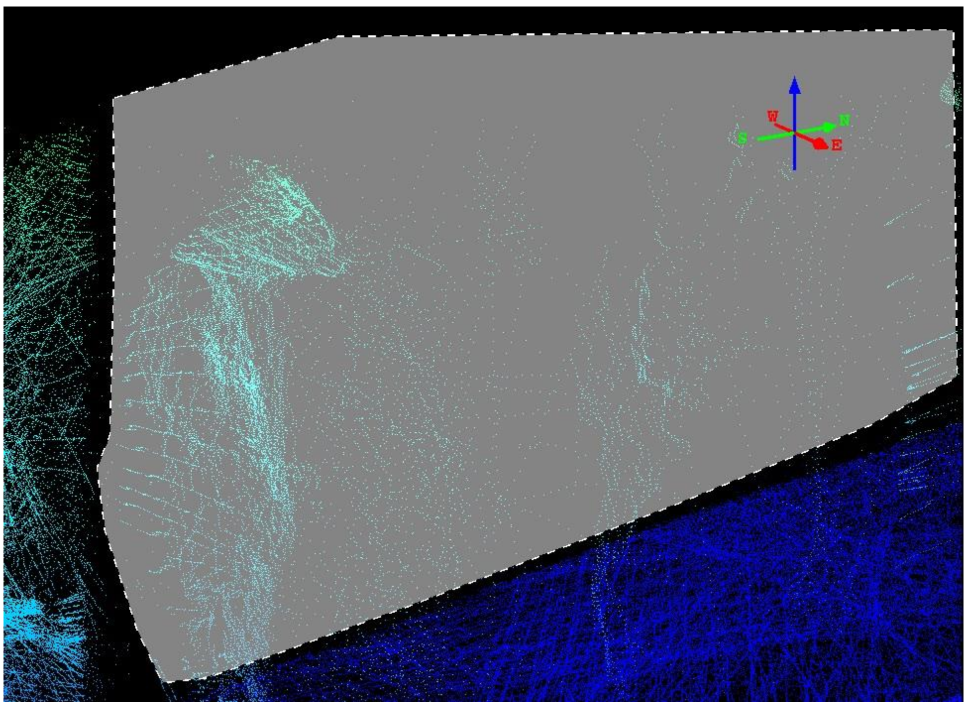


(59)

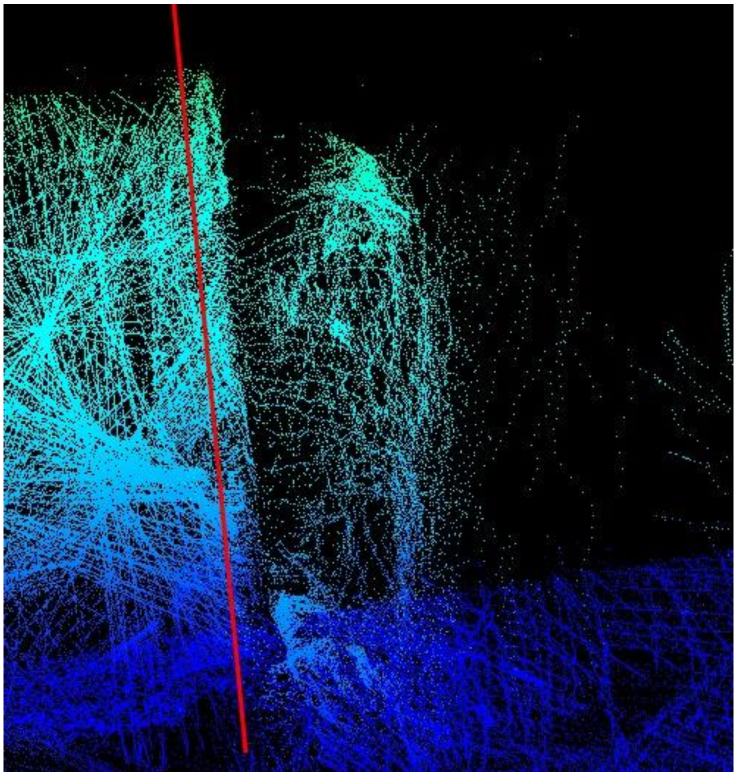
(60)

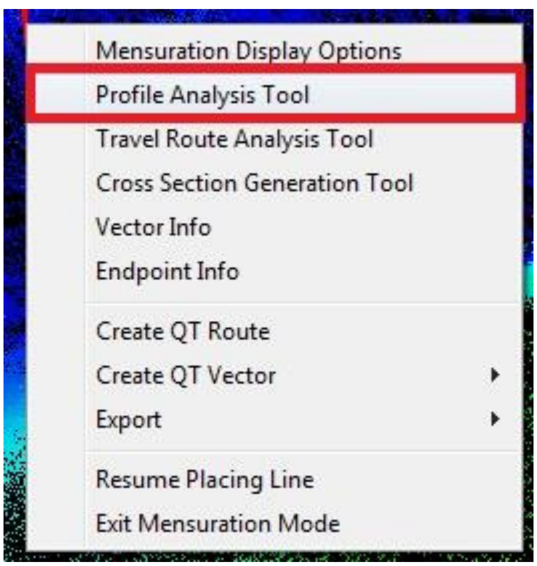


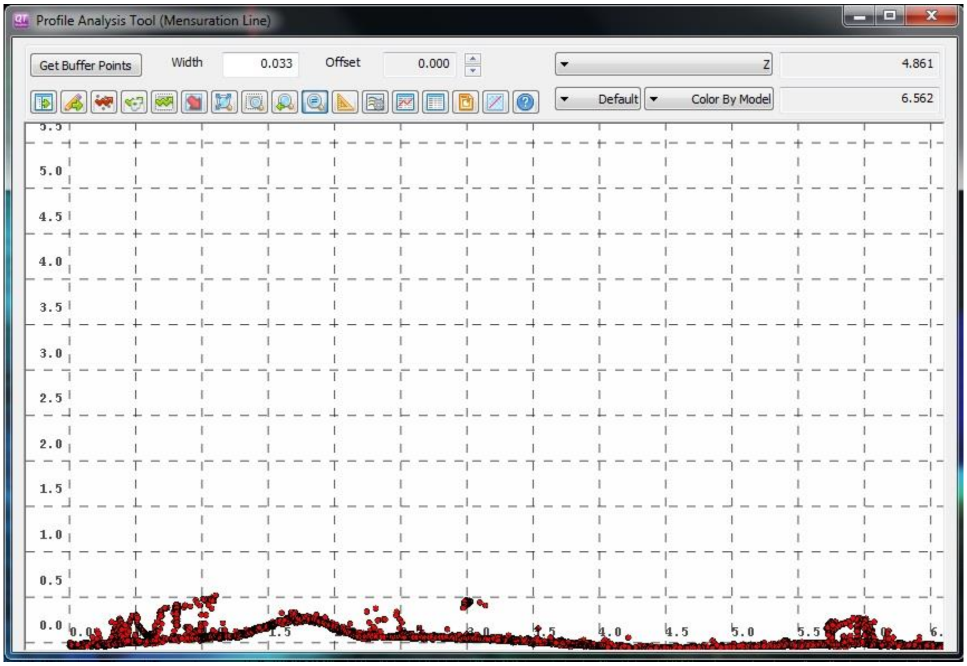
(61)

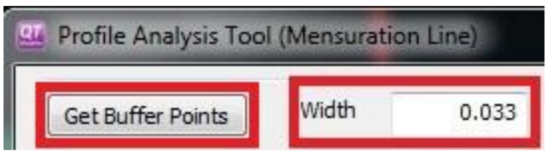


(62)


(63)

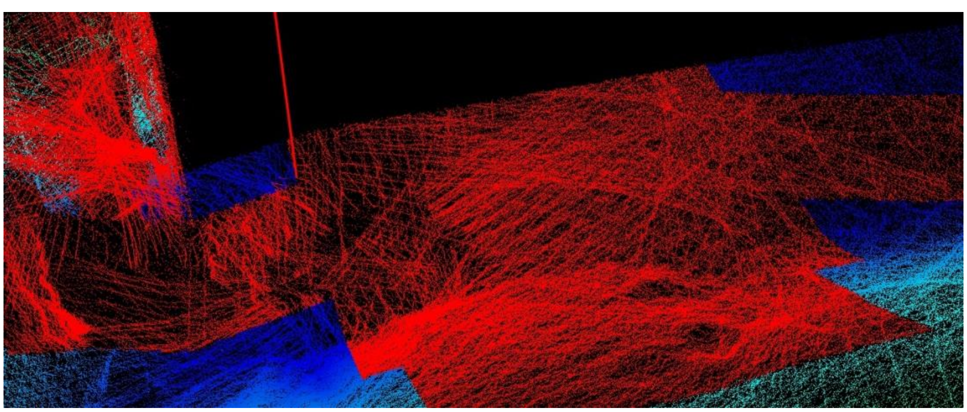

Mensuration Display Options
Profile Analysis Tool
Travel Route Analysis Tool
Cross Section Generation Tool
Vector Info
Endpoint Info
Create QT Route
Create QT Vector
Export
Resume Placing Line
Exit Mensuration Mode
(64)


Profile Analysis Tool (Mensuration Line)
Get Buffer Points
Width
0.033
Offset
0.000
Z
4.861
Default
Color By Model
6.562
(65)


Profile Analysis Tool (Mensuration Line)
Get Buffer Points
Width
0.033
(66)

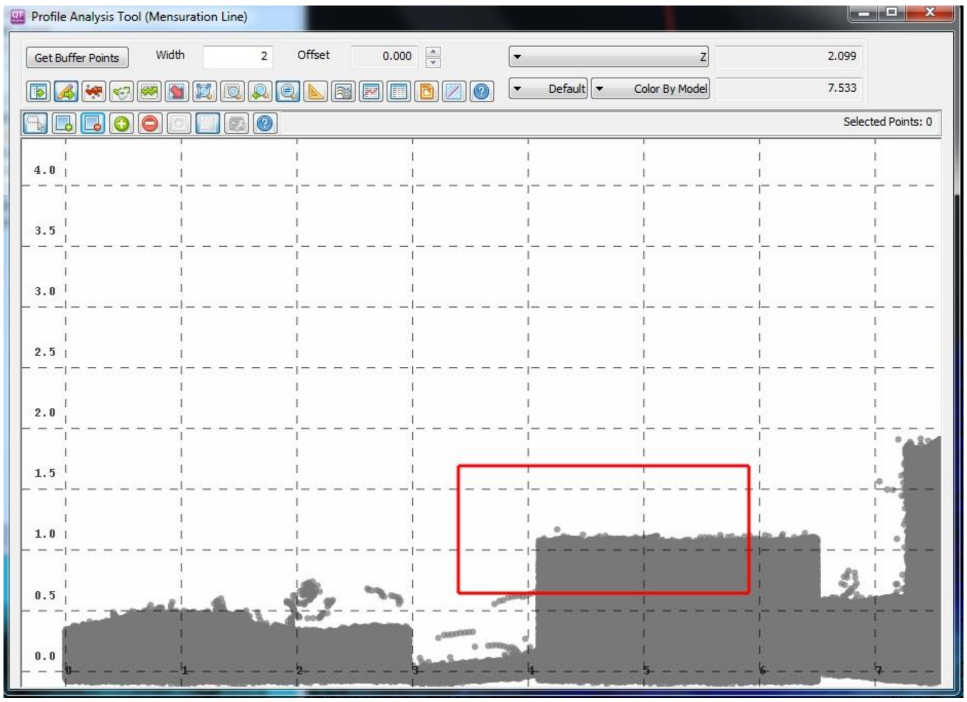

Select All Points
(67)


Highlight Selected Points in 3D
(68)

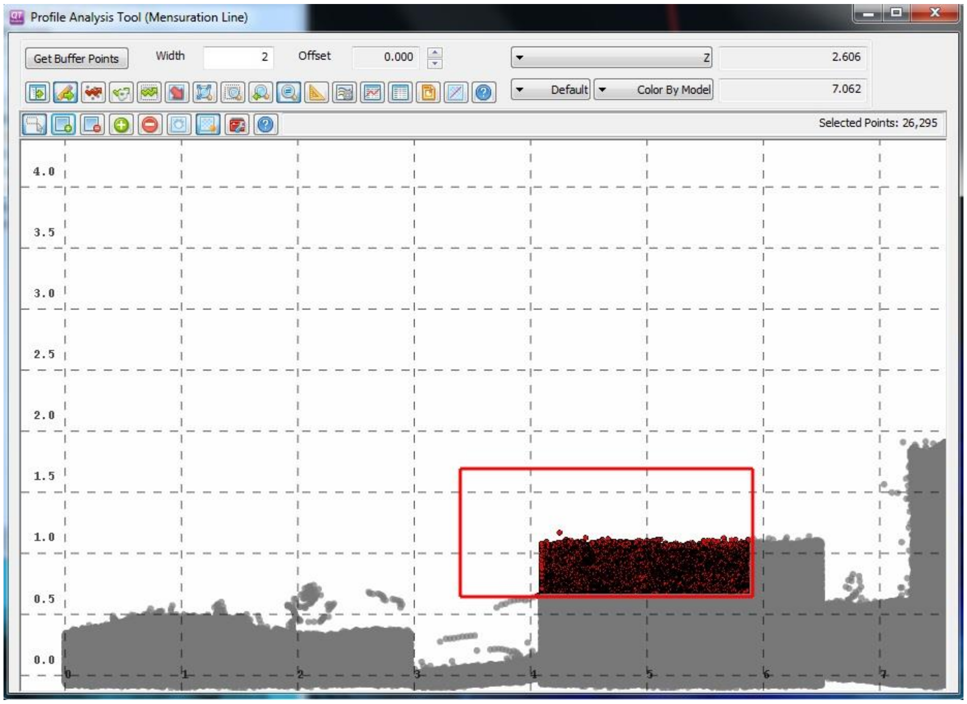

(69)


Unselect All Points
(70)


Select Area
(71)

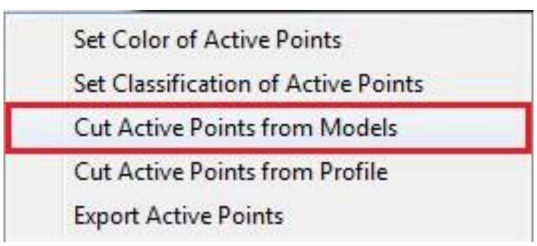

Profile Analysis Tool (Mensuration Line)
Get Buffer Points
Width
2
Offset
0.000
Z
2.099
Default
Color By Model
7.533
Selected Points: 0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(72)


Select Points in Selection Area
(73)



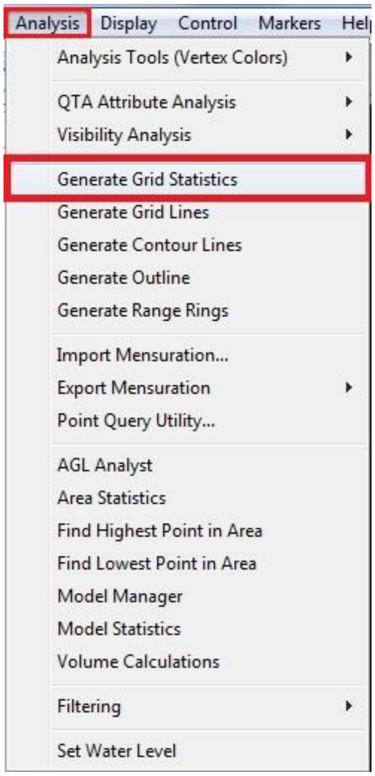
(74)

(75)

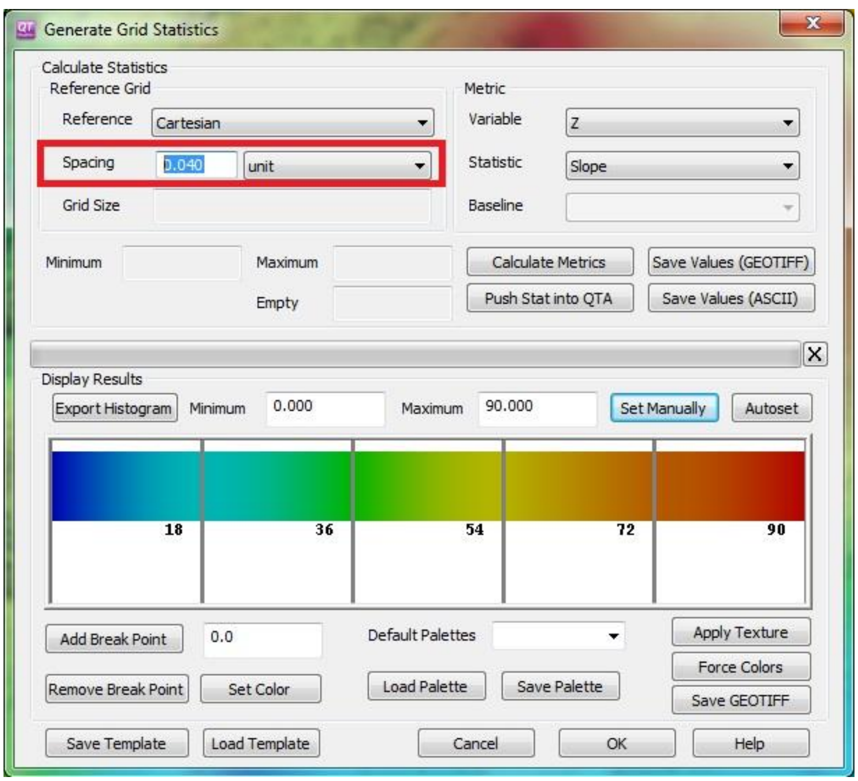


(76)

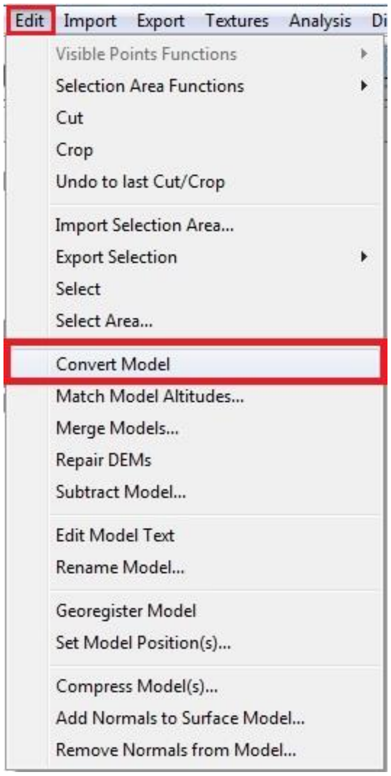
8. **Model Conversion**: Now that the irrelevant points are removed (at least as much as is practical), it is time to convert the LiDAR point cloud into a raster surface. The first step is to figure out the 'spacing' for the LiDAR model. In order to do this, select 'Analysis' -> 'Generate Grid Statistics' **(77)** and then copy the 'Spacing' value **(78)**. After having retrieved this value, the dataset of LiDAR points needs to be converted into a 'Gridded Surface' model. First, select 'Edit' -> 'Convert Model' **(79)**. Once the new window opens, be sure to change the 'Model Format' to 'QTT (Gridded Surface)' **(80)**. Now use the 'Spacing' value that you received from 'Generate Grid Statistics' and paste/type it into the 'Grid Sampling' value **(81)**. Next, select the 'Gridding Options' button **(82)**. With the new window that pops open, make sure that the 'Apply Antialiasing?' option is unchecked, choose 'Mean Z' for the 'Algorithm' option and then click 'OK' **(83)**. Now click 'Convert' on the previous 'Convert Model' window **(84)**. After QTM has finished converting, you will notice a stark change in the appearance of your LiDAR model as it is now a raster surface **(85)**.

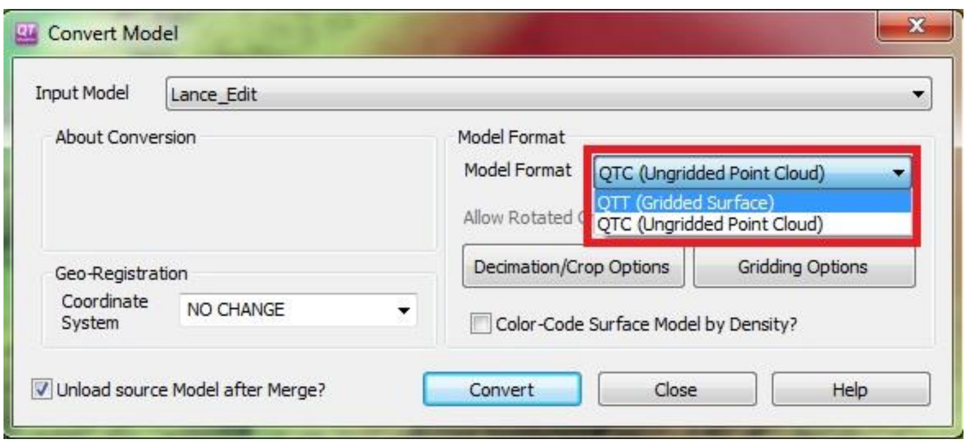

Analysis
Display
Control
Markers
Analysis Tools (Vertex Colors)
QTA Attribute Analysis
Visibility Analysis
Generate Grid Statistics
Generate Grid Lines
Generate Contour Lines
Generate Outline
Generate Range Rings
Import Mensuration...
Export Mensuration
Point Query Utility...
AGL Analyst
Area Statistics
Find Highest Point in Area
Find Lowest Point in Area
Model Manager
Model Statistics
Volume Calculations
Filtering
Set Water Level

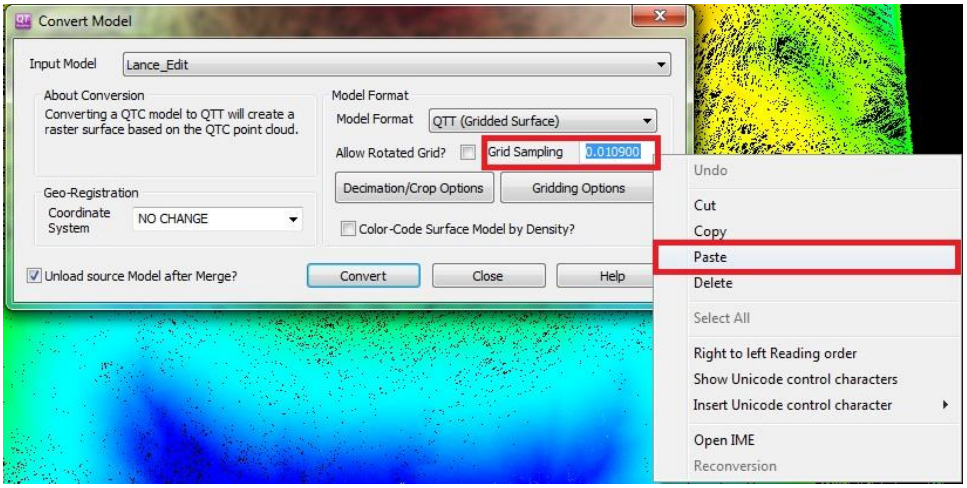
(77)


Generate Grid Statistics
Calculate Statistics
Reference Grid
Reference
Cartesian
Spacing
unit
Grid Size
Metric
Variable
Z
Statistic
Slope
Baseline
Minimum
Maximum
Empty
Calculate Metrics
Save Values (GEOTIFF)
Push Stat into QTA
Save Values (ASCII)
Display Results
Export Histogram
Minimum
0.000
Maximum
90.000
Set Manually
Autoset
18
36
54
72
90
Add Break Point
0.0
Default Palettes
Apply Texture
Force Colors
Remove Break Point
Set Color
Load Palette
Save Palette
Save GEOTIFF
Save Template
Load Template
Cancel
OK
Help

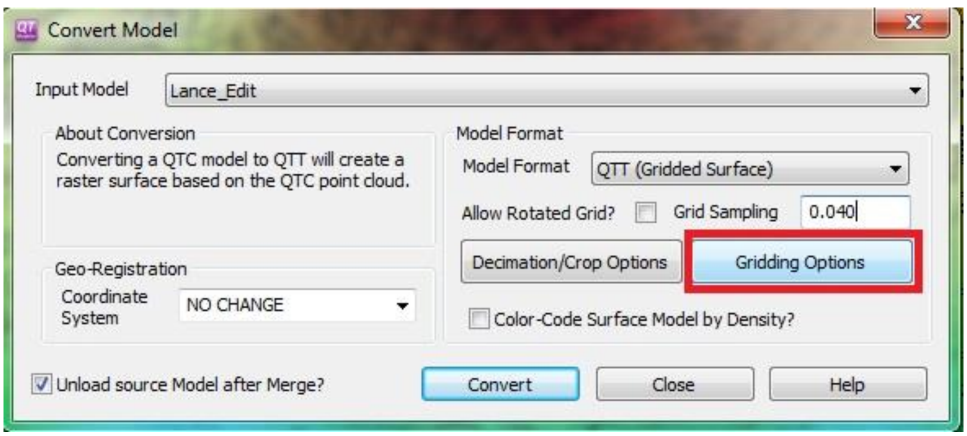
(78)


Edit
Import
Export
Textures
Analysis
Di
Visible Points Functions
Selection Area Functions
Cut
Crop
Undo to last Cut/Crop
Import Selection Area...
Export Selection
Select
Select Area...
Convert Model
Match Model Altitudes...
Merge Models...
Repair DEMs
Subtract Model...
Edit Model Text
Rename Model...
Georegister Model
Set Model Position(s)...
Compress Model(s)...
Add Normals to Surface Model...
Remove Normals from Model...
(79)

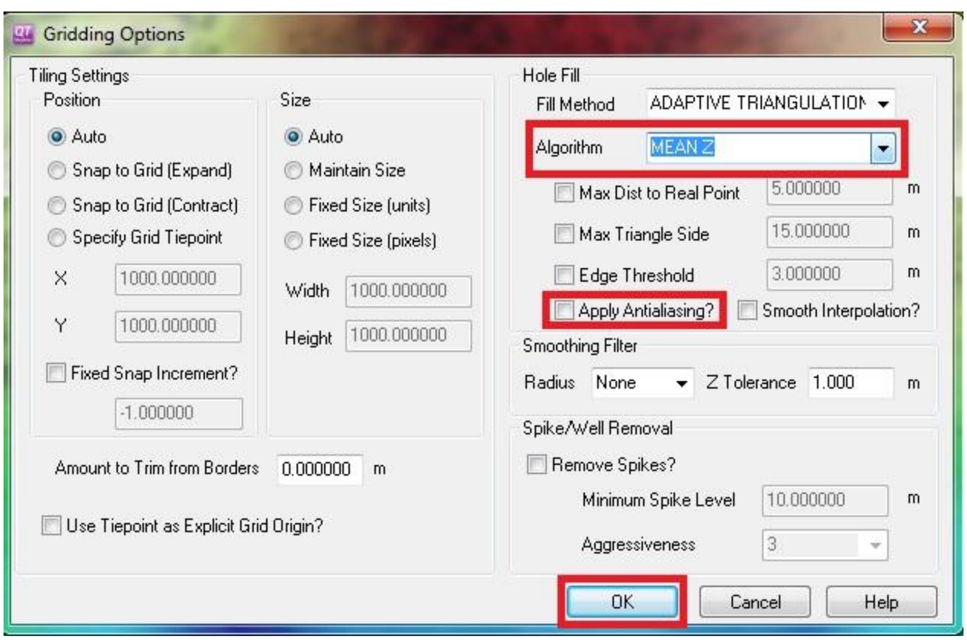

Convert Model
Input Model
Lance_Edit
About Conversion
Model Format
Model Format
QTC (Ungridded Point Cloud)
QTT (Gridded Surface)
QTC (Ungridded Point Cloud)
Allow Rotated
Geo-Registration
Coordinate System
NO CHANGE
Decimation/Crop Options
Gridding Options
Color-Code Surface Model by Density?
Unload source Model after Merge?
Convert
Close
Help
(80)


Convert Model
Input Model
Lance_Edit
About Conversion
Converting a QTC model to QTT will create a raster surface based on the QTC point cloud.
Model Format
Model Format
QTT (Gridded Surface)
Allow Rotated Grid?
Grid Sampling
0.010900
Geo-Registration
Coordinate System
NO CHANGE
Decimation/Crop Options
Gridding Options
Color-Code Surface Model by Density?
Unload source Model after Merge?
Convert
Close
Help
Undo
Cut
Copy
Paste
Delete
Select All
Right to left Reading order
Show Unicode control characters
Insert Unicode control character
Open IME
Reconversion

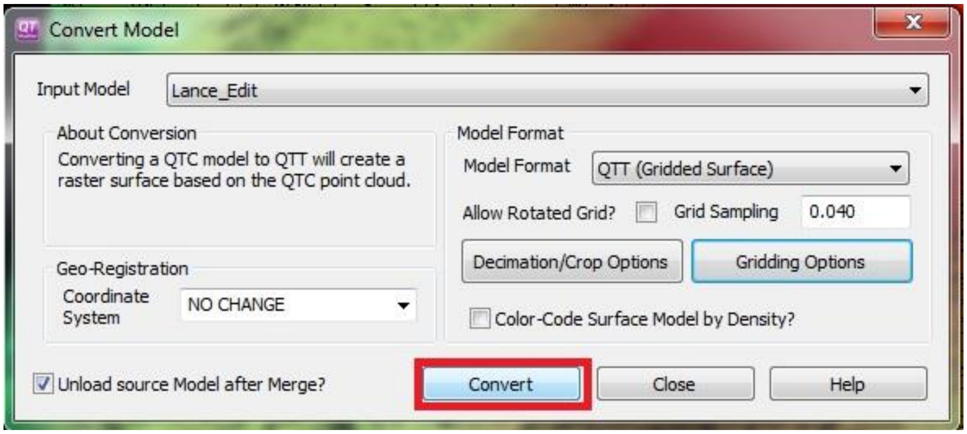
(81)


Convert Model
Input Model
Lance_Edit
About Conversion
Converting a QTC model to QTT will create a raster surface based on the QTC point cloud.
Model Format
Model Format
QTT (Gridded Surface)
Allow Rotated Grid?
Grid Sampling
0.040
Decimation/Crop Options
Gridding Options
Geo-Registration
Coordinate System
NO CHANGE
Color-Code Surface Model by Density?
Unload source Model after Merge?
Convert
Close
Help

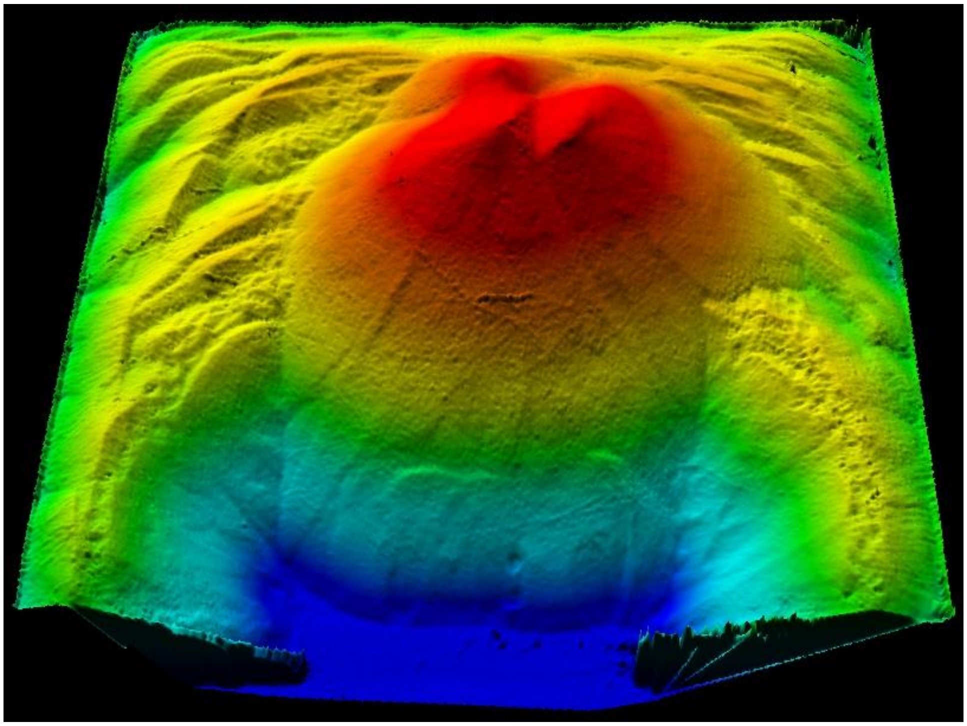
(82)


Gridding Options
Tiling Settings
Position
Auto
Snap to Grid (Expand)
Snap to Grid (Contract)
Specify Grid Tiepoint
X
1000.000000
Y
1000.000000
Fixed Snap Increment?
-1.000000
Size
Auto
Maintain Size
Fixed Size (units)
Fixed Size (pixels)
Width
1000.000000
Height
1000.000000
Amount to Trim from Borders
0.000000
m
Use Tiepoint as Explicit Grid Origin?
Hole Fill
Fill Method
ADAPTIVE TRIANGULATION
Algorithm
MEAN Z
Max Dist to Real Point
5.000000
m
Max Triangle Side
15.000000
m
Edge Threshold
3.000000
m
Apply Antialiasing?
Smooth Interpolation?
Smoothing Filter
Radius
None
Z Tolerance
1.000
m
Spike/Well Removal
Remove Spikes?
Minimum Spike Level
10.000000
m
Aggressiveness
3
OK
Cancel
Help

(83)

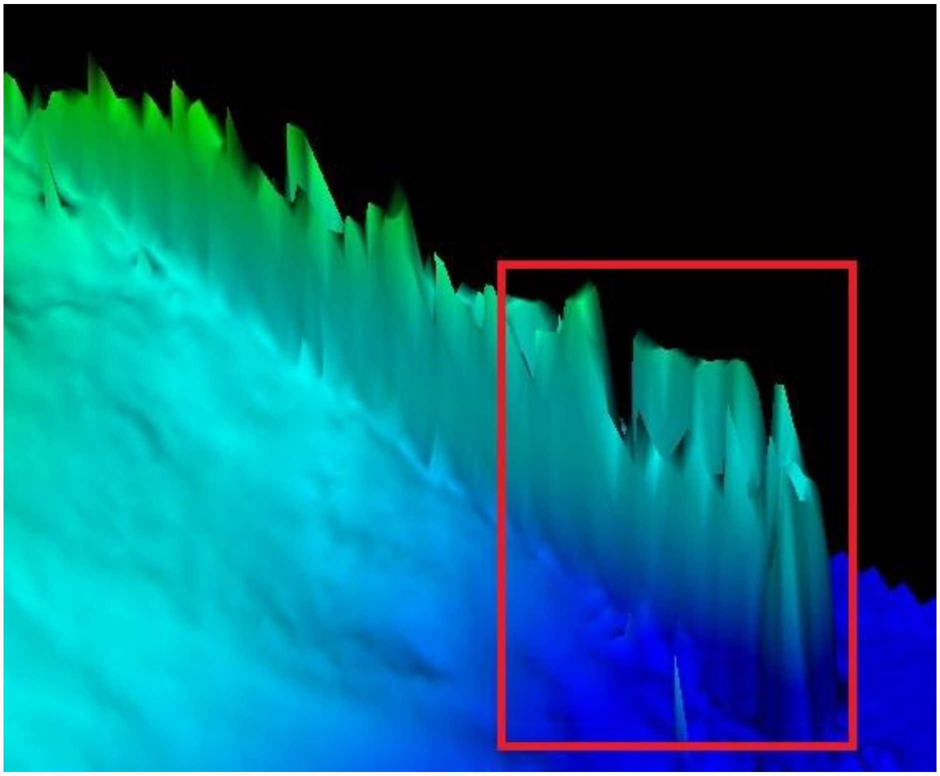


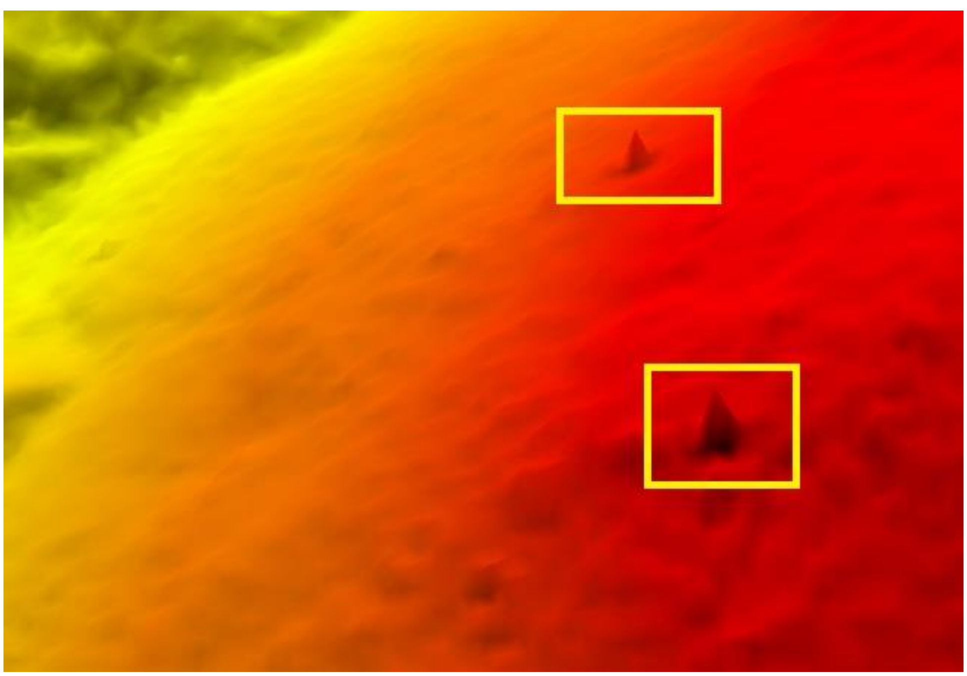
(84)

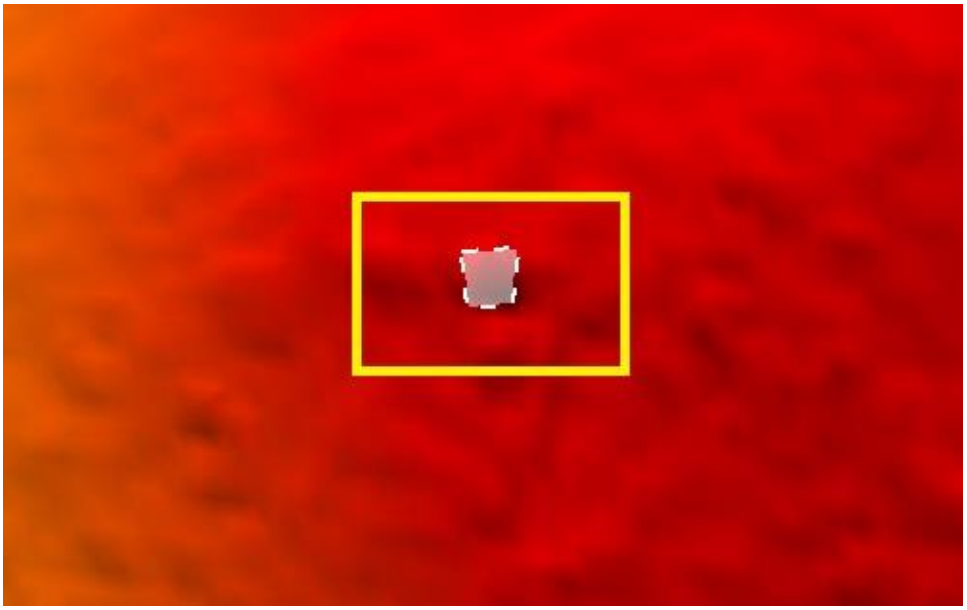

(85)

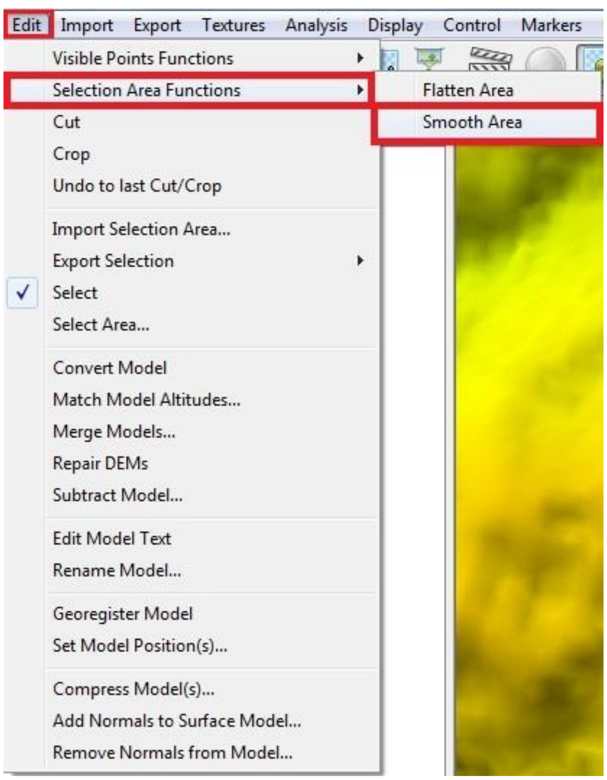
9. **Raster Surface Touchup**: With the new raster surface created, you may now notice some 'spikes' or 'pointy' areas in which there were outliers that were originally missed and not properly disposed of. Having these extra elevated points causes the creation of these 'spikes', which will now need to either be deleted or 'smoothened'. Image **(86)** displays a great example of this, which shows the building walls showing up as 'spikes' in the data. Also, image **(87)** is a good example of outlier salt points that had erroneous height values, which led to 'spikes' or 'high points' in the salt. Whichever option is easiest for your dataset (deletion or smoothing) is how the anomalies in the data should be taken care of. In order to 'smooth' a spike/high point, first locate an area that you want to fix. Then make sure you are viewing it from a top-down angle and click the 'Select Polygon (Screen)' tool and select the area that needs to be smoothed **(88)**. Lastly, select 'Edit' -> 'Selection Area Functions' -> 'Smooth Area' **(89)**. This will smooth your peak to that of the mean surrounding values **(90)**.

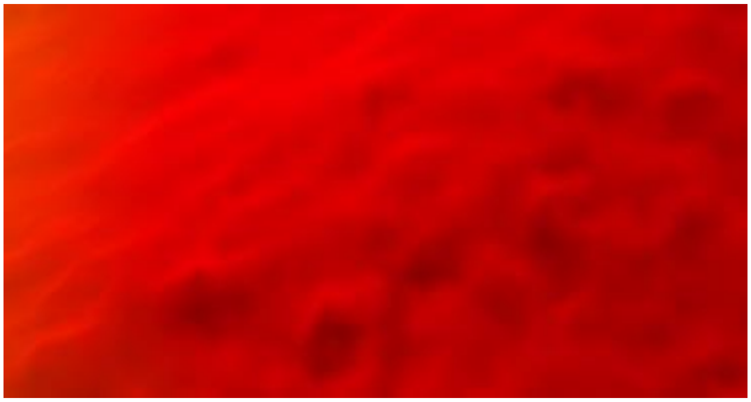
Repeat this process as needed (a few may not throw off the entire calculation very much, but depending on your desired accuracy, the more anomalies that are fixed, the better).


(86)


(87)


(88)


Edit
Import
Export
Textures
Analysis
Display
Control
Markers
Visible Points Functions
Selection Area Functions
Flatten Area
Smooth Area
Cut
Crop
Undo to last Cut/Crop
Import Selection Area...
Export Selection
Select
Select Area...
Convert Model
Match Model Altitudes...
Merge Models...
Repair DEMs
Subtract Model...
Edit Model Text
Rename Model...
Georegister Model
Set Model Position(s)...
Compress Model(s)...
Add Normals to Surface Model...
Remove Normals from Model...
(89)

 **(90)**

10. **Salt Volume Calculation**: With a completed raster surface, the final salt volume calculations are ready to be processed. The first step is to go to 'Analysis' -> 'Set Water Level' **(91)**. The point of doing this is to establish a base level height in which the calculations will be based on (bare floor essentially). When the 'Set Water Properties' window appears, use the up/down arrows of the 'Water Level' to find an appropriate level that suits your data **(92)**. Once you are comfortable with it, copy the 'Water Level' value **(92)**. Now zoom out to your dataset's fullest extent and use the 'Select Polygon (Z)' tool to select the entire area of your raster surface **(93)**. Go to 'Analysis' -> 'Volume Calculations' **(94)**, and with the new window open select 'Volume of 1 Above 2' from the drop-down of 'Comparison' **(95)**. Next, paste the 'Water Level' value into the 'Reference' input **(96)** and finally click 'Calculate' **(97)** in order to receive your 'Flat Surface Volume'. With this calculation value, now open the 'Excel Calculation' spreadsheet (excel_calculation.xlsx). This excel document is both for reference as to what values were used to calculate the total volume (for others to test against), as well as the total volume calculation itself. In the spreadsheet **(98)** enter in the calculated 'Flat Surface Volume' into Line 11 (*Enter Flat Surface Volume), the weight of the 5-gallon bucket filled with salt (line 5, *Enter Bucket Weight) and the 'Water Level' value into line 3 (*Enter Water Level). Entering the values will cause the excel document to automatically do the calculations needed to provide the other information listed, to include the main objective of this SOP, salt tonnage (Line 14, Tons).

11. **Calculations (Further Detailed)**: Although the pre-existing excel document does the calculations automatically, the following is an explanation of how to get the salt volume in tons manually. **NOTE**: For ease of reading, this example only uses two decimal places for calculations. However, the more precise you want your total, the more additional decimal points are advised. As it cannot be overstated that due to the large volumes that are commonly worked with in salt sheds/domes, even slight differences in numbers can lead to exponentially different outcomes.
    a. *Weigh a 5-gallon bucket while completely empty. The bucket used in this SOP weighed 775.2 grams (1.7090235 lbs.)*
    b. *Take the 5-gallon bucket and completely fill it with salt (make sure top is leveled off for consistency each iteration)*
    c. *Take the weight of the bucket (e.g. 55.35 lbs.) and subtract the bucket's empty weight from it (55.35 lbs. – 1.71 lbs. = 53.64 lbs.)*

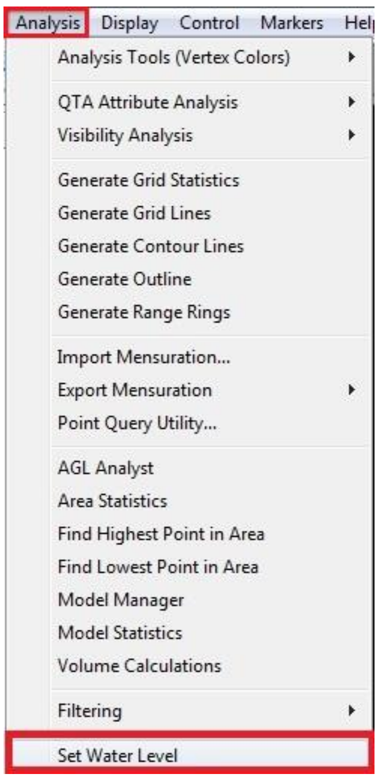
d. Divide the weight of the 5-gallon bucket (salt only: 53.64 lbs.) by the equivalent cubic meter (5-gallons = 0.0189271 m^3), so 53.64 lbs./0.0189271 m^3 = 2,834.03 lbs. per m^3

e. Now multiply the answer above by the volume in cubic meters determined by the 'Flat Surface Volume' of the scanned salt shed in QTM. 2,834.03 lbs. per m^3 x 1150.88 m^3 (example from Spirit Lake) = 3,261,628.44 lbs.

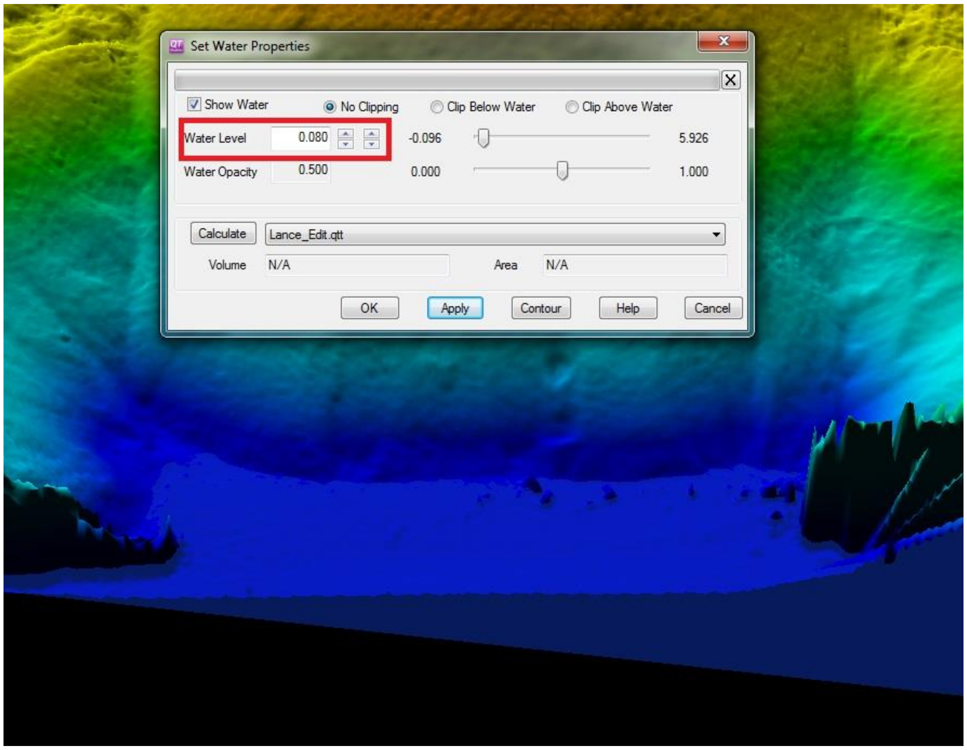
f. Lastly, divide the answer by 2,000 lbs. (1 Short Ton), in order to get the total amount of tons (3,261,628.44 lbs. / 2,000 lbs. = ***1,630.81 tons****)*

12. QTM Tutorial Videos*:*

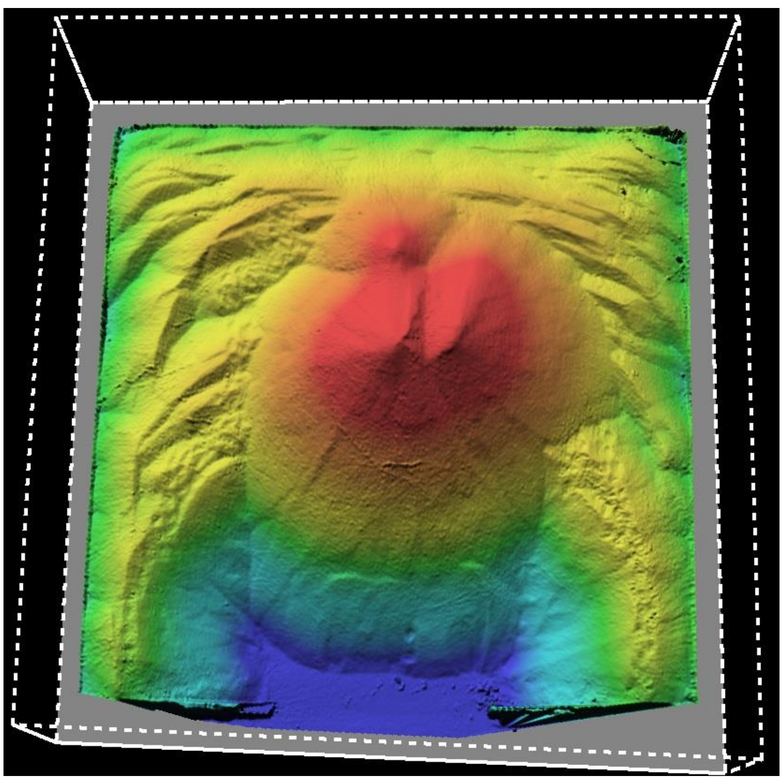
g. Further help with various tutorials on using the tools within QTM can be viewed here: *http://appliedimagery.com/tutorials*



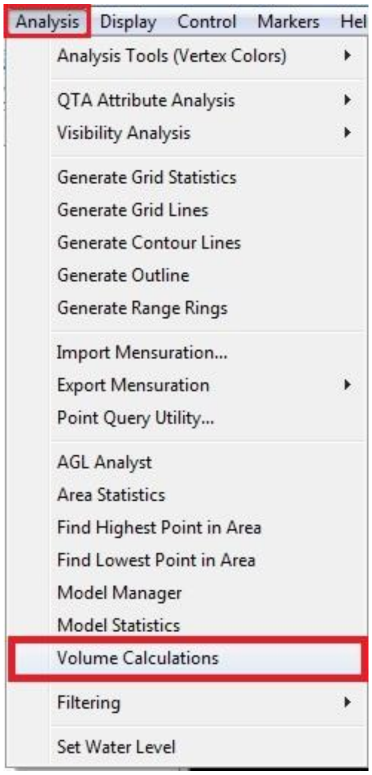
(91)

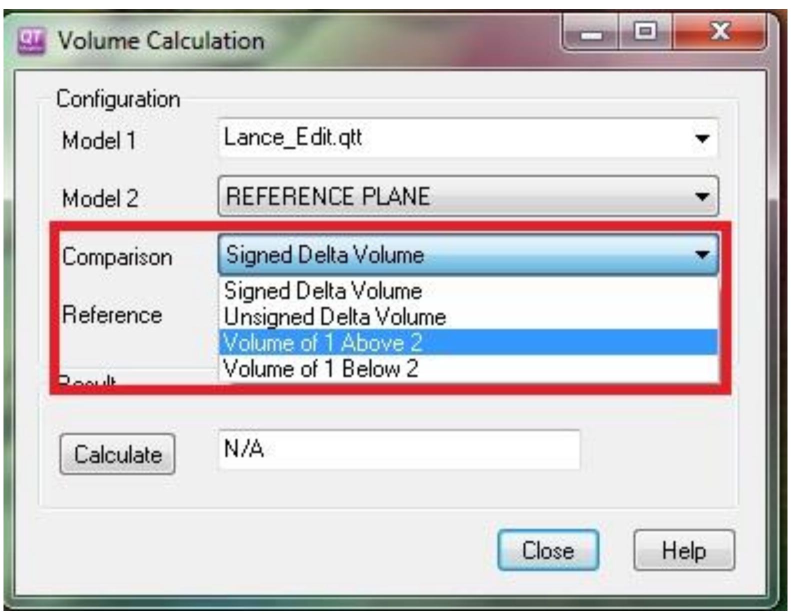

Set Water Properties
Show Water
No Clipping
Clip Below Water
Clip Above Water
Water Level
0.080
-0.096
5.926
Water Opacity
0.500
0.000
1.000
Calculate
Lance_Edit.qtt
Volume
N/A
Area
N/A
OK
Apply
Contour
Help
Cancel

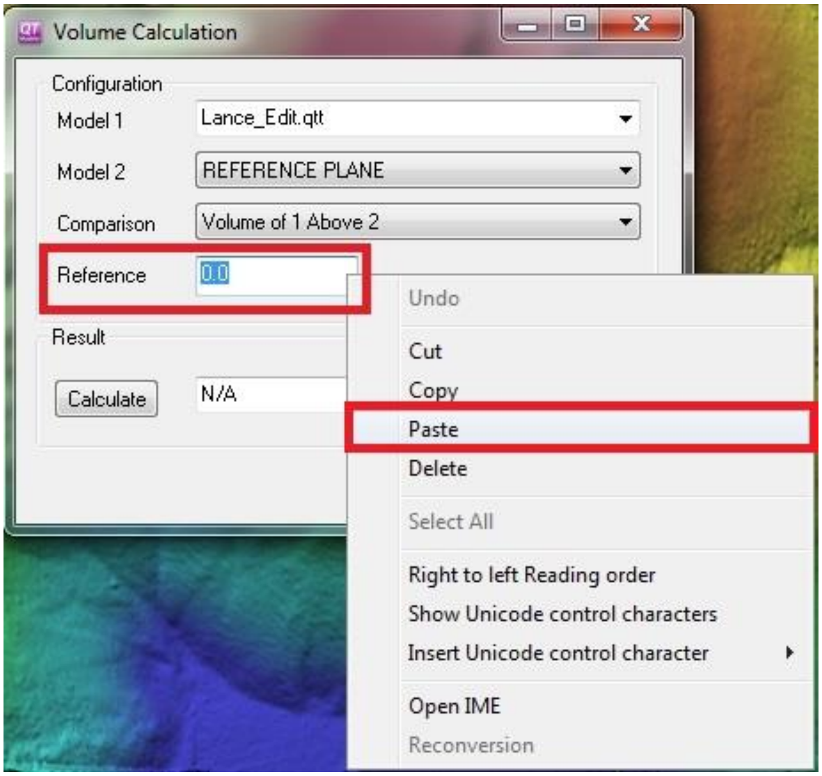
(92)



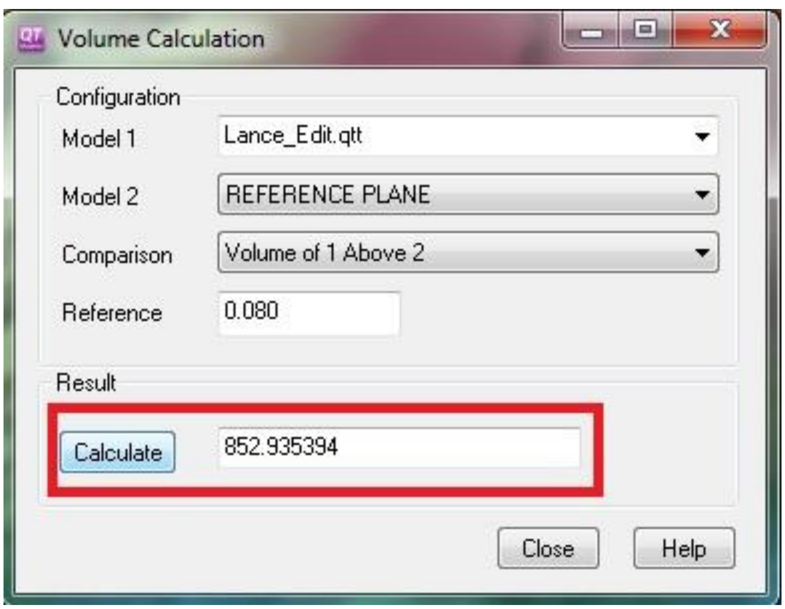
(93)


Analysis
Display
Control
Markers
Hel
Analysis Tools (Vertex Colors)
QTA Attribute Analysis
Visibility Analysis
Generate Grid Statistics
Generate Grid Lines
Generate Contour Lines
Generate Outline
Generate Range Rings
Import Mensuration...
Export Mensuration
Point Query Utility...
AGL Analyst
Area Statistics
Find Highest Point in Area
Find Lowest Point in Area
Model Manager
Model Statistics
Volume Calculations
Filtering
Set Water Level
(94)


Volume Calculation
Configuration
Model 1
Lance_Edit.qtt
Model 2
REFERENCE PLANE
Comparison
Signed Delta Volume
Signed Delta Volume
Unsigned Delta Volume
Volume of 1 Above 2
Volume of 1 Below 2
Reference
Calculate
N/A
Close
Help
(95)


Volume Calculation
Configuration
Model 1
Lance_Edit.qtt
Model 2
REFERENCE PLANE
Comparison
Volume of 1 Above 2
Reference
0.0
Result
Calculate
N/A
Undo
Cut
Copy
Paste
Delete
Select All
Right to left Reading order
Show Unicode control characters
Insert Unicode control character
Open IME
Reconversion

(96)

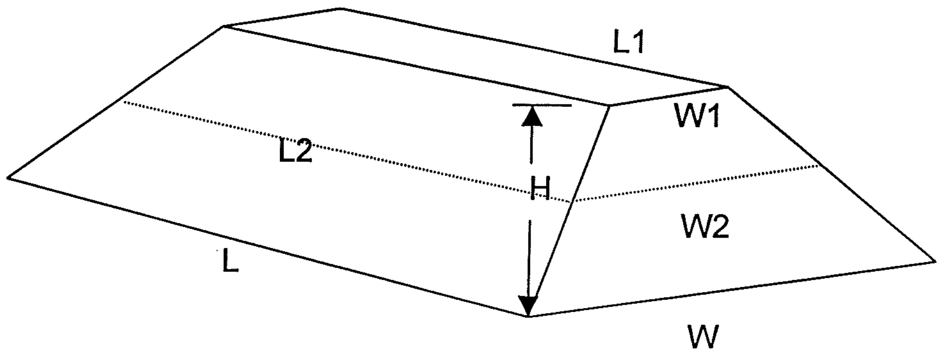

Volume Calculation
Configuration
Model 1
Lance_Edit.qtt
Model 2
REFERENCE PLANE
Comparison
Volume of 1 Above 2
Reference
0.080
Result
Calculate
852.935394
Close
Help

(97)

	A	B	C
1	Newton - Lance		
2			
3	QTM water level setting	-0.42	*Enter water level
4			
5	5 gallon bucket weight:	57.12	*Enter bucket weight
6	Salt weight	55.4109765	
7			
8	lbs per cubic foot	82.90055027	
9	lbs per cubic meter	2927.599923	
10			
11	Cubic meters (from flat surface)	244.876402	*Enter flat surface volume
12			
13	Total lbs.	716900.1356	
14	Tons	358.4500678	
15			

(98)

COMPUTING STOCKPILE VOLUME



PRISMOIDAL FORMULA METHOD:

Measure length of base = **L**
Measure length of top = **L1**
Average these two lengths = **L2**

Measure width of base = **W**
Measure width of top = **W1**
Average these two widths = **W2**

Measure total (vertical) height = **H**

To average any number of measurements, add all the measurements together and divide the sum by the number of measurements.

Tip:
1. (Always) compute what is in the brackets first.
2. Then do the multiplication that is outside the brackets above the line.
3. Then do the addition above the line.
4. Then do the division (from below the line).
5. Then multiply the result by the height **H**.

$$\text{Stockpile Volume} = \frac{(L \times W) + 4(L2 \times W2) + (L1 \times W1)}{6} \times H$$

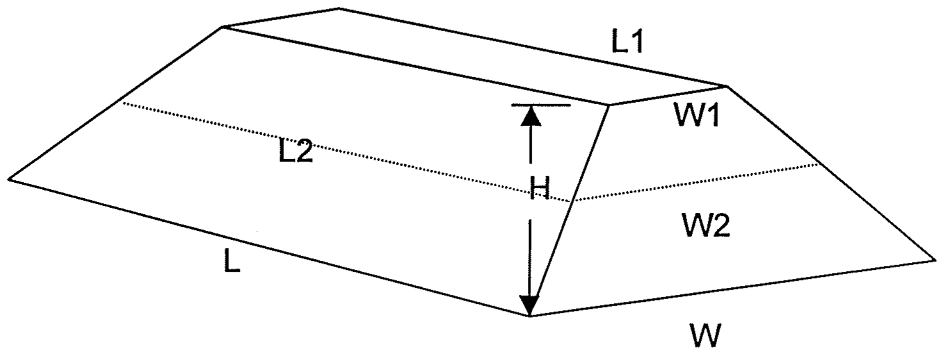
If measurements were done in feet the Stockpile Volume will be in cubic feet.
To change cubic feet to cubic yards divide by 27.

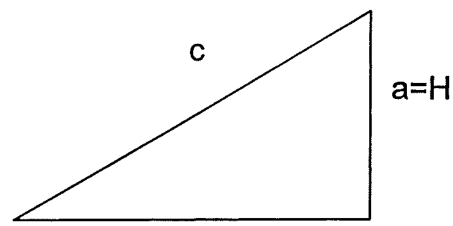
$$\frac{\text{cubic feet}}{27} = \text{cubic yards}$$

* Be sure to use this formula when you have to compute volumes on tapered shapes.

COMPUTING STOCKPILE VOLUME

FOR A SIMPLE PILE





PRISMOIDAL FORMULA METHOD:

* Measure length of base = L ________
* Measure length of top = L1 ________

Average these two lengths = L2 L ______ + L1 ______ = ______
divide by 2 = L2 ________

* Measure width of base = W _______
* Measure width of top = W1 _______

Average these two lengths = L2 W ______ + W1 _______ = ________ divide by 2 = W2 ________

* Measure the length of the slope (hypotenuse c) _______
* Measure the angle of the slope (angle A) ________

Calculate the total height = H Sine of A = opposite a (H) / hypotenuse c
Opposite a (H) = Sine of A _______ x hypotenuse c ________ = __________

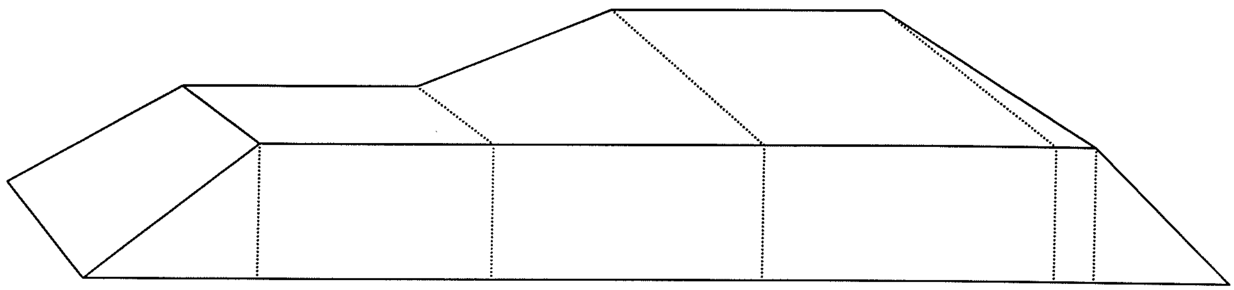
Stockpile volume = $\frac{(L \times W) + 4(L2 \times W2) + (L1 \times W1)}{6} \times H$

(L ________ x W ________) = _______
4 x (L2 ________ x W2 ________) = + _______
(L1 ________ x W1 ________) = + _______

= _______ / 6 x H _______ = _______

Note: * Identifies field measurements, all others can be computed later

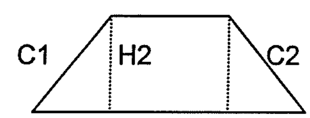
COMPUTING STOCKPILE VOLUME
For an irregular shaped pile



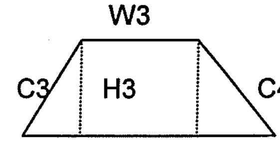
CROSS SECTION METHOD:

Calculate the area of a cross section at beginning of stockpile = A1
Calculate the area of cross section where the shape of the stockpile changes = A2
Average the two areas A1 + A2 and divide by 2 to get the average area
The volume for that portion of the stockpile is the average area multiplied by the distance between the two cross sections.

Cross Section at A1 is at the toe of the pile and has an area of zero, A1 = 0



Cross Section at A2 given W2=40, H2=12, C1=15, and C2=20
B1 = $\sqrt{C1^2 - H2^2} = \sqrt{15^2 - 12^2} = \sqrt{225 - 144} = \sqrt{81} = 9'$
B2 = $\sqrt{C2^2 - H2^2} = \sqrt{20^2 - 12^2} = \sqrt{400 - 144} = \sqrt{256} = 16'$
A2 = (½ x B1 x H2) + (1/2 x B2 x H2) + (W2 x H2) =
(½ x 9 x 12) + (½ x 16 x 12) + (40 x 12) = 54 + 96 + 480 =
A2 = 630 ft^2
The volume of area between A1 and A2 is (A1+A2)/2 X L1 = (0+630)/2 x 20 =
630/2 x 20 = 315 x 20 = 6300 ft^3

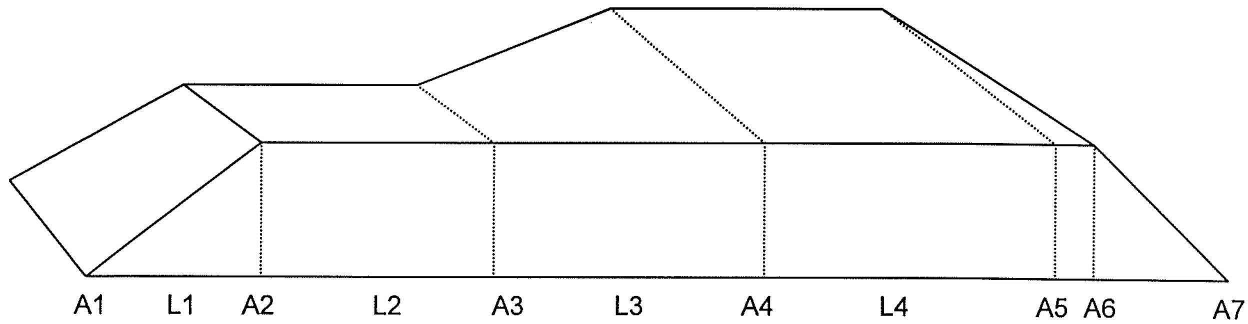


Cross Section at A3 given W3=45, H3=12, C3=15, and C4=20
B3 = $\sqrt{C3 - H3} = \sqrt{15 - 12} = \sqrt{225 - 144} = \sqrt{81} = 9'$
B4 = $\sqrt{C4 - H3} = \sqrt{20 - 12} = \sqrt{400 - 144} = \sqrt{256} = 16'$
A3 = (½ x B3 x H3) + (½ x B4 x H3) + (W3 x H3) =
(½ x 9 x 12) + (½ x 16 x 12) + (45 x 12) =
54 + 96 + 540 = 690 ft^2
The volume of stockpile between A2 and A3 is (A2+A3)/2 X L2 = (630+690)/2 x 25 =
1320/2 x 25 = 660 x 25 = 16500 ft^3

The volume of stockpile between A1 and A3 is 6300 + 16500 = 22800 ft^3

Repeat these steps for every change in the stockpile and add these volumes together to get the total volume of the stockpile.

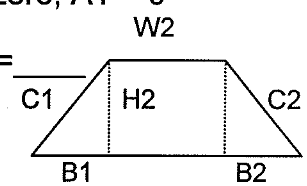
COMPUTING STOCKPILE VOLUME
For an irregular shaped pile



CROSS SECTION METHOD:

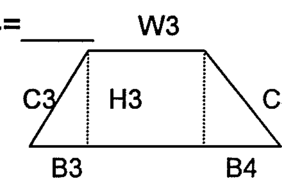
Calculate the area of a cross section at beginning of stockpile = A1
Calculate the area of cross section where the shape of the stockpile changes = A2
Average the two areas A1 + A2 and divide by 2 to get the average area
The volume for that portion of the stockpile is the average area multiplied by the distance between the two cross sections.

Cross Section at A1 is at the toe of the pile and has an area of zero, A1 = 0



Cross Section at A2, *W2=____, H2=____, *C1=____, and *C2=____
$B1 = \sqrt{C1^2 - H2^2} =$
$B2 = \sqrt{C2^2 - H2^2} =$
$A2 = (\frac{1}{2} \times B1 \times H2) + (1/2 \times B2 \times H2) + (W2 \times H2) =$

The volume of area between A1 and A2 is (A1+A2)/2 X *L1 =



Cross Section at A3, *W3=____, H3=____, *C3=____, and *C4=____
$B3 = \sqrt{C3 - H3} =$
$B4 = \sqrt{C4 - H3} =$
$A3 = (\frac{1}{2} \times B3 \times H3) + (\frac{1}{2} \times B4 \times H3) + (W3 \times H3) =$

The volume of stockpile between A2 and A3 is (A2+A3)/2 X *L2 =

Repeat these steps for every change in the stockpile and add these volumes together to get the total volume of the stockpile.

Note: * Identifies field measurements, all others can be computed later

CLEAR ROADS

research for winter highway maintenance

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