New Remote Sensing Systems for Improved Planning and Management of Mine Tailings Storage Facilities

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ABSTRACT: Managers of mill tailings storage facilities (TSFs) seek practical, cost-effective, and efficient approaches to facility planning, operation, and closure for environmentally-effective disposal solutions. Recently, several new technologies have been utilized to help optimize TSF management, including Unmanned Aircraft Systems (UASs), Manned Aircraft Systems (MASs), and Unmanned Surface Vehicles (USVs). Portable UASs use a programmed camera to generate composite (orthomosaic) aerial imagery and topography with spatial resolutions superior to those of commercial satellite imagery. Similar systems can be mounted on aircraft (MASs) to more efficiently cover larger areas. The data have been used to (i) provide volume estimates of deposited/stockpiled materials (such as construction quantities); (ii) estimate volume differences between aerial and/or land survey dates; (iii) develop detailed contour maps; and (iv) create qualitative surface moisture maps of exposed TSF areas. USV systems (remotely-operated watercraft) can reveal characteristics of submerged tailings within individual TSFs and improve facility management. USV bathymetric information has been analyzed in conjunction with UAS- or MAS-generated data and/or TSF as-built data to assess (i) changing tailings and water volumes, (ii) mean tailings bulk densities, and (iii) spatial and temporal density variations beneath the sediment-water interface. Using advanced sonar, USV sensors can distinguish between low-density fluid mud layers and deeper consolidated sediments to provide improved storage estimates and facilitate the identification and/or evaluation of TSF underwater slopes, tailings structures, and depositional patterns. Integrated UAS/MAS/USV data acquisition allows users to create a continuous and complete topographic-bathymetric snapshot of exposed and submerged tailings. These new technologies can (i) give an operator a detailed map of tailings surfaces; (ii) provide improved estimates of future TSF capacity; (iii) help maximize the use of existing facilities; (iv) delay unneeded capital TSF investment while providing more accurate capital expenditure projections; (v) facilitate improved tailings management plans; and (vi) inform TSF closure planning.

1 INTRODUCTION

Mine operators around the world employ several types of engineered structures that provide permanent disposal and containment solutions for fine-grained mine wastes (tailings) generated during the milling process. These structures, collectively known as Tailings Storage Facilities (TSFs), typically receive wastes as saturated slurries (conventional), pastes (thickened), or unsaturated fine-grained materials (filtered “dry stack”). For a TSF operator, facility work phases often include permitting, compliance monitoring, and planning; geotechnical investigations and evaluations; civil design; storm water management; groundwater characterization/modeling and remediation; underdrain and seepage collection design; and facility closure. Prudent facility managers typically seek practical, cost-effective approaches to TSF development, operation, and closure, in addition to searching for methods and procedures that increase the overall efficiencies of their facilities. For example, TSF managers and operators will benefit from more detailed information about the present and projected volumes of water and solids contained within a particular facility as well as more precise data regarding spatial and temporal variations in tailings density. This detailed information is use to develop improved estimates of future TSF capacity, more complete and comprehensive tailings deposition plans, and more accurate capital layout projections.

Recently, several new technologies have been developed to help optimize TSF operation and management. The purpose of this paper is to highlight the use of several of these technologies that help operators better manage their facilities at mine sites. Unmanned aircraft systems (UASs; also known as “drones”), manned aircraft systems (MAS), and unmanned surface vehicles (USVs) are used, individually or in combination, to collect a variety of TSF-related environmental and geotechnical data. These systems are commercially configured and available from several different manufacturers. Typical output includes highly accurate topographic and bathymetric profiles and maps, as well as high-resolution aerial photographic imagery. This paper includes examples of data interpretation and use as well as a discussion of the advantages of each type of system.

2 AERIAL REMOTE SENSING EQUIPMENT

These platforms include unmanned aircraft systems (UASs), also referred to as drones, and manned aircraft systems (MASs). The systems employ various kinds of sensory equipment for collecting data from sources radiating at different locations along the electromagnetic spectrum. Most commonly-used sensors are for visible and near-infrared wavelengths. This paper focuses on the use of cameras mounted to a UAS or an MAS for generating digital surface models (DSMs) and orthomosaic imagery through the use of widely-available commercial software packages.

The process for using UASs and MASs for performing aerial surveys is essentially the same for each and typically completed in a semi-autonomous fashion in the field. A high-resolution digital camera mounted to a UAS or MAS may be combined with a Global Positioning System (GPS) to generate topographic survey data and images for project areas up to 30 square miles (78 km^2). To perform the survey, the aircraft flies pre-planned flight paths, or transects, over the project areas while the equipment captures overlapping aerial photographs. The flight paths are established during the mission planning phase of the work, and are designed to ensure adequate coverage of the survey area for a given set of conditions. The spacing of flight transects, extent of image overlap, and flight altitude is determined by the desired topographic data accuracy. Hundreds to thousands of overlapping images are typically collected during a single project, which may consist of dozens of individual transects and multiple flights.

Surveyed ground control points (GCPs) are required at each site to calibrate and validate the field data. Coordinates for the GCPs may be obtained using a variety of options such as the site’s own survey crew, Global Navigation Satellite System (GNSS) static observations processed through a web-based Online Positioning User Service (OPUS) portal, or through the careful use of existing monuments. Please note that the current best-case horizontal spatial resolution using this type of equipment is generally less than 5 cm, substantially superior to commercial satellite imagery which typically exceeds 25 cm and is subject to cost and timing limitations.

Following the field survey, flight data and aerial imagery may be refined and compiled using post-processing software and then presented using a Geographic Information System (GIS) or computer-aided design (CAD). The survey and ground control data are processed to generate a geometrically-corrected composite aerial image (i.e. an orthomosaic) and a topographic model (contour map) of the survey area. Standard protocols must be followed before, during, and after the flight(s) and during the subsequent data reduction phase to ensure high data quality and complete coverage of the project area. Data accuracy for mine projects typically meets the national standard developed by the Federal Geographic Data Commission (FGDC).

2.1 *Aerial Imagery for Smaller Regions*

A small fixed-wing unmanned aircraft system (UAS) is ideal for performing an aerial survey when operators need detailed information about a specific feature of a mine facility, such as a single TSF that covers an area of less than one square mile (2.5 km^2). A typical UAS unit consists of a fixed-wing foam platform with a wingspan of 122 cm that weighs less than two pounds including the onboard battery, GPS receiver, and a 16-megapixel camera (Fig. 1). These types of UASs, which have proven to be efficient for capturing terrain data, are small, portable, and relatively low-cost. In addition they provide flexibility in operation logistics, can be used “on demand” (unlike satellite systems), and are not impacted by mid- or high-elevation clouds. UAS platforms have the additional advantage of communicating with a mobile or permanent base station which can be configured to transmit real time kinematic (RTK) position corrections.

Figure 1. Inspecting an unmanned aircraft system (UAS) prior to launch.

Typical UAS data requirements are provided in Table 1. In general, the horizontal accuracy of UAS surveys is within 1-2 times the spatial resolution (i.e. ground sampling distance (GSD)) of the survey data (approximately 7.5 cm) and the vertical accuracy is within 2-3 times the GSD of the survey data (approximately 13 cm). This level of accuracy allows for the production of topographic maps with a one-foot contour interval. When operated with an RTK base station, this level of accuracy has been achieved without the use of GCPs.

Advantages of the UAS over the MAS include portability, ease of use, and reduced risks associated with manned aerial surveys. In remote locations or high altitudes, chartering manned aircraft to perform survey work is often too risky or not even possible.

Table 1. Example UAS data requirements using typical mission parameters.

Ground sampling distance	Area (acres)	Flight lines	Flight time	Total images	Approximate processing time
1.5 cm (0.6 in)	100	32	54 min	2733	50 hours
2.5 cm (1 in)	100	19	25 min	811	12 hours
3.5cm (1.4 in)	500	25	87 min	1686	25 hours
4cm (1.6 in)	500	22	68 min	1163	16 hours
5cm (2.0 in)	500	18	58 min	823	12 hours
10cm (4.0 in)	500	10	35 min	248	4 hours

The completion of legal UAS commercial surveys within the United States' national airspace system requires compliance with the Federal Aviation Administration (FAA) Part 107 Small Unmanned Aircraft Rule. Part 107, which took effect in August 2016, allows a maximum altitude of 400 feet (122 m) above ground level; requires an operator with a remote pilot-in-command certification; and the UAS must remain within visual line-of-sight of the remote pilot-in-command or a designated visual observer.

2.2 *Aerial Imagery for Larger Regions*

Although the UASs can provide the necessary information when the collection of topographic and imagery data is required for larger areas, other tools may be more efficient for completing the project. For larger mine sites, one such tool is a camera system that mounts directly to the outside of a small manned fixed-wing aircraft or rotorcraft. The instrument consists of two cameras and a GPS which can be rapidly attached to the wing strut of a single-engine aircraft (Fig. 2) that is piloted along pre-determined flight lines. As with the UASs, ground control points are typically established at each site to calibrate and validate the field data. The GSD, which typically ranges from 5 to 10 cm, allows for the creation of a topographic model of the study area with one- or two-foot contour intervals. A composite orthophoto is also generated from the aerial imagery.

The ability to capture large areas during a single flight using this system is significant. Flight times are shorter than a UAS for a comparable area. The camera is less impacted by timing and cloud conditions than commercial satellite services, and the technology is well-suited for capturing information associated with long, linear features such as pipelines or electricity distribution systems.

The geolocation, topography, and imagery data collected with MASs are processed using the same photogrammetry software as the UASs to derive the final contour maps and orthomosaic image. The accuracy of the data collected for mine projects meets the national standard developed by the FGDC. The horizontal aerial mapping data are accurate to within 1-2 times the spatial resolution of the mapping data (5-10 cm) and the vertical accuracy is within 2-3 times the spatial resolution (10-15 cm). Table 2 provides typical data requirements for the MAS system.

Figure 2. Manned aircraft system (MAS) mounted on a fixed-wing aircraft.

Table 2. Example MAS data requirements using typical mission parameters.

Ground sampling distance	Area (mi^2)	Flight lines	Flight time	Total images	Approximate processing time
5 cm (2.0 in)	5	20	84 min	1712	46 hours
7 cm (2.8 in)	5	15	60 min	911	29 hours
10 cm (3.9 in)	5	10	42 min	438	14 hours
15 cm (5.9 in)	5	7	36 min	204	6 hours
20 cm (7.9 in)	5	5	36 min	114	3 hours

Advantages of using the MAS over the UAS include 1) acquisition time is reduced because all data can be collected during a single flight; 2) the camera system is suitable for large areas; 3) the system is less sensitive to windy conditions; and 4) MASs are not hampered by the regulatory restrictions associated with UASs. In the United States, FAA approvals for use of wing-mounted camera systems are not required; however, an FAA certified commercial pilot must be used to pilot the aircraft. Commercial pilots and aircraft are available at local flight schools or airports.

3 WATER-BASED REMOTE SENSING EQUIPMENT

3.1 *Unmanned Surface Vehicle (USV)*

Tailings storage facilities (TSFs) typically contain a supernatant pond which can be highly variable in size and areal extent. Depths in the ponds may range from a foot or less near the beach to 9 m or more at the deepest point. Water volume measurements and information about the tailings surface beneath the water are critical for efficient management of TSFs. Traditional survey techniques to obtain these data include deployment of sonar fish-finders or physical measuring devices from piloted boats. These methods are time-consuming and carry substantial risks for personnel that have to enter the pond to perform the measurements. In addition, traditional techniques are often labor-intensive, result in insufficient data density to accurately model the surface, and generate inaccurate data for the low-density tailings-water interface.

As an alternative, unmanned surface vehicles (USV) adapted for the TSF environment have been utilized for the performance of bathymetric surveys to improve survey data quality and frequency. The USV payload consists of an integrated positioning and echosounder system which wirelessly transmits data for real-time navigation and data review. The USV data acquisition system includes hardware and software developed for hydrographic surveying. The use of this approach streamlines the survey from data acquisition to final product, which improves quality, workflow, safety, and reliability.

The USV is a battery-operated shore-controlled hydrographic survey platform powered by twin 24-volt DC outdrive motors (Fig. 3). The 6-foot long USV has an operational range exceeding 600 m, and is equipped with a dual-frequency single-beam echosounder and a dual-channel GNSS receiver. The echosounder calculates depth based on the precise travel time of a series of acoustic pulses that are emitted by a hull-mounted transducer and recorded after they are reflected from the bottom. This process occurs at up to 20 times per second to record a nearly continuous depth profile along the boat track. In addition, the low-frequency component of the pulse is detected by a separate channel to produce an acoustic snapshot of the water column and shallow underlying sediments.

The USV is piloted manually along pre-planned transect lines, with precise depths, locations, and high-definition acoustic data transmitted in real-time to the shore station. The transect spacing may be modified depending on the project's technical objectives, site-specific characteristics of the survey area, or changes in bottom characteristics such as consistency or slope. The precise elevation of the water surface at the time of the survey may be used to convert the raw depths to elevations, or the elevation of the tailings surface can be recorded in real-time by transmitting positioning corrections from an RTK base-station over a known location.

The accuracy of the data collected by the USV can be influenced by a combination of factors including variation in sound velocity (SV) within the water column, vessel motions, and technical specifications of the on-board equipment. Under ideal conditions the bottom resolution is less than 2.5 cm and the accuracy is ± 0.1% of the water depth. Data are processed using commercial hydrographic survey software and standardized procedures published by the United States Army Corps of Engineers. The data are then exported to GIS or CAD to construct a digital surface model (DSM) of the tailings for areas not measured by the sonar. The DSM can then be merged with subaerial topography data obtained using a UAS or MAS, creating a seamless surface for the derivation of elevation contours and the facilitation of volumetric calculations. The low-frequency sonar data can be further analyzed to validate the reported depths and determine the relative densities of tailings in the pond.

Figure 3. Unmanned surface vehicle (USV) collecting data in Perú at an elevation above 4000 m.

4 RESULTS, INTERPRETATIONS, AND DATA USES

4.1 *Aerial Surveys*

Both the UAS and the MAS platforms produce high-quality aerial imagery that can be used by mine planners and managers to improve facility operations. Figure 4 is an example of recent UAS photography produced for a mine site near Elko, Nevada. The orthoimagery and elevation data produced from the aerial surveys can be used for tasks such as providing volume estimates of solid materials (e.g., stockpiles) present in the survey area. Figure 5 shows the volumes of three such stockpiles at a mine site in Perú. The data can be used to estimate volume differences between different aerial survey dates for the purposes of measuring incremental changes in tailings or waste rock quantities. Aerial survey information may be used to create qualitative surface moisture maps of exposed TSF areas (Fig. 6) or regions of undisturbed ground. Aerial photographs produced with the UAS or MAS can be combined with topographic and bathymetric data to create seamless contour maps of mine facilities (see below).

4.2 *Water-Based Surveys*

Basic bathymetric data for TSFs can be furnished by surveys conducted with simple single-frequency (200 KHz) echosounders. In this paper we focus on the application of a USV unit outfitted with a dual-frequency echosounder (200 KHz and 33 KHz) capable of recording digitized water depths as well as high-resolution acoustic profiles of the water column and sediment. The sonar, developed by CEE HydroSystems of Sydney, Australia, has been designed for use in water depths ranging 1 to 300 feet, and has been thoroughly evaluated for TSF pond applications. Analysis of the acoustic profile data (echogram) facilitates verification of the bottom elevation beneath turbid suspensions, and can be used to assess the thickness and relative density of solids deposited within individual storage facilities. The value-added acoustic profile data are useful for helping to improve TSF planning/management and optimizing efficiency, and have also been used to help solve environmental problems in urban areas (Martin et al. 2015).

Figure 4. UAS imagery of tailings storage facility cell in northeastern Nevada. Inset on the right shows USV collecting data during the UAS flight. Inset on the left shows mine site infrastructure.

4.2.1 *Bathymetry*

Bathymetric data from USV surveys can be analyzed in conjunction with TSF as-built topographic information to determine the current volume of tailings, the mean in-place dry bulk density of tailings, and the volume of water stored in the supernatant pond. This information will be more accurate than traditional methods due to 1) the high density of survey data generated by the USV (greater than 100,000 points for a typical 50-acre pond survey), and 2) the ability to verify an accurate bottom trace in high turbidity environments or deep pools. The survey data may also be used to identify and/or evaluate subsurface slopes and tailings structures, areas of historical deposition, and spatial and temporal patterns that can help guide facility management decisions. Figure 7 shows a bathymetric map of a natural tailings settling pond at a remote site in the Andes Mountains of Perú. A comparison to historical bathymetry highlights concentrated areas of significant annual tailings deposition. A single transect is highlighted showing the low-frequency acoustic data (echogram). This serves as validation for the measurement and confirms the presence of several meters of sedimentary deposits which can be delineated from bedrock.

Figure 5. Example of stockpile volume estimation in Perú using UAS software and aerial imagery

Figure 6. Surface moisture mapping using UAS data, northeastern Nevada.

Accurate tailings slope data below the water surface can be used during mine operations to identify areas where additional space is available to maximize the lifespan of an existing facility and possibly delay capital investment associated with TSF expansion. Tracking the evolution of these areas through time can help managers better understand how operational decisions affect the shape and distribution of subaqueous tailings. Data for closed facilities can be used to plan cover procedures, identify areas requiring additional fill to allow for proper drainage, and estimate surface densities of the in-place tailings, all of which can reduce or refine closure cost estimates.

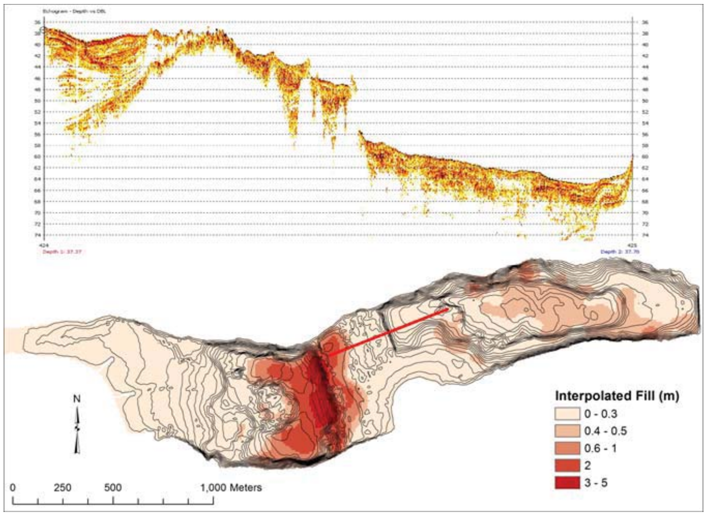

Figure 7. Elevation changes due to tailings deposition over a one-year period at a TSF in the Peruvian Andes. Upper image is a representative echogram.

4.2.2 *Sedimentology and Sub-Bottom Information*

A high-definition echogram is recorded and analyzed for every bathymetric transect. An echogram is a vertical profile of the acoustic signal detected by the echosounder along the USV track. Each acoustic pulse transmitted by the USV is reflected back to the detector by sharp density gradients present at the mud/water interface and between subsurface layers. The intensity of the reflection and penetration of the pulse can be a function of initial pulse energy, material type, signal attenuation, and water content (i.e. bulk density) of the substrate. The echogram information is linked to the bathymetric transects in a GIS to facilitate detailed analysis of submerged features. For example, the relative thickness of sediment deposits can be shown for the same location over time to demonstrate tailings deposition above a TSF subgrade (Fig. 8). For recurring surveys at the same facility, the most valuable comparative data are generated by navigating the same planned lines for each survey.

4.2.3 *Examples of Value-Added Data Products Generated By the USV Surveys*

The analyses presented below are examples of the types of value-added information that can be obtained from dual-frequency USV surveys at TSF sites.

Using GIS or CAD to examine the bathymetric data allows for an in-depth analysis of spatial patterns that may impact management of a facility. In Figure 9, areas with locally high slopes are visible, and sub-bottom detail is revealed by an echogram transect across a cell filled with subaqueous tailings. Sharp reflection and minimal penetration of the low-frequency sonar is associated with the subgrade surface underneath the low-density tailings. This information can be used to clearly delineate where tailings are accumulating in this newly-constructed facility. Steep slopes mapped throughout the facility in Figure 9 are associated with constructed berms and embankments, with the exception of a broad area where the local slope of the tailings surface is as high as 10 percent. Observations of subaqueous morphology at other facilities suggests that the transition from low-slope tails on the beach to steeper slopes in the pond occur at the seasonal minimum pond level, which demonstrates the importance of keeping supernatant ponds to an absolute minimum to maximize storage.

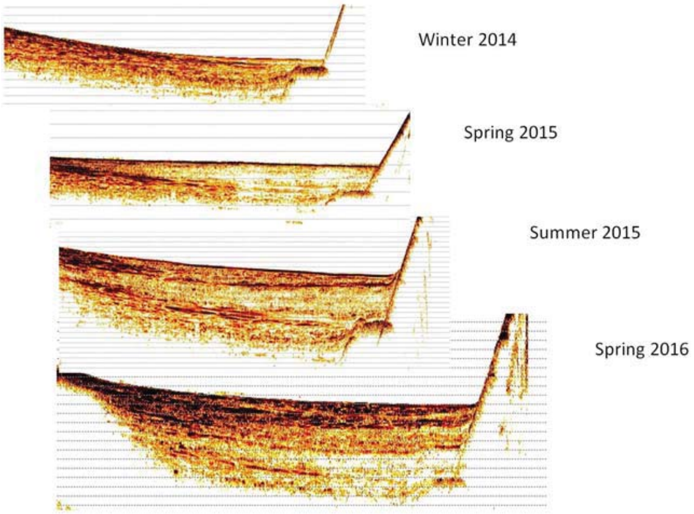

Figure 8. Example of USV sonar data collected at the same location over a multi-year period.

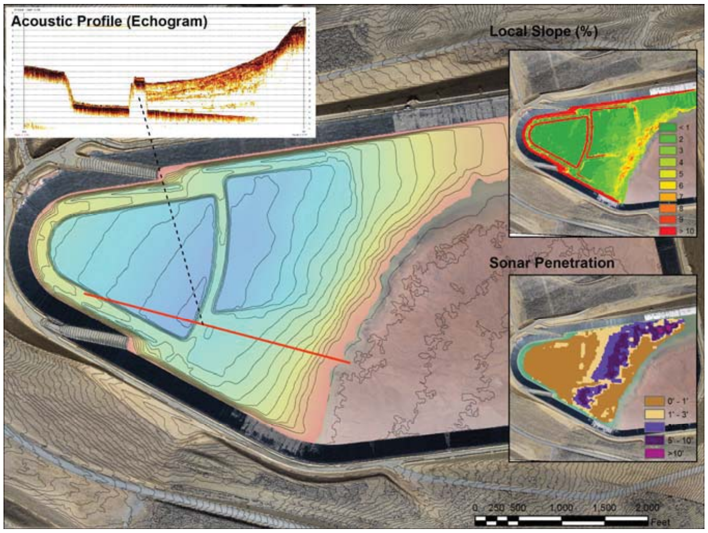

Figure 9. Example of low-frequency sonar data.

In the Figure 9 inset which shows sonar penetration, areas highlighted in purple represent low-density tailings with a thickness greater than 1 m. In this case the low-frequency sonar penetrates through loose tailings until the signal is reflected completely by the subgrade (consolidated tailings). Meanwhile, the high-frequency sonar continues to track the surface of the sediment-water interface. By differencing the depth of sonar penetration from the depth of the sediment-water interface, it is possible to map the relative thickness of unconsolidated sediments in the pond. This technique has been used at some facilities to track the relative volume changes of low-density sediment pools in deep areas of the pond. Through these observations it has been possible to demonstrate where consolidation and dewatering of subaqueous tailings occurs through time. The data have also been used to inform dam operators that significant storage space within the pond will be available as the subaqueous tailings continue to dewater and improve the overall in-place dry bulk density.

4.3 *Combined Surveys*

At several mine sites, both UAS/MAS and USV surveys are now being performed on a quarterly basis. The increased frequencies of these high-accuracy, low cost surveys has led to a better understanding of water balance and storage needs to help optimize operations. Integrated data acquisition and processing allows for a continuous and complete topographic snapshot of subaerial (exposed) tailings and subaqueous (underwater) deposits at each TSF. These holistic datasets, delivered as seamless digital surface models (DSMs), combine topographic and bathymetric information into a single gridded dataset (Fig. 10).

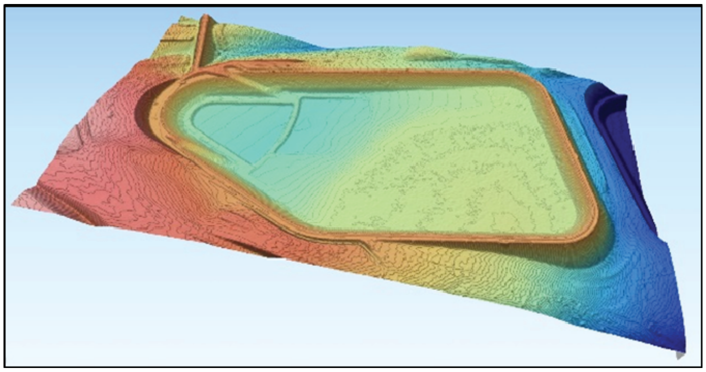

Figure 10. Three-dimensional oblique digital surface model (DSM), tailings storage facility, Nevada.

The volume of tailings in a TSF can be determined using the difference between the topography from the UAS/USV surveys and the initial as-built facility survey. Although for some older facilities the total TSF lifetime solids deposition volume may not be known, the incremental depositional mass can often be determined, and a highly accurate incremental tailings dry density for the period between surveys can be calculated as long as tonnage data for the given time frame is available. Using the merged DSM, accurate estimates can also be made for available storage of tailings to better plan for capital investment costs (such as dam raises) and the need for construction of new facilities. The same information can also be used to construct accurate stage-volume relationships to develop and update water balance models. Because both exposed and submerged tailings are most often present at TSFs, both UAS and USV surveys are needed to perform these calculations.

Aerial imagery, topography, and bathymetry (data sets that are typically obtained separately) can be collected and processed in the same week by the same group of scientists and engineers already familiar with the site. Control of the data from acquisition through processing can add value by uncovering details that might otherwise be overlooked. For example, analysis of aerial imagery for a TSF surveyed on a quarterly basis (Fig. 11) revealed distinct plumes, which suggests the transport of subaqueous tailings by density-driven flows. Analysis of depositional patterns within the pond for the same period showed a distinct tongue with measureable elevation change extending through the middle and deflecting along the embankment on the deep end of the pond. Superimposing aerial imagery with a map of spatial depositional patterns reveals that the independent observations are likely linked to the same physical process of tailings transport and deposition.

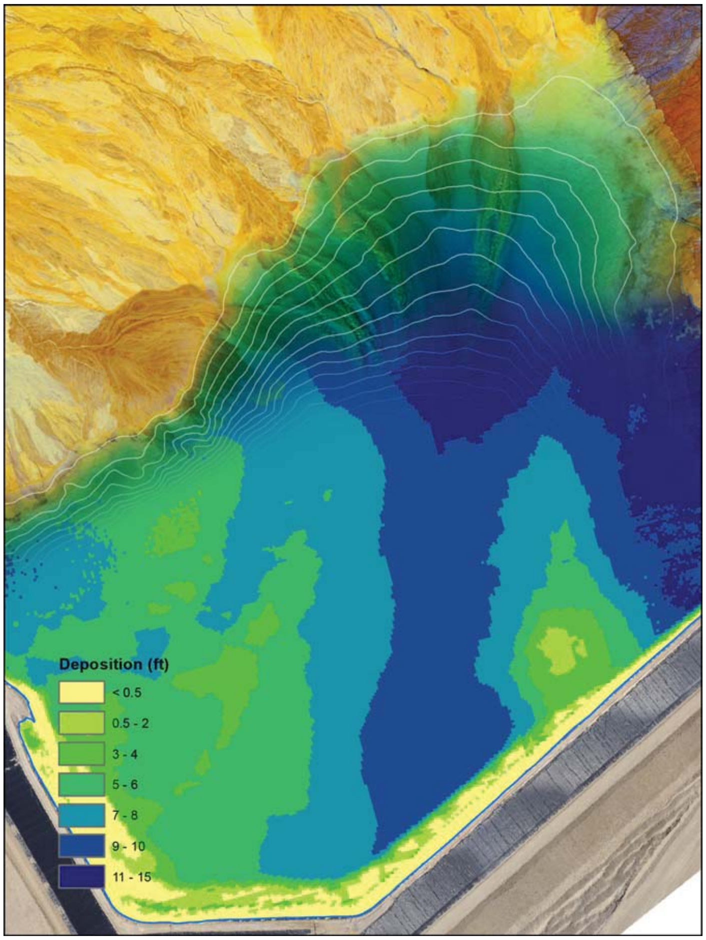

Figure 11. Aerial imagery and bathymetry at a tailings storage facility, Nevada.

5 ADVANTAGES OF NEW REMOTE SENSING TECHNOLOGIES

The new techniques presented in this paper are being rapidly introduced to help solve problems in the mining industry. UASs are relatively inexpensive to purchase and operate, are highly efficient with respect to data collection and processing times, and are safe to deploy when controlled by experienced and trained operators. For larger areas, small and lightweight camera systems mounted to piloted aircraft (MAS's) are cheaper to operate than more traditional remote sensing units and interface with powerful software for rapid data reduction and processing.

The principal advantages of unmanned watercraft include: the collection of highly accurate data that far surpasses that obtained by more traditional methods; a more adaptable platform for use in locations where standard methods are impractical or impossible to implement (e.g., shallow water, low overhead clearance, submerged hazards, strong currents, or limited access situations); and expediency (rapid delivery of data products) through the use of standardized workflows developed for hydrographic surveys. Use of USVs reduces risks to personnel because the need for manned boats operating in industrial water bodies is eliminated.

Combining UAS/MAS and USV technologies for the development of seamless topographic-bathymetric maps results in an integrated dataset that can immediately and positively assist mine site management. New technologies, when efficiently and skillfully applied, are better, faster, safer, and cheaper than more traditional methods.

6 LESSONS LEARNED

- UAS technologies function best in areas with little vegetation. Large amounts of foliage can increase the time required during the post-processing phase to create accurate and reliable base topography.
- Commercial UAS operation is restricted by applicable FAA rules.
- Both data collection strategy and post-processing efficiency are critical and need to be conducted by experienced and trained personnel. A black box, "off the shelf" approach will not produce accurate and useable results. Inappropriate ground control setup and incorrect post-processing can lead to both calculation errors and erroneous results and interpretations.
- High-quality ground control data collection in the existing coordinate system must be completed at the time of the survey. Post-processing of data using poor or inaccurate ground control information can lead to inaccuracies of surfaces and volume calculations.
- For USV surveys, temporal comparisons are best when the survey transect lines coincide with previous surveys. In some cases, the precise locations of previous surveys are unknown. At some sites, the repeatability of a survey is hampered by changes in the facility's infrastructure. For example, USV navigation has been controlled to some degree by the changing layouts and locations of mobile tailings delivery systems.
- Data collection with the USV works best for small- to moderately-sized water bodies (i.e., less than one square mile [2.5 km^2]).
- Through combined processing of the traditionally separate datasets of imagery, topography, and bathymetry, hidden patterns may emerge that might otherwise go unnoticed.

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