Improving Tailings Deposition Management with Multi-Method Survey Integration at Teck Alaska—Red Dog Operations

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Abstract

Teck Alaska—Red Dog Operations (RDO) has improved monitoring, planning, and execution of tailings deposition by integrating surveys from drones, satellites, and bathymetry. This multi-method integration process, implemented in 2020, improves data accuracy and consistency, providing comprehensive insights into tailings behaviour. The integrated survey data is also used to measure stored water and tailings, and the remaining storage capacity of the tailings storage facility (TSF).

Survey integration is completed annually and supports reconciliation of actual tailings deposition against modelled and planned tailings deposition. The annual reconciliation evaluates tailings volumes, deposited tailings tonnage, tailings density, deposition slopes, and tailings beach lengths, which are used to update tailings model parameters and set new tailings deposition plan targets. Additionally, monthly satellite monitoring is used to measure tailings beach lengths and elevations. These measurements support assessing conformance with tailings deposition key performance indicators (KPIs).

Tailings deposition management follows a Plan-Do-Check-Act (PDCA) cycle, which is a systematic approach to how RDO plans, executes, verifies, and improves processes and work. The PDCA cycle is a four-step iterative process that ensures continuous improvement in how work is planned and executed. The information and data gathered using the integrated survey methodology are critical in the Check-Act steps of the tailing deposition management process.

By leveraging the unique strengths of each technology, superior monitoring and risk mitigation are achieved, compared to using each method independently. This holistic approach, coupled with the Teck tailing deposition management process, demonstrates more robust operational decision-making and supports short- and long-term planning. This approach enables RDO to consistently achieve key tailings

beach deposition objectives, including meeting tailings beach length targets; reducing tailings fugitive dust and acid generation; and ensuring efficient use of TSF storage capacity.

Introduction

Tailings storage facilities (TSFs) are highly variable in their design and operation. They differ in size, location, accessibility, construction methods, and operational requirements. These differences make it difficult to apply a single, standardized approach to surveying and monitoring the tailings deposit. Instead, a tailored strategy that considers the unique characteristics of each facility is required. One critical aspect of TSF monitoring is understanding the topography—both above and below the waterline. These surveys are required inputs into the tailings deposition and water management plans, and they provide insight into tailings deposition behaviour, facility capacity, and potential risks.

Operators face several recurring challenges when it comes to topographic surveying. These include the need for data at varying frequencies to support different operational and reporting needs; ensuring consistency across datasets collected using different tools or at different times; and correcting for offset errors that can arise when integrating multiple data sources. These challenges can hinder effective operational decision-making and short- and long-term planning.

Many surveying technologies are available to operators, such as ground surveyors, piloted airborne LiDAR, drones, and satellites. Each technology brings unique advantages and limitations, but when used in combination, they offer a powerful and flexible approach to TSF monitoring that can be adapted to a wide range of site conditions and operational needs.

This paper presents a case study from Teck Alaska's RDO tailings team, which demonstrates how integrating data from multiple sources—including drones, high-resolution satellites, GPS RTK survey equipment, and bathymetric sensors—can provide a more complete and accurate picture of TSF conditions. By leveraging the strengths of each technology and a robust planning process, the team can overcome individual limitations and generate reliable, actionable data that supports informed decision-making. This integrated approach supports operational efficiency and achieving key tailings deposition management objectives.

Red Dog Mine and Tailings Storage Facility Background

Red Dog Mine is a zinc/lead mine operating in northwestern Alaska; the mine has been in operation since 1989. The RDO TSF is a 570-acre impoundment formed by two dams: the Tailings Main Dam (TMD) to the north (Fig. 1, left) and Tailings Back Dam (TBD) to the south (Fig. 1, right).

Tailings generated at RDO are the product of conventional froth flotation processing of sulfide ores from the Aqqaluk and Qanaiyaq Pits that produce lead and zinc concentrates. Additionally, tailings within the TSF were generated from the Main Pit, which has been fully mined. Tailings are primarily stored underwater to mitigate acid generation.

Tailings are deposited sub-aqueously and subaerially in the TSF. A tailings distribution system is operated to deposit tailings throughout the facility based on operational execution plans, including a Life of Tailings Plan, Annual Deposition Plans, Monthly Deposition Plans, and Weekly Deposition Plans. Tailings are discharged into the impoundment either subaerially using slotted spigot pipes or subaqueously via a floating single-point or perforated pipe.

Figure 1: Red Dog operations TSF layout

Tailing Deposition Management Strategy and Planning

The key tailings deposition management objectives for tailings deposition planning are as follows:

- Maintain a target beach length of 600 feet along the TMD Embankment and Northern Wing Wall with a lower beach length threshold of 300 feet.
- Maintain a target beach length of 200 feet along the Southern Wing Wall.
- Reduce potential dust generation.

- Reduce potential acid generation.
- Minimize the possibility of the tailings pipe freezing in winter.

The general tailings deposition strategy is to deposit tailings subaerially, beginning as early as March and typically continuing to mid-August along the TMD Embankment and Wing Wall to construct the tailings beach and allow for tailings dust suppression activities while temperatures are above freezing. Typically, tailings are deposited sub-aqueously through winter to reduce the risk of tailings pipe freezing; reduce fugitive dust and acid generation potential; and utilize TSF capacity efficiently.

The tailings deposition management process at RDO follows a Plan-Do-Check-Act (PDCA) cycle, a systematic approach to planning, executing, verifying, and improving processes and work. The PDCA cycle is a four-step iterative process that ensures continuous improvement in how work is planned and executed. Applying the PDCA cycle to tailings deposition has allowed RDO to meet the key deposition management objectives described above.

RDO applies the PDCA cycle at various levels for tailings deposition management. Short-term Tailings Deposition Plans (Weekly and Monthly Plans) were integrated into to process to improve sitewide integration, drive performance and efficiency, and continually improve tailings deposition planning and execution. Tailings deposition plan execution is discussed within the Mill Short Interval Control (SIC) Meetings. It is included in the Maintenance Work Control processes, which have improved adherence to planning and scheduling of work. The following meeting and plan frequencies occur within the PDCA cycle processes:

- Daily Operations: Teams plan their tasks, execute them, review the outcomes, and make necessary adjustments for the next day.
- Weekly Plans: Plans are developed, executed, with progress tracked to identify areas for improvement and ensure we are on track with weekly goals.
- Monthly Objectives and Plans: Analyze performance against the budget and site objectives, using the PDCA methodology to improve planning for the next month's activities.

Information communicated in the plan review meetings includes planned tailings deposition location, duration, tailings tonnage to be deposited, and field inspection targets. The Weekly Tailings Operations Performance Review includes a comparison of the plan to actuals of the previous mentioned items, as well as beach length measurements. Plan variances are discussed during performance review meetings, and actions to address them are developed. These variances may result from operational decision-making, production impacts, or technical and planning-related factors. If significant one-time or cumulative variances occur, more robust analysis tools such as Root Cause Analysis or 5-Why process are completed. The learnings are then incorporated into the planning process to improve the next PDCA cycle results.

TSF Base Surface and Existing Conditions

Base Surfaces are required in tailings modelling and reflect the TSF and its available capacity for both tailings and water. Base Surfaces are also used for:

- Developing tailings model parameters.
- Assessing tailings and water volumes currently stored within the TSF.
- Assessing remaining tailings and water storage capacity within the TSF.
- Evaluating long-term settlement trends of the tailings.

Comparison of Topographic Surveying Technologies

To effectively deploy the available topography surveying technologies, it is essential to understand the capabilities and limitations of each one. Each method—whether ground-based, airborne, or satellite—offers unique advantages in terms of accuracy, coverage, and operational flexibility. The following section provides a brief overview of the primary topographic data acquisition tools used in TSF monitoring, highlighting how each can contribute to a comprehensive and integrated survey strategy.

Ground surveying offers unmatched accuracy—often at sub-centimetre levels—for small, discrete areas, especially when performed by on-site teams. While it is cost-effective and flexible, it can pose logistical challenges due to limited personnel and the need to coordinate with ongoing operations. Despite these limitations, ground survey data is highly valuable, particularly when used as ground control or integrated with other survey methods to enhance overall accuracy.

Piloted airborne LiDAR is the benchmark for high-accuracy, large-area surveys, capable of capturing an entire mine site in a single flight with vertical accuracies as low as 5 cm when ground control is used. Its ability to penetrate vegetation makes it ideal for generating bare-earth Digital Terrain Models (DTMs), often used as baseline surfaces. However, LiDAR surveys produce large, complex datasets that require significant processing time. The need for piloted aircraft also makes this a high-cost option and may limit accessibility in remote or logistically challenging locations.

Drones have advanced significantly in recent years, offering improved payload capacity and autonomy. They can be equipped with optical or LiDAR sensors for topographic surveys, though high-end sensors may still require larger, costlier drones. Flying at low altitudes allows drones to capture high-resolution data and avoid some atmospheric issues, but they remain vulnerable to adverse weather conditions. In-house drone programs offer flexible and frequent data collection, though limited flight times can result in incomplete coverage and data offsets. Drone-derived surfaces often require post-processing to remove vegetation and structures, as they typically produce Digital Surface Models (DSMs) rather than bare-earth terrain.

High-resolution optical satellites, available since the early 2000s, can capture detailed imagery (30–50 cm resolution) over large areas in a single pass. By using stereo imagery and referencing existing ground control, these systems can produce topographic data with vertical accuracies better than 15 cm RMSE. For TSFs, this means entire facilities—or even full mine sites—can be surveyed in one consistent, highly accurate snapshot. Because the data comes from a single acquisition and consistent processing, it avoids stitching errors and offers excellent repeatability across time and locations.

While each survey method provides valuable data independently, integrating them—along with bathymetric data—creates a single, up-to-date surface that enhances accuracy and usability. A key challenge in this process is correcting offsets and aligning data from different sources or mine grids.

Application at RDO

At RDO, annual Base Surfaces are generally created using the following input surfaces:

- TSF Bathymetry Survey data captured using RTK GPS survey and bathymetry sonar equipment.
- Satellite Survey ground surface of the whole TSF, produced from high-resolution satellite imagery processed through PhotoSat's proprietary systems.
- Drone Photogrammetry Survey to refine the tailings beach and tailings dam surfaces.

PhotoSat uses proprietary processing systems to generate high-accuracy topographic surveys from high-resolution satellite imagery. These surfaces are georeferenced and tied to ground control points provided by RDO, which are collected by on-site ground surveyors with RTK GPS survey equipment. To further enhance resolution and accuracy in select areas, drone-derived photogrammetry data is integrated into the satellite imagery-derived surface using PhotoSat's processing workflows. This merging process corrects for any offsets, tilts, or artifacts that may be present in the drone data. Similarly, the bathymetric survey data is incorporated into the surface model, with interpolation applied in shallow transition zones to create a seamless, continuous surface. The resulting Base Surface leverages the strengths of each data acquisition method—satellite, drone, ground, and bathymetry—while mitigating their individual limitations. Updated surfaces from any of these sources can be integrated into the Base Surface as frequently as they are available, ensuring the teams always work with the most up-to-date Base Surface. This integrated approach provides the RDO tailings team with the most detailed, accurate, and reliable surface possible for operational planning and analysis.

Tailings Deposition Model Inputs and Design Criteria

The following section details the tailings model inputs and design criteria used to create this tailings deposition plan. The key model inputs are the forecasted TSF water elevations, tailings mass tonnage (dry tonnes), and deposition geometry. Using a given water elevation, tailings tonnage, deposition locations, and

Base Surface, the model calculates the volume of tailings that can be deposited at the specified locations. The model then layers the tailings volume onto the Base Surface while adhering to the given tailings slopes and density.

Tailings Deposition Geometry and Physical Properties

RDO uses commercially available modelling software to model tailings deposition, with the flexibility to assign different slope and density values above and below the water surface. To support and enhance this modelling process, the Base Surfaces serve as a critical input for model calibration and validation. The RDO tailings team relies heavily on this data to improve their understanding of site-specific conditions and ensure that model parameters remain aligned with real-world observations. Parameters are selected and adjusted based on insights gained from the survey and monitoring methods outlined above, enabling continuous improvement in tailings planning and operational decision-making.

Tailings Density

An annual tailings density reconciliation is conducted at RDO by comparing the Base Surfaces to determine the total volume of tailings deposited over a defined time period. This volumetric data is then paired with mass data derived from mill mass balance tracking, and flow meter and density meter readings from the tailings slurry pipeline, to calculate the total tonnes of tailings deposited during the same period.

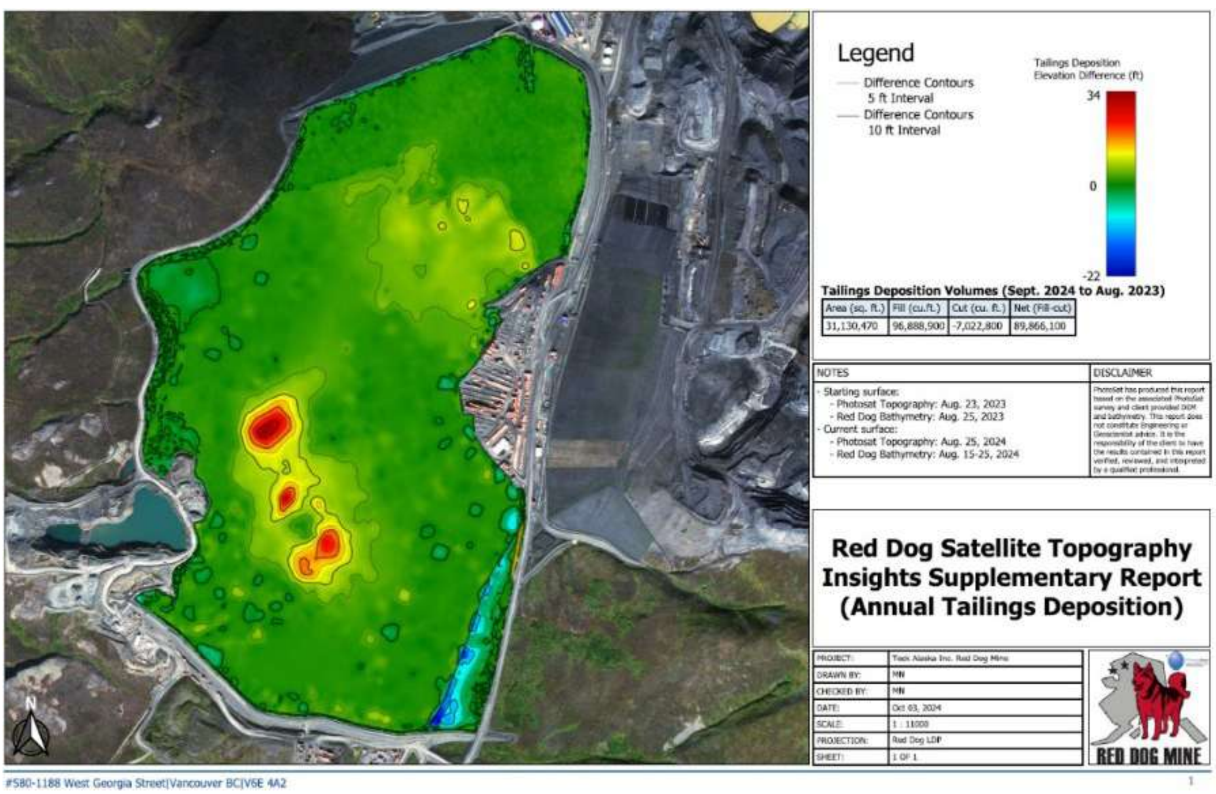

Figure 2: August 2023 to September 2024 tailings deposition volumes

The deposited mass and corresponding volume values are used to calculate the annual average tailings density. This process is conducted annually, and the results are used to update a cumulative dry density value. This cumulative density is a key input for tailings deposition modelling and is used to improve the accuracy of long-term planning and deposition strategies.

Tailings Deposition Slope Parameters

Subaerial and subaqueous tailings deposition slopes are evaluated by generating cross-sectional drawings through the Base Surfaces. These surfaces, generated from merged satellite, drone, and bathymetric survey data described above, provided the foundation for analyzing slope geometries associated with different deposition methods. Three distinct beach slope profiles are reviewed, each corresponding to a specific deposition point type: the 18-inch subaqueous single-point spigot, the TMD subaerial 18-inch single-point spigot (Fig. 3), and the WW subaerial 18-inch manifold with 6-inch spigots.

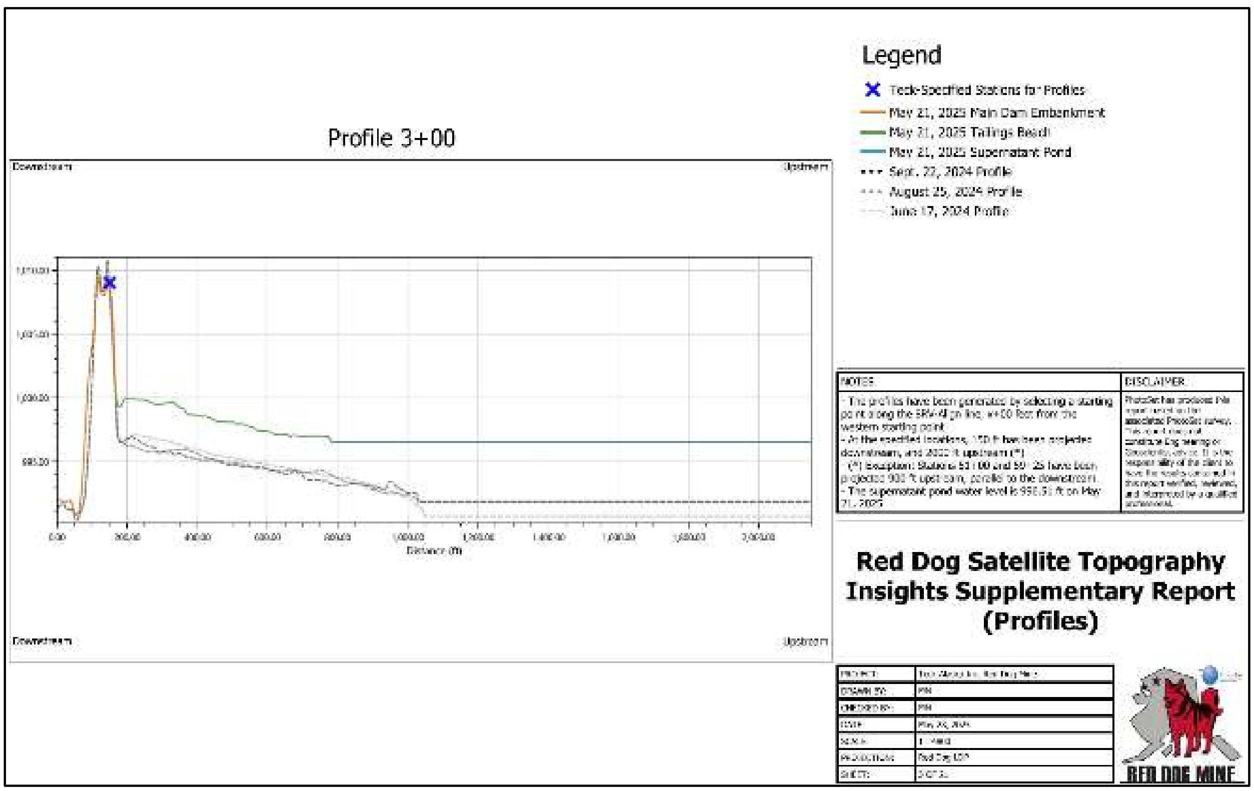

Figure 3: Tailings main dam subaerial beach cross-sections

To account for natural variability along the TMD and WW, slope parameters are averaged across the length of each structure. These averaged slopes are then used as inputs in the tailings deposition model. Model calibration and performance checks are conducted to ensure the selected parameters accurately reflect observed deposition behaviour. This iterative process often involves multiple model runs and minor adjustments to slope and/or density values until a satisfactory match is achieved. Since the introduction of

PhotoSat's surveys from satellite imagery in 2020, the accuracy and consistency of slope parameter development have significantly improved, resulting in fewer year-to-year changes and more reliable modelling outcomes.

TSF Tailings and Water Volume Measurements

Water Volumes, Capacity, and Stage Storage Curves

The Base Surfaces are also used to assess the volume of free water within the TSF at the time of each data capture. By identifying the water surface elevation and comparing it to the bare ground topography, the volume of ponded water can be accurately estimated. This information is critical for both operational decision-making and long-term planning.

In addition to point-in-time assessments, a stage-storage curve is developed using the Base Surface data. This curve serves as a key input to the RDO TSF GoldSim Water Balance Model, which is used to forecast future water elevation changes within the facility. Accurate forecasting of water levels and volumes is essential for Life of Mine planning, as well as for managing operational and environmental risks associated with TSF water management. Understanding how water levels may evolve under different scenarios enables proactive planning and supports compliance with regulatory and safety standards. Table 1 below shows examples of the various TSF volume capacity measurements. These measurements support:

- Life of Mine Planning (Strategic Planning Department collaboration).
- Evaluation of Mine Life Extension potential using the existing TSF capacity.
- Corporate and regulatory reporting.
- Public disclosure reporting.

Table 1: TSF Volume Capacity Measurements

Case	Volume (ft^3)	Volume (Mgal)
From 2024 surface to crest (1007.4 ft)	1,028,421,890	137.5
From 2024 surface to maximum operating level (1002.4 ft)	870,208,892	116.3
From original ground surface to crest (1007.4 ft)	2,750,667,530	367.7
From original ground surface to maximum operating level (1,002.4 ft)	2,592,454,532	346.6

Tailings Beach Lengths

Monitoring tailings beach lengths is a key input to tailings deposition plan development. RDO prioritizes deposition in areas where beach lengths are shortest to construct a uniform tailings beach and maintain target beach lengths. Tailings beach length measurements are taken using satellite imagery. Figure 4 is heavily reliant on the Base Surfaces being used in the tailings deposition model software to measure and track tailings beach lengths.

FACILITY PERFORMANCE SUMMARY (2024)

Tailings Beach Length & Annual Plan Conformance (Internal Erosion Control)

Date	TMD (ft) Target - 600 ft	NWW (ft) Target - 600 ft	SWW (ft) Target - 200 ft	Source
1/17/2024	750	1500	300	Muk3D
2/17/2024	650	1450	225	Muk3D
3/18/2024	625	1300	200	Muk3D
4/8/2024	600	1200	180	Muk3D
5/4/2024	460	1150	170	Muk3D
5/13/2024	600	1050	110	Muk3D
5/21/2024	634	1159	97	PhotoSat
5/30/2024	760	920	100	Muk3D
6/17/2024	876	1636	379	PhotoSat
7/4/2024	1000	1700	475	Muk3D
7/31/2024	1050	1850	525	Muk3D
8/9/2024	1050	1850	500	Muk3D
8/25/2024	875	1580	323	PhotoSAT
9/22/2024	876	1630	284	PhotoSAT
10/27/2024	750	1275	250	Muk3D
11/28/2024	601	920	156	Muk3D
12/20/2024	600	932	152	Muk3D

Annual Target	YTD Conformance	EOY Forecast Conformance
85%	90%	90%

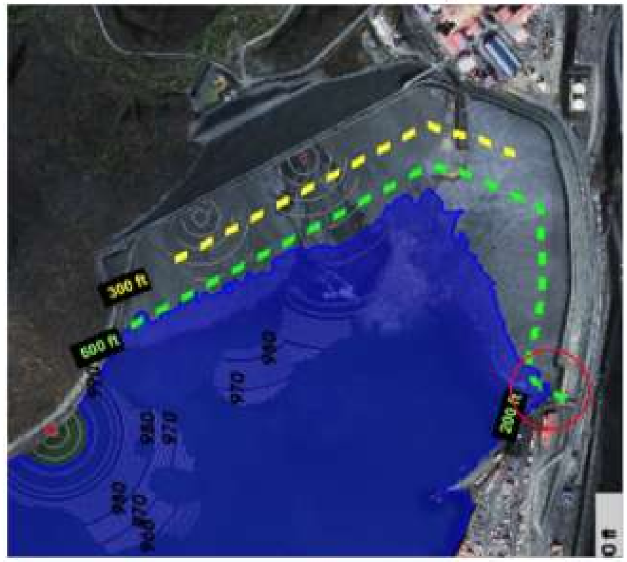

Figure 4: Tailings beach length tracking

The elevation heat map is used to supplement deposition planning by targeting deposition in areas where the tailings beach elevations are lowest. This enables RDO to construct a uniform tailings beach and maintain target beach lengths when the TSF water level rises. For example, Figure 5 would result in decisions to target areas where the green beach areas are closest to the upstream face of the TMD and WW.

Conclusion

The integration of multiple surveying technologies at RDO has significantly enhanced the accuracy, consistency, and utility of TSF monitoring and management. By combining high-resolution satellite imagery, drone photogrammetry, bathymetric surveys, and ground control data, the RDO tailings team develops robust and reliable base surfaces that support a wide range of operational and planning needs. This integrated approach enables accurate modelling of tailings deposition, accurate volume and density calculations, and effective tailings and water volume forecasting—each of which is critical for meeting regulatory requirements, managing risk, supporting short- and long-term planning, and meeting sustainability objectives.

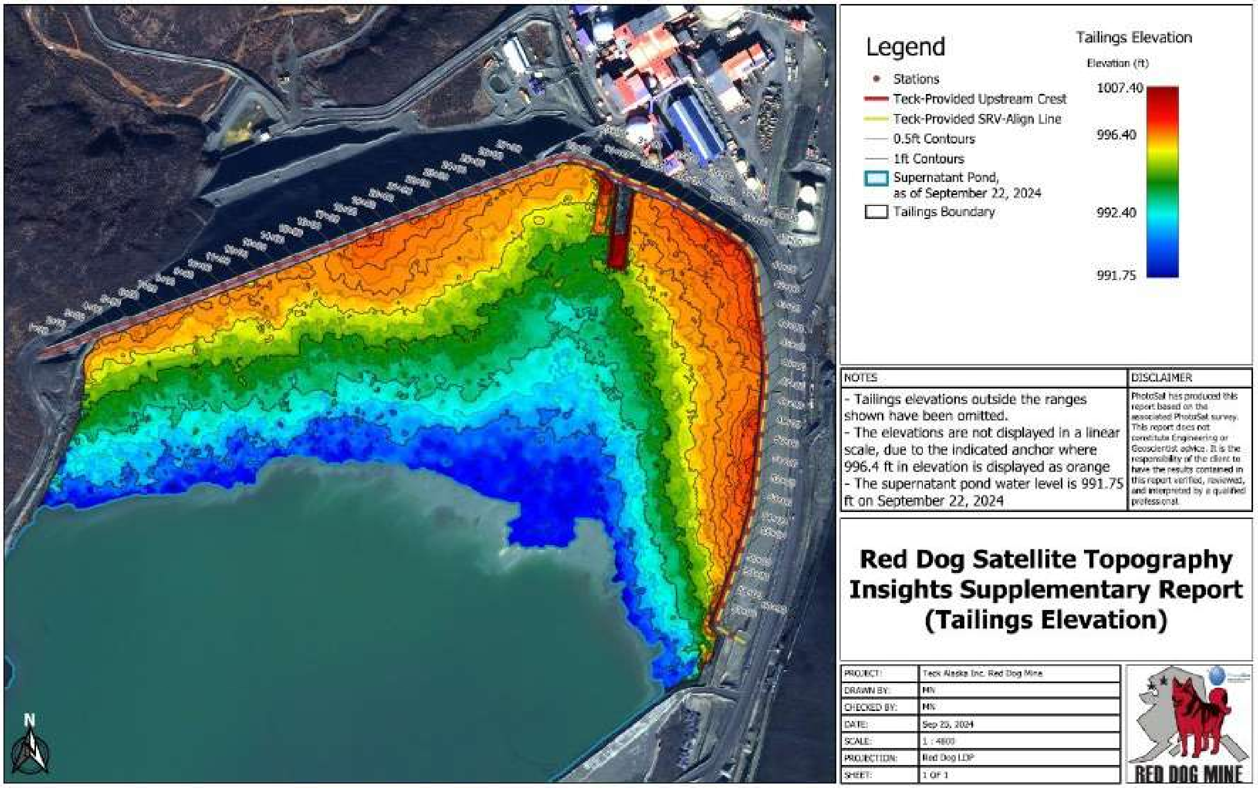

Figure 5: Tailings beach elevation heat map

The use of these complementary data sources has improved the quality of tailings deposition planning, allowing for better alignment with design intent and risk mitigation strategies, such as maintaining critical tailings beach lengths and completing subaqueous deposition during freezing temperatures. The implementation of the Teck tailings deposition management process further strengthens this approach by embedding continuous improvement into daily, weekly, and monthly planning cycles using the PDCA process.

Overall, this case study demonstrates that a multi-method survey integration strategy not only enhances technical accuracy but also drives operational efficiency and informed decision-making. As industry standards continue to evolve, the RDO approach offers a valuable model for other operations seeking to modernize and optimize their tailings deposition management practices.