Advances in Pit Lake Water Quality Monitoring Using Unmanned Aerial Vehicles

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Abstract

Sampling of pit lake water quality by unmanned aerial vehicle (UAV; i.e., drone) presents an emerging technology in the monitoring and management of mine-affected waterbodies. The use of UAV for data and sample collection mitigates the need for persons to enter a non-operational pit void or be in contact with a waterbody, thereby increasing the safety of the monitoring program.

Experienced gained through conducting sampling programs at both open and closed sites, and repeated sampling events at individual sites have allowed for refinement of the sampling procedure to improve health and safety outcomes and increase the efficiency of the sampling procedure.

Samples are taken at different water depths, as determined using sonar to measure water depth, and *in-situ* water chemistry measurements made using a multi-parameter probe. Both sonar and probe are suspended from the UAV. Samples for laboratory analysis are collected by bailers and Hydrasleeves® housed within an upright structure, for surface and sub-surface water samples, respectively.

Ongoing refinements to the sampling methodology are improving the efficiency in sample collection and enabling more robust monitoring programs to support mine waste and tailings management objectives through to closure.

Keywords: UAV, drone sampling, pit lake, monitoring

Introduction

Following the cessation of dewatering within a mined-out pit void where excavation extended to below the pre-mining groundwater level, the water table rebound commonly results in the formation of a pit lake. Such voids may also be repurposed for in-pit disposal of mine waste material, reducing reliance on external waste rock dumps or a designated tailings storage facility (McCullough *et al.* 2024, 2010; Obermeyer *et al.* 2025). The introduction of waste rock or tailings into a pit lake as backfill, can alter pit lake water quality through geochemical interactions between the waste materials and lake water (Schultze *et al.* 2011). Vertical stratification can develop when density gradients form between surface and bottom waters, driven by differences in salinity and temperature. Stratification can have an influence on dissolved oxygen concentrations and redox conditions within stratified layers of pit lake water. This can cause water chemistry to change as a function of depth, especially for redox-sensitive chemical species. Recent studies (Gammons and Icopini (2020); Vandenberg and Litke (2017); and Obermeyer *et al.* (2025)) indicate that the depth of tailings and/or sludge deposition within a pit lake can influence pit lake behaviour such as stratification. Consequently, at sites undergoing active material deposition, systematic monitoring of pit lake water quality is important to track the evolution of water chemistry relative to water quality objectives and validate water quality modelling (Schultze *et al.* 2024). Furthermore, regulatory agencies often require pit lake water quality to be monitored and reported, thus creating an external requirement for ongoing pit lake water quality monitoring.

Traditional (grab) sampling and sampling from surface water vehicles both require direct access to the pit lake and present a risk of drowning associated with working on or near the waterbody. Moreover, grab sampling from the shore only allows for a small, and often unrepresentative, portion of the lake to be sampled, and sampling from surface water vehicles involves considerable efforts to transport equipment to site (Banerjee et al. 2018; Ross and McCullough 2011). Pit geometry and water quality conditions can oftentimes create unsafe environments such as steep, unstable pit walls with the potential for slope failure and restricted access, making direct sampling hazardous to site personnel. Furthermore, several sample locations, and multiple depths may need to be sampled to account for differences in water quality at different depths due to stratification (Castendyk *et al.* 2019), and different areas of the pit lake influenced by pit wall geology.

Sampling of pit lake water by UAV is becoming the preferred method of water quality monitoring for pit lakes owing to its benefit to personnel health and safety. Our team have enhanced an established methodology (Castendyk *et al.* 2020, 2019; Straight *et al.* 2021) to undertake both surface and sub-surface *in-situ* monitoring and sampling at target depths.

Methods

An overview of sampling programs conducted are presented in Table 1. The number of locations within a pit was dependant on pit size and bathymetry. Sampling points (*in-situ* measurements and water samples collected) were taken at either 5 m intervals or 10 m intervals, with the number of sampling points at each location dependant on the total pit lake depth at that location. A typical cross-section of a pit lake indicating locations and sampling points is presented in Figure 1.

Table 1 *Pit lake sampling program overview.*

Program	Pits	Locations	Sampling points	Total number of sampling points	Monitoring events
A	11	41 (1-6 per pit)	1-6 depths at each location. Surface to 30 m	145	1
B	1	3	4 depths at each location. Surface to 30 m	12	4

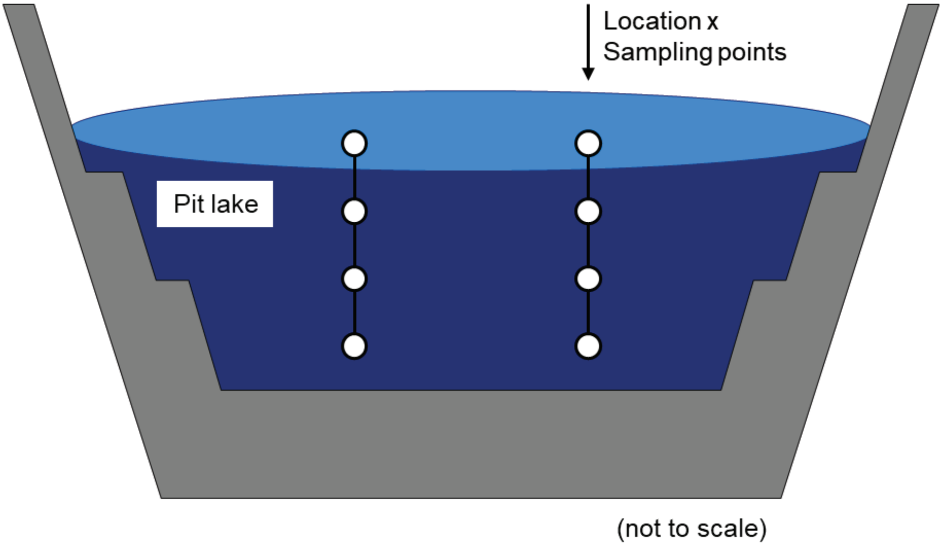

Figure 1 *Typical pit lake with n locations and x sampling points at depth intervals per location.*

Under a typical pit lake sampling program, depth and *in-situ* water chemistry measurements are taken by instruments suspended from the UAV (DJI Matrice 300 RTK; Figure 2). Samples for laboratory analysis are collected by bailers and Hydrasleeves® for surface and sub-surface water samples, respectively.

During each sampling event, the following tasks were undertaken for multiple locations within a pit lake:

- Pit lake water depth was measured using either a tether-mounted CastAway conductivity-temperature-depth (CTD) sonde (Program A), or a tether-mounted custom-built sonar which recorded depth, GPS location, time and date, and certainty (Program B).
- A YSI EXO Sonde multi-parameter data logger was used to collect *in-situ* measurements of pH, electrical conductivity (EC), oxidation-reduction potential (ORP), dissolved oxygen (DO), and temperature.
- Water samples were submitted for laboratory testing of physico-chemical parameters, major ions, total and dissolved trace metal(loids), nutrients, and total organic carbon (TOC). Samples for dissolved metal(loid) analysis were filtered in the field, and all samples were preserved in the field.

Outcomes

Health and Safety Considerations

UAV-based sampling eliminated the need for personnel to enter the pit void and work on or near water, thereby reducing exposure to slope failure, drowning hazards and potentially harmful water (Castendyk *et al.* 2019).

Key health and safety risks associated with UAVs, such as falling object/material and battery fire or explosions were controlled by the following protocols and procedures:

- Risk of falling object/material controlled by:
  - Demarcating an exclusion zone for UAV pilot and sampling personnel only;

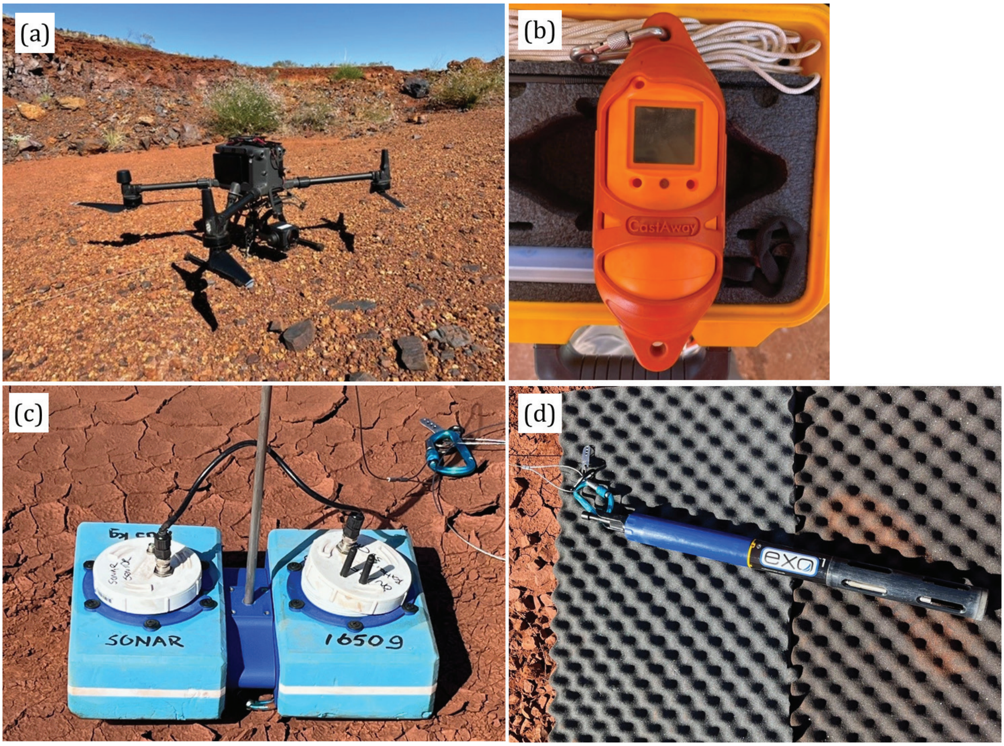

Figure 2 Equipment set-up: (a) UAV (DJI M300 RTK), (b) CastAway conductivity-temperature-depth (CTD) sensor, (c) sonar device, and (d) EXO sonde multi-parameter probe.

  - Personnel working within the exclusion zone were briefed on hazards and protocols in place to control for hazards, and at an operational site, a site-wide notice was issued regarding UAV operations including date, time and location of operations;
  - Zero access below the UAV and suspended was allowed load during take-off and landing;
  - Consideration that weather conditions were within allowable flight tolerances;
  - Adhering to payload limitations such that instruments and/or sampling equipment, water sample and tether were within the lift capacity of the UAV used; and
  - Return to home (RTH) procedures were initiated when battery level reduced to 30%.

- Risk of battery fire or explosions controlled by:
  - Batteries were stored, transported and managed according to documented policies and charged in accordance with manufacturer recommendations; and
  - RTH procedures at low battery level.

These controls safeguarded the health and safety of the sampling team whilst in the field.

Sampling Methodology

Sampling events were conducted with three persons; one UAV pilot, and two samplers/spotters.

UAV flight times to collect water samples varied depending on distance to location, difference in vertical elevation between take-off/landing zone and lake level, and depth to sampling points. Travel distance between pit lakes and respective take-off/landing zones should also be considered for a program with multiple pit lakes.

Approximate times for each task were as follows:

- Depth by sonar: 15 minutes for a pit with three locations.
- *In-situ* measurements: 20 minutes for flights that recorded data at three sampling points to 20 minutes for flights that recorded data at four sampling points. Measurements were recorded at 2 second intervals such that the UAV hovering with the sonde at the specified depth three minutes in order for the pH measurements to settle allowed for a minimum of 90 measurements at each data collection point.
- Water sample collection: Up for six minutes for a sampling location at a distance of 850 m from the take-off/landing zone, and 30 m depth. With the UAV model used, a single water sample was collected per flight. However, with a larger UAV capable of handling a larger payload, multiple water samples may be collected in a single flight.

UAV flights were limited by battery discharge time, and in some cases the *in-situ* measurements needed to be collected with more than one flight. Reliable access to an electrical supply for battery charging should be considered.

Measurement of pit lake depth by a sonar device that floated on the water surface eliminated the need to lower instruments, suspended from the UAV, to the depth of the pit lake where there is the possibility for instruments to become entangled with or damaged by aquatic plants, unconsolidated material or uneven surface at the base of the pit lake. This reduced the risk of instruments being lost or damaged and minimised the cost and program feasibility impacts.

Several methods for retrieving the water sample from the UAV were trialled to optimise the volume of sample collected with consideration of health and safety and flight capacity limitations. Detaching the sample from the tether whilst the UAV was airborne did not align with health and safety protocols. Landing the Hydrasleeve® on a tarpaulin mat permitted safe UAV landing before the sample was retrieved, but substantial sample was lost through the unsealed valve such that this technique was not suitable. Use of a custom-built, lightweight tripod to house the Hydrasleeves® in a contained way allowed the full Hydrasleeve® to remain upright on landing, achieving minimal sample loss and retrieval of the sample upon landing of the UAV. Retention of a full sample on landing, allowed for a reduced number of sampling vessels to be filled at each flight. Fewer sample vessels initially filled offset the weight of the tripod to retain a low payload weight. Further to this, sampler skill in transferring the water sample from Hydrasleeves® with minimal loss of sample allowed for a single Hydrasleeve® (1L capacity) to be used for each flight, further reducing the payload weight.

Discussion

Improvements to the sampling methodology allowed for a reduction in bailer or Hydrasleeve® needed for collecting each sample, reducing effort for each UAV flight. By measuring *in-situ* water quality for surface and subsurface sample points, the stratification status of the pit lake could be demonstrated for repeated monitoring events.

Further enhancements to the sampling technique that we aim to realise in future sampling events include the use of larger UAV's with a higher payload capable of retrieving multiple samples in one flight. These changes will further improve drone flight time efficiencies and battery usage.

Besides water quality monitoring, this methodology and the use of UAVs in a mine water context can be modified for other applications such as depth profiling and evaluating water depth to backfilled materials, mounting of sediment samplers to collect pit lake sediments for characterisation. Additionally, UAVs can be used to collect high resolution imagery, for example evaluating the geology of pit walls, mounting other environmental sensors for site-specific applications, or deploying long-term monitoring stations.

Conclusions

Improvements to sampling by UAV methodologies enabled depth, *in-situ* data and samples to be collected in a safe and efficient manner emphasizing the benefits of using UAVs to monitoring pit lake water quality. We continue to make improvements to the sampling by UAV methodology with a focus on safety and efficiency.

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